Indoor Air Quality Guidelines for Sydney Olympic Facilities

Prepared for
Green Games Watch 2000
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Note:
Throughout this document the term "Olympic" is used to signify both Olympic and Paralympic facilities and activities

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1. Recommendations

- **That consideration of indoor air quality constitutes a key design input for Olympic facility structures, products and services.**

Official environmental guideline documents issued for the Sydney Olympics indicate the importance of providing healthy indoor environments in Olympic facilities. This requirement needs to be made explicit in tender documents and briefs issued by OCA, SOCOG and other organisations responsible for the delivery of Olympics' facilities. Tendering organisations and contractors working on these facilities should therefore demonstrate how their activities will contribute to achieving good indoor air quality. Where trade-offs are required, tendering organisations and contractors should clearly indicate the criteria used to rank various options. This requirement applies to all stages of building design, interior design, construction, refurbishment, fit-out and post-occupation facility management.

- **That protocols for maintaining good indoor air quality be included in operating manuals for all Olympics' facilities – public, commercial and residential.**

Post-Olympics building management of the Athletes' Village, in particular, may be left to the discretion of individual occupants. Ecologically sustainable development of Olympics' facilities will probably involve use of innovative building design and materials. Residents need to understand how their own activities impact on the quality of indoor environments. Operating manuals, written in plain language and suitable for use by the non-expert, should therefore be provided for the residential components of the development, for use by Athletes' Village occupants, both during and after the 2000 Olympics. Similar operating manuals, tailored to the needs of building services professionals, should also be provided for non-residential components. Protocols for commercial and public buildings, at least, should incorporate quality assurance procedures and indoor air quality monitoring programmes.

- **That the Olympic Co-ordination Authority's Environmental Management System incorporate a documented system of quality assurance for achieving and maintaining good indoor air quality.**

All stages of the building process and occupation have a potential impact on indoor air quality. Responsibilities for management of indoor air quality should therefore be clearly defined for each of these stages. To help ensure compliance, quality assurance procedures contained in the Environmental Management System should be logical, thorough and as simple as possible. The procedures should be subject to independent, expert audit at appropriate intervals.

- **That two types of indoor air quality measurement programmes for Olympic facilities be implemented: those for continuous assessment of indoor air quality against national goals; and, those for deductive, scientific assessment of pollution prevention and mitigation measures undertaken in these facilities.**

Monitoring information will be a necessary tool in ongoing facility management and will help ensure the health and well-being of building occupants. Monitoring programme findings should be included as part of OCA's annual *State of Environment Reports*. Scientific assessment of air quality in Olympics' facilities in comparison to conventional buildings will provide important benchmarks for the future design and operation of ecologically sustainable building developments, both in Australia and overseas.

- **That indoor air quality in all Olympics' facilities at least meet the indoor air quality goals recommended by Australia's National Health and Medical Research Council.**

The goals are recommended maximum densities for nine pollutants. Goals are subject to review and, with the exception of formaldehyde and radon, are interim. The goals do not cover the full spectrum of pollutants and factors which can influence indoor air quality. Meeting the goals is a minimum requirement but should not inhibit innovation to provide even better air conditions.

- **That indoor air pollution in Olympics' facilities be managed, as far as possible, by selection of building materials, finishes and furnishings that:**
  - **do not emit harmful levels of pollutants, respirable particles, dust or unpleasant odours**
  - **after installation, emit any pollutants over the short-, rather than the long-, term**
  - **have low adsorption characteristics**
  - **are resistant to micro-organisms such as bacteria, mould and dust mites**
  - **can be effectively cleaned using benign cleansers and processes**
  - **do not emit harmful levels of radiation, and,**
  - **are safe as possible during installation and under extreme conditions.**

For environmental and economic reasons, it is preferable to limit the use of materials that are sources of indoor air pollution. Effective removal or cleansing of polluted indoor air is generally costly and energy-demanding and adds pollutants to the total air environment. Pollution from materials that emit over the short-term can be effectively managed by temporary increases in ventilation rates. Low adsorption materials, which are generally hard and smooth, cause less of problem for ongoing indoor air quality management than fleecy or porous materials, and are generally easier to clean and less likely to support growth of undesirable micro-organisms. The occupational hazards of installing or using materials should also be considered in the selection process. Any additional costs incurred in using low-emission and low-adsorption materials may be offset by a concomitant reduction in mechanical ventilation costs. Recycled materials are generally well cured, so can constitute an additional source of low-emission materials. Specific recommendations for particular building, finishing and furnishing materials are provided in these guidelines.

- **That, to allow emissions from construction materials, finishes and furnishings to dissipate, an adequate period of time is allowed between completion and occupation of Olympics' facilities.**

People typically spend at least a third of each day indoors, either at home or in comparable living quarters. Newly constructed and refurbished buildings generally have high levels of indoor chemical pollutants, as each material out-gases a large proportion of its volatile constituents in the first few weeks or months of service. Techniques for accelerating out-gassing, such as flush-out and bake-out, should be investigated and appropriately implemented in the Athletes' Village and in other new or refurbished Olympics' facilities.

- **That the following "smoke-free" policy be adopted for Olympic facilities: all indoor spaces completely smoke-free for the duration of the Olympics; all indoor, non-residential spaces permanently smoke-free; and, if possible, all residential indoor spaces permanently smoke-free.**

Environmental tobacco smoke is a significant contributor to indoor air pollution. Adequate ventilation of indoor smoking spaces is demanding of energy and maintenance effort. If designated smoking areas are deemed necessary, then these should be (1) outdoors spaces only and (2) located well away from building entrances, opening windows and ventilation ducts. This recommendation supports the *Draft Smokefree Policy for the Sydney 2000 Olympic Games* issued by the Smoke Free Olympics Taskforce.

- **That outdoor landscaping of Olympics' facilities, particularly in the immediate vicinity of buildings, avoid the use of plant species known to produce common human allergens.**

Plants produce substances that can be allergenic to humans, in particular, pollens from flowering plants. These can enter indoors via ventilation air or by transportation on people and their clothing Consideration should therefore be given to the types of vegetation planted around buildings.

- **That, to provide expert advice on strategies for avoiding the use of chemical pesticides, integrated pest management advice be sought during the design of Olympics' facilities.**

The use of pesticides, both inside and outside, is a potential source of indoor air pollution. By appropriate design of structural and interior features, integrated pest management strategies minimise the need to use chemical pesticides. This process should therefore be undertaken at the detailed design stage for each facility.

- **That, to ensure cleaning processes maximise the maintenance of healthy indoor environments, cleaning contracts established for Olympics' facilities include specially written clauses to this effect.**

Because some pollutants, such as dust, continually build up in interior spaces, good indoor air quality can only be achieved with adequate and regular cleansing. However, to avoid contributing indoor air pollutants and to safeguard the health of cleaning staff, cleaning should be conducted with minimal use of hazardous products.

- **That, where indoor air pollutant sources cannot be avoided, adequate local exhaust is provided in Olympics' facilities.**

It is unlikely that all sources of indoor air pollution can be eliminated in any building. Local exhaust systems should be provided for fixed sources of moist heat, odours, and pollutants, including combustion by-products. These fixed sources include rooms, such as toilets, bathrooms and laundries, and appliances, such as stoves and gas heaters. Some appliances that need local exhaust systems, such as photocopiers and printers, tend to be moved around; adequate ventilation of such mobile sources of pollutants also needs to be provided.

- **That energy consumption associated with the provision of adequate ventilation in remaining Olympics' facilities be minimised by use of building designs which maximise natural supply, removal, heating, cooling, and cleaning of ventilation air.**

The overall size, configuration and placement of a building largely determine the extent to which ventilation air can be provided by natural or passive means. Some heating and cooling strategies are less demanding of energy than others, so are less likely to be associated with detrimental under-ventilation in cold or hot weather. These strategies include making buildings thermally massive and utilising the temperature of exhaust air to moderate the temperature of intake air. Strategies for ensuring that energy need not be spent cleaning ventilation air include the careful location of intake vents and the provision of indoor foliage plants.

- **That energy consumption associated with any mechanical ventilation in Olympics' facilities be minimised by use of sensors and provision of individual occupant controls.**

To help ensure indoor spaces are not over-ventilated, mechanical ventilation systems can be fitted with air quality and motion sensors, which appropriately modulate the ventilation rate. However, energy conservation measures should not jeopardise the health and well-being of building occupants. Research has shown that when occupants have control over their immediate indoor environments, there can be both energy savings as well as higher levels of occupant satisfaction with those environments.

- **That foliage plants with known capacity to absorb indoor air pollutants be used as widely as possible in indoor spaces at Olympics' facilities.**

Certain plant species have a demonstrated ability to absorb and metabolise various air pollutants. For both air-cleaning and aesthetic purposes, the use of such plants indoors, especially those that produce little or no pollen, is recommended. Maintenance of indoor plants should not use polluting products. Provision for indoor plantings should be made when designing floor layouts.

- **That the Olympic Co-ordination Authority should cooperatively develop an Australian best practice guide to building and furnishing materials selection for indoor air quality.**

The experience gained in the detailed design and fit-out of Olympics' facilities will be a valuable future resource for the Australian building, design and construction industries. By showing how materials choices contribute to indoor air pollution, the best practice guide would facilitate systematic selection of low-emission and low-adsorption building and furnishing materials in future developments. Detailed and suitably presented information of this type is not currently available for Australian materials, products and building practices. The guide should discuss the total impact of particular components on indoor air quality by considering installation methods and maintenance requirements as well as the materials themselves.

Note: This report includes review of specific components including structural building materials, interior construction and finishing materials, surface finishes, floor coverings, furnishings and furniture, equipment and appliances, based on currently available data.

2. Objectives of these guidelines

Green Games Watch 2000 is a coalition of major environment groups working towards achieving an environmentally responsible Sydney Olympics Games. In commissioning this document, Green Games Watch 2000 requested guidelines which would:

- explore best practices for preventing or minimising indoor air pollution in residential and commercial premises
- be suitable for use by tendering organisations and contractors working on Olympic facilities and fit-out
- be consistent with the principles outlined in the *Environmental Guidelines for the Summer Olympics Games* and *Homebush Bay Development Guidelines: Environment Strategy*, and,
- show how good indoor air quality is an essential component of ecologically sustainable development of Olympics' facilities.

3. Scope of these guidelines

A major challenge for Sydney Olympics authorities, tendering organisations and contractors is to develop and maintain facilities in an ecologically sustainable manner. The goal of these guidelines is therefore to provide a starting point for architects, designers, specifiers, builders, building managers and the users of facilities to address indoor air quality as an integral part of facility design, construction, maintenance and use.

The National Health and Medical Research Council's interim goals for indoor air quality (see Appendix A) address indoor air pollution by expressing upper limit concentrations for various indicator air pollutants. While a numerical approach to indoor air pollution is a useful monitoring tool, guidance on practical means to address the *causes* of this pollution are required.

The effect of poor quality air on human health is the most obvious indoor air pollution issue. People commonly spend up to 90% of their time indoors, with Australians spending between 53 and 82% of their time at home (statistics cited by Dingle & Murray, 1993). The quality of indoor environments is therefore likely to be an important determinant of people's health.

The effects of pollutants *generated within* or *released from* Olympic buildings to the external air environment must also be considered. The indoor air quality issue is therefore not confined to its effects on building occupants but also what that building and those occupants do to the total air environment.

The quality of indoor air also clearly affects functional aspects of a building other than human shelter, such as equipment operation and goods storage[1]. Optimal air conditions will differ from aspect to aspect depending on a building's function. The specific air quality requirements for these building functions are not directly considered in these guidelines. Human health needs and the well-being of the total environment are of prime importance. Materials, machinery and processes should be selected to optimise human and total environmental health.

These guidelines attempt to provide practical guidance on designs, materials and processes for preventing indoor air pollution problems. They also aim to help individuals understand how their own professional activities affect and are affected by those of other disciplines. Where accessible,

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[1] For example, optimal humidity requirements for long-term preservation of museum items may differ from what is comfortable for humans.

information on best practice has been included. To further guide the reader, in addition to cited literature (Section 11.2), further useful information resources have been indicated (Section 13).

3.1 Olympics' indoor spaces

Facilities to be used for indoor sports during the Sydney Olympics include:

Aquatic Centre, Homebush Bay [Swimming, Diving, Synchronised Swimming; Water Polo];
Convention Centre, Darling Harbour [Weightlifting];
Entertainment Centre, Darling Harbour [Basketball];
Exhibition Halls, Darling Harbour [Boxing, Judo, Taekwondo,Table Tennis];
Multi-Use Indoor Arena, Homebush Bay [Gymnastics];
Showground Sports Halls, Homebush Bay [Handball, Volleyball, Badminton]; and,
State Sports Centre, Homebush Bay [Fencing, Wrestling] (OCA, 1996).

At this stage, it is envisaged that at all Paralympic indoor sports will be held at Sydney Olympic Park, Homebush Bay (Brady, *personal communication*, 23/1/97).

Other significant indoor facilities include:

Athletes' Village, Newington (adjacent to Homebush Bay);
Multi-storey carpark, Homebush Bay;
Underground railway station, Homebush Bay; (OCA, 1996) as well as
Offices, including demountable temporary offices, shops, cafes, amenities, changing rooms, training rooms, plant rooms and other enclosed areas in otherwise outdoor sports venues.

Many of the Olympics' indoor facilities have been built for some time, such as those at Darling Harbour. Some renovation of these facilities, if only of a cosmetic type, is likely to occur prior to the Olympics. Others have been built since Sydney's successful bid for the 2000 Olympics. Construction on some, such as the Athletes' Village, has either not started or is in its early stages. The NSW Government intends that the Olympics' development will provide a "major legacy" for the people of NSW (OCA, 1996). If this "legacy" is to be beneficial, post-Olympics facility management is as important as that prior to and during the Games.

These factors, together with the wide variety in the types of Olympics' indoor spaces, means appropriate options for achieving good indoor air quality are similarly wide and varied.

3.2 Methodology

To assess the current state of indoor air quality management in Australia, the authors consulted with representatives of relevant industry associations – manufacturing, trades and professional. Few industry organisations have their own specific indoor air quality policy. Some publish material on environmental issues as a whole. Some contribute by way of representation on technical committees for various relevant Australian Standards. Within resource limits, this consultative process was conducted as far as possible.

In the most part, the authoritative literature used was professional or academic level text books. Generally, insufficient time was available to go back to research journals and academic theses. The authors also felt it was important that recommendations were based on proven methods.

4. Definitions

4.1 Indoor air pollutants

Indoor air pollutants can be categorised as chemical, biological or physical. Chemical pollutants include volatile organic compounds [VOCs][2], formaldehyde, pesticides[3], cigarette smoke, heavy metals and combustion products such as carbon monoxide and nitrogen dioxide. Biological pollutants include dust mite allergen, other allergens, moulds, fungi and pathogenic micro-organisms. Physical pollutants include radiation from radon and electromagnetic fields, dust and respirable particulate matter[4].

The pollutants mentioned above are widely regarded as the pollutants of most concern during normal building occupation (e.g., Godish, 1991). Others, like asbestos (American Institute of Architects, 1996, MAT07200), generally only cause problems when a building is being demolished, refurbished or is in poor repair. There are many sources of chemical, biological and physical indoor air pollutants.

According to a local indoor air quality expert, the indoor pollutants of most concern in NSW are nitrogen dioxide, from unflued gas heaters and stoves, respirable particulates, from, for example, cigarette smoke, and house dust mite allergen (Ferrari, *personal communication*, 10/12/96). Dust mites are of particular concern because of the high humidity of populated coastal areas, the high proportion of carpeting in homes and the high incidence of asthma in Australia.

Unlike North America and Europe, due to differing soil types and building practices, radon is not regarded as a significant indoor air pollutant in Australia (findings reported in Brown, 1996).

4.2 Indoor air quality

Critical aspects of the indoor air environment include air temperature, humidity and ventilation rate. The term *indoor air pollution* does not necessarily suggest these aspects. At what point does a substance become a pollutant? Using the word "*quality*" is more embracing than the word "*pollution*".

Indoor air quality [IAQ] may be defined as the nature of air that affects the health and well-being of a building's occupants. This definition incorporates the concept of health in the Constitution of the World Health Organisation: "Health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity" (SMACNA, 1988).

In temperate climates, indoor temperature and humidity conditions regarded as comfortable and pleasant by most people are 18°C–25°C and 30–60 percent relative humidity, respectively (Pearson, 1989). Acceptable ventilation or air exchange rates are dependent on a building's use. For instance, outdoor air flow rates for indoor sports playing floors, beauty salons and smoking rooms recommended in Australian Standard *AS 1668.2*: 1991 are minima of 10, 15 and 25 litres per second per person, respectively. The extent to which individual occupants can control their immediate air environment is also widely regarded as important to their perception of indoor air quality (e.g., Appleby, 1990).

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[2] "Volatile" refers to the fact these substance have boiling points in the range 50-100°C to 240-260°C, so take up to several years to be liberated in typical indoor environments (Appleby, 1990). "Organic" refers to the fact these substances are carbon-containing compounds.

[3] Formaldehyde and many pesticides are volatile organic compounds, however, conventionally these substances are separately discussed because of their individual significance as indoor air pollutants.

[4] Particles, of less than 10 micrometers in diameter, that can penetrate and lodge in the lungs (Levin, 1992 July).

4.3 Best practice

These guidelines explore best practices for preventing or minimising indoor air pollution in residential and commercial premises.

Best practice is the design and/or use of processes, products and services which perform in a *superior manner* to alternative processes, products and services. *"Normal"* products, processes and services are those that achieve their primary function. For the purpose of these guidelines, *superior* products, processes and services are those which go beyond their *normal* function by achieving the best possible indoor air quality and the lowest possible contribution of pollutants to the total air environment.

Best practice can be considered across a particular product type, for example, comparing air quality impacts of one paint product to another. It can also be considered across a particular process, for example, comparing air quality in a building fitted with an air-conditioning system to one using passive ventilation, cooling and heating.

Today's best practice may be next year's expected or average practice. In fact, if Australian industry meets the degree of innovation and sophistication expected for Sydney Olympics' facilities, these new practices will become benchmarks. The financial and environmental imperatives for continual technological and process improvement in modern industry are widely recognised.

5. Overview of indoor air quality

Indoor air quality is a critical component to consider in any discussion of ecologically sustainable development. Indoor air quality has become a significant public health issue and a matter of liability for employers and building managers who fail to provide a safe working environment.

During this century, the amount of time people spend indoors has increased dramatically. Estimates have been made that people in industrialised countries now spend 70-90 percent of their time indoors: at work, at home, and in enclosed vehicles (USEPA & CPSC, 1988). In every interior space, air quality exerts a possible impact on health. The rapid proliferation of new building materials and consumer products since World War II, such as plastics, has exposed people and the environment to many new sources of toxicants.

Indoor air quality is primarily a function of pollutant sources and strength, ventilation, moisture and odour control and interior materials that act as *sinks*[5]. From an environmental and an economic standpoint, it is preferable to limit the use of sources of indoor air pollution before they become an in-building problem. Contractors to Olympic facilities are well placed to implement source control IAQ strategies and provide innovation in this increasingly important area of environmental management.

5.1 The total air environment

In Australia, considerable effort has been spent investigating outdoor air[6] quality. In comparison, indoor air quality issues, beyond occupational health and safety concerns, have only recently received regulatory and research attention.

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[5] "Sinks" are surfaces that adsorb pollutants. *Adsorption* is the process by which substances, such as gases or dust, collect on the surface of a material in a condensed layer. This should not be confused with the process of *absorption*, such as when a sponge absorbs water. The problem with sinks is not that they adsorb pollutants but that they re-emit [desorb] them at a later time (Sparks, 1991).

[6] The "outdoor air" environment is sometimes referred to as the "ambient air" environment.

Air Emission Trials for the National Pollutant Inventory (Boyle *et alia*, 1996) were completed in 1996. The emission trials investigated methods for collecting data on industrial and diffuse sources of pollution in four trial regions: Dandenong, Port Pirie, Newcastle and Launceston. Diffuse source considered included surface coatings, aerosols and solvents. The trial found pollutants emitted in the largest quantities in the study regions were carbon monoxide, sulfur dioxide, volatile organic compounds and oxides of nitrogen.

The *MAQS Metropolitan Air Quality Survey* (NSW EPA, 1996a) addressed regional air pollution across the Sydney, Illawarra & Lower Hunter area. Domestic sources of emissions included in the survey's Emissions Inventory, such as gas heating, wood burning stoves and aerosols, were estimated using modelled figures based on domestic activity data and population statistics. The total estimated contribution of reactive volatile organic compounds[7] from domestic and commercial sources to the Sydney region was 41% (NSW EPA, 1996a). The NSW Government Green Paper *Developing a smog action plan for Sydney, the Illawarra and the Lower Hunter* (NSW EPA, 1996b) states that the *MAQS* Emission Inventory identified that surface coatings and thinners contribute 12.5% of the total reactive VOCs to Sydney's air environment.

The NSW Health Department is investigating the impact of air pollution on health under the *Health & Air Research Program* (which started in August 1994 and is due to finish in 1997). At this stage, the study has not included the impacts of indoor air pollution and health.

The impact of outdoor air on indoor air quality is well recognised. Often not considered, however, is the flow of indoor air pollutants back to the total air environment. To achieve the desired level of air quality both inside and outside, air quality management must involve a total air environment approach.

5.2 Indoor air quality and health

The health impacts of individual chemical components in building materials are not well understood. Many chemicals present in indoor air environments have not been thoroughly tested and little is known about their long term health effects (Meek, 1991). Even less understood is the health impacts from constant exposure to mixtures of chemicals that result inside (Pollak, 1993).

Common health problems that result from exposure to poor IAQ include: sensory and skin irritation; neurotoxic symptoms; hypersensitivity; and, odour and taste symptoms (Berry, 1994). The term *sick building syndrome* is used to describe an excess of chronic symptoms which include sore and running eyes, nasal blockage, sneezing, dry throat, headaches, flu-like symptoms, lethargy and lack of concentration. The term *building related illness* is used to describe specific and clear causes of illness related to the building environment, such as Legionnaires' Disease.

5.3 Indoor air quality and energy efficiency

There is a potential conflict between requirements for energy efficiency and satisfactory indoor air quality. Since the "energy crisis" in the 1970s there has been a growing need for energy conservation in buildings. There was a consequent trend towards design and construction of "tight buildings", with reduced rates of natural or passive ventilation. As a result, contaminants can concentrate inside. This is also true of buildings with mechanised ventilation, where the need buildings energy efficient can also lead to lower air exchange rates and a consequent concentration of indoor pollutants.

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[7] The *MAQS* report uses the term *reactive organic compounds* [ROCs]. The significance of reactive VOCs in outdoor air quality is their contribution to the formation of photochemical smog (State of the Environment Advisory Council, 1996).

6. Olympics' environmental guidelines and indoor air quality

The two environmental guideline documents of most relevance to Sydney Olympic developments are:

- the Sydney Olympics 2000 Bid's (1993) *Environmental Guidelines for the Summer Olympic Games*; and,
- the Olympic Co-ordination Authority's (OCA, 1995) *Homebush Bay Development Guidelines: Environment Strategy*.

The purpose of the *Environmental Guidelines for the Summer Olympic Games* is to outline the environmental issues the bid organisation considered relevant to the summer Olympic games and the associated environmental guidelines developed to address these issues (Sydney Olympic 2000 Bid, 1993, p1). The document specifies criteria for sustainable development and outlines how compliance with these criteria shall be demonstrated in Olympics' facilities (Table 6.1).

The purpose of the *Homebush Bay Development Guidelines: Environment Strategy* is to interpret the concept of ecologically sustainable development for Homebush Bay (OCA, 1995, p4). The document specifies environmental outcomes and associated processes and actions to achieve these outcomes (Table 6.2).

Fourteen aspects of the *Environmental Guidelines for the Summer Olympic Games* directly affect indoor air quality; these range from a requirement that building design maximises indoor air circulation to a requirement that, wherever possible, non-toxic paints, glues, varnishes, polishes, solvents and cleaning products are used in Olympic buildings (Table 6.1).

The requirements of *Homebush Bay Development Guidelines: Environment Strategy* (Table 6.2) have less direct impact on indoor air quality than the *Environmental Guidelines*. A key action of the strategy is formation of a Construction Materials Expert Advisory Panel (Table 6.2). whose purpose is to review the overall environmental impact of selected construction materials. This process *of life cycle assessment* generally includes consideration of air pollutant emissions associated with, at least, the production of the materials in question (Boustead, 1996).

Both documents include requirements for use of recycled materials; these are materials choices which, like all other material choices, can affect indoor air quality.

Table 6.1: *Environmental Guidelines for the Summer Olympic Games* and IAQ

All elements of the guideline document (Sydney Olympics 2000 Bid, 1993) are shown in the table. Not all elements have a direct effect on indoor air quality but are shown for contextual reasons.

Element	Criteria for sustainable development	Compliance with environmental guidelines
• Planning and construction of Olympic facilities	"building and infrastructure design that considers environmental issues" (p5)	"all new Olympic projects being subject to assessment of their environmental impact" (p15) "companies tendering for construction contracts will be required to submit details demonstrating how they will satisfy the requirements of the 'Environmental Guidelines'" (p16)
	"building material selection being subject to consideration of environmental implications..." (p5)	"selection of components that go into new projects will be subject to life-cycle costing and consideration of environmental implications during manufacture, use and disposal" (p16)
• Energy conservation:		
Planning and transport integration	*Criteria and compliance have no direct influence on IAQ*	
Low-energy design for buildings and urban infrastructure	"use of insulation and natural ventilation" (p6)	"mechanical ventilation will be zoned to allow ventilation flow to be switched off when spaces are unoccupied" (p18)
	"use of recycled and recyclable building materials" (p6)	
• Water conservation	*Criteria and compliance have no direct influence on IAQ*	
• Waste avoidance and minimisation	*Criteria and compliance have no direct influence on IAQ*	
• Improving air, water and soil quality	"building design at Olympic sites to maximise indoor air circulation, without compromising energy saving features" (p8)*	
	"improved fitout and management procedures at Olympic sites to minimise toxic fume emission and out-gassing from paints, carpets, glues and pest control practices" (p8) *and* "minimising and ideally avoiding the use of chlorine based products (organochlorines) such as PCBs, PVCs and chlorine bleached paper" (p8)	"the selection wherever practicable of materials and processes that are non-toxic in use such as natural fibre insulation, and non-toxic paints, glues, varnishes, polishes, solvents and cleaning products" (p20)**
• Protecting significant natural and cultural environments	"implementation of non-chemical pest control at Olympic sites" (p8)	"use of building techniques and interior design that minimise the need for chemical pest control and maximise opportunities for integrated pest management" (p20)***

* Maximising indoor air circulation *per se* will not necessarily improve air quality. Maximising ventilation of indoor spaces is more likely to lead to improved IAQ.

** Strictly speaking, no substance is completely non-toxic, however, some substances have low or extremely low toxicity.

*** Integrated pest management does not totally preclude the use of chemical pest control.

Table 6.2: *Homebush Bay Development Guidelines: Environment Strategy* and IAQ

All elements of the document (OCA, 1995) are shown in the table. Not all elements have a direct effect on indoor air quality but are shown for contextual reasons.

Element	Outcome or Action or Process
• Conservation of Species:	
Flora and Fauna (ecosystems)	*Outcomes or actions or processes have no direct influence on IAQ*
People (their environment)	"that after re-development, Homebush Bay offers a high quality of life to those who live or work at the site..." (p23)
• Conservation of Resources:	
Water	*Outcomes or actions or processes have no direct influence on IAQ*
Energy	"that all structures incorporate features which reflect 'design for climate' and energy demand minimisation" (p33)
Construction Materials	"that Homebush Bay development minimises the use of materials which...create toxic pollution in their manufacture, use or disposal" (p35) *and* "establishment of the Construction Materials Expert Advisory Panel...The following will be taken into account:...any threat to human health from deterioration of the product" (p36) *and* "wherever appropriate, recycled materials will be incorporated into such elements as...buildings [and] fittings" (p36)
Open Space	*Outcomes or actions or processes have no direct influence on IAQ*
Topsoil	*Outcomes or actions or processes have no direct influence on IAQ*
• Pollution Control:	
Air	"That development at Homebush Bay minimises impact on Sydney's air quality..." (p41)
Noise	*Outcomes or actions or processes have no direct influence on IAQ*
Light	*Outcomes or actions or processes have no direct influence on IAQ*
Water	*Outcomes or actions or processes have no direct influence on IAQ*
Soil	*Outcomes or actions or processes have no direct influence on IAQ*
Waste Management	*Outcomes or actions or processes have no direct influence on IAQ*

6.1 Sporting body requirements for Olympics' indoor spaces

International Sporting Federations, which exist for each Olympics' sport, have the right to specify and approve all technical installations, sports equipment and facilities (Ottesen, *personal communication*, 19/3/97). However, it could not be established whether any of these federations have any specific requirements for indoor air quality in sports facilities. Similarly, it is not clear whether there are specific indoor air quality requirements for residential quarters used during the games period.

7. Legislation, standards, guidelines and codes of practice relevant to indoor air quality

No single government authority, in any jurisdiction, has responsibility for indoor air quality. In contrast to the outdoor air environment, no regulations have been developed specifically for indoor air environments, except if they are workplaces (State of the Environment Advisory Council, 1996). Legal regulation of indoor air quality is complex as there are many interacting factors which need to be considered such as: the effects of building and ventilation system design, construction, operation and maintenance; outdoor climate and pollutant sources; diverse health effects; and protection of a wide range of people and their sensitivities (State of the Environment Advisory Council, 1996).

Presented below is a selection of standards and other key documents relevant to indoor air quality management in NSW.

- **National Occupational Health & Safety Commission (May 1995) *Exposure standards for atmospheric contaminants in the occupational environment*, AGPS, Canberra**

This document includes NOHSC:1003 (1995) *Adopted national exposure standards for atmospheric contaminants in the occupational environment*. Exposure standards (expressed as upper limit densities) for over 500 air contaminants of potential concern are specified. The standard only applies to workplaces.

- **NHMRC Indoor Air Quality Goals (see Appendix A).**

The goals are recommended maximum densities for only nine "indicator" pollutants, so clearly do not cover the full spectrum of pollutants and factors which can influence indoor air quality. These goals are subject to review and, with the exception of formaldehyde and radon, are interim.

Indoor air goals must consider somewhat different factors and risk levels from those in the work environment. The boundary between goals for indoor air and occupational exposure standards has become blurred in buildings that act as one person's workplace and another's public place, for example, shopping malls (State of the Environment Advisory Council, 1996).

- ***Building Code of Australia* (1990), Australian Uniform Building Codes Council, Department of Industry, Technology & Commerce, Canberra**

The *Code* makes reference to various Australian Standards, including *AS 1668* and *AS 3666*, mentioned below. According to a Building Advisory Office (Department of Local Government, Bankstown) the revision of the *Code* in force in NSW, as at 18/2/97, is Amendment 8 to the 1990 edition. The new edition of the *Code*, completed in 1996, is performance-based rather than prescriptive. It is likely to be endorsed by the NSW Parliament and adopted on 1/7/97.

- **AS 1668 series of Australian Standards for *The use of mechanical ventilation and air-conditioning in buildings*:**

  1668.1: 1991 - Fire and smoke control. Under review as draft standard *DR96503*.

  1668.2: 1991 - Mechanical ventilation for acceptable indoor-air quality. Under review as draft standard *DR96425 Ventilation of buildings.*

  1668.2 (Supp 1): 1991 - Mechanical ventilation for acceptable indoor-air quality – Commentary (Supplement 1 to AS1668.2 - 1991).

The *draft* standard *DR96425* set outs requirements for natural ventilation systems and, where required, mechanical air-handling systems. The coverage of natural ventilation systems is more comprehensive and coherent than that in the current *AS 1668.2*. This change in focus is reflected in the proposed series title change from "use of *mechanical* ventilation and air-conditioning..." to "use of ventilation and air conditioning...". At 29/1/97, draft *DR96425* had not reached voting stage, so is unlikely to be finalised until June or July 1997 (according to an Information Officer at Standards Australia).

- **AS 3666 Australian Standards series for *Air-handling and water systems of buildings - Microbial control***

  AS 3666.1: 1995 - Design, installation and commissioning

  AS 3666.2: 1995 - Operation and maintenance

These standards describe work practices for preventing growth of pathogenic micro-organisms, such as Legionnaires' disease, in air-handling and water systems, such as air-conditioners. The standards do not apply to conventional houses and other sole occupancy buildings.

- **Building material standards**

As far as could be established, only two Australian manufacturing sectors place emissions limits on their products because of particular concerns over indoor air pollution. Both sectors, the reconstituted boards industry and the urea-formaldehyde foam insulation industry, have limits for formaldehyde emissions from their products, as described below.

- **AS/NZS 1859 series of Australian/New Zealand Standards for *Reconstituted Wood-Based Panels*:**

  1859.1 (Int): 1995 - Particleboard. An interim standard which expires 5/3/97. Under review as draft standard *DR96380*.

  1859.2 (Int): 1995 - Medium density fibreboard MDF. An interim standard which expires 5/3/97. Under review as draft standard *DR96381*.

  1859.3: 1996 - Decorative overlaid wood panels. Relates to overlaid particleboard and MDF.

  1859.4: In preparation - Hardboard.

  1859.5: In preparation - Fibre insulation board.

The two *draft* standards specify limits on formaldehyde emissions from particleboard and MDF as maxima of 10 mg formaldehyde per 100 g *or* 0.12 mg formaldehyde per cubic cm per hour. When these draft standards are formalised, these formaldehyde limits will be mandatory for all Australian and New Zealand producers of particleboard and MDF (Stevenson, *personal communication*, 18/12/96). According to Bruce Stevenson, Australian Wood Panels Association, there are no formaldehyde emission limits on imported boards or products made from such boards.

The Plywood Association of Australia already meets the European E1 standard of 0.1 parts per million as its standard for formaldehyde emissions from plywood (Lyngcoln, *personal communication*, 24/1/97).

- **Australian Standard *AS 4075: 1993 Urea-formaldehyde foam thermal insulation – installation requirements for in situ set foam***

This standard includes clauses about formaldehyde emissions associated with this type of spray-in foam insulation [UFFI]. Contracts for installing UFFI must include statements warning the customer of the dangers of formaldehyde emissions from the product, especially during the foam curing period of up to 3 months (Clause 9). The installer must also ensure that after 31 days from installation, the formaldehyde concentration in the interior air does not exceed national guidelines for homes and schools (Clause 13.2).

- **AS/NZS ISO 9000 series of quality assurance and quality management standards and guidelines**

This series has no *direct* relationship to management of indoor air quality. However, the standards have important ramifications for how Olympics' projects and services are delivered. See Section 9.7 of these guidelines for further commentary.

- **AS 14000 series of interim standards and guidelines for *Environmental management systems***, which includes:

  14001 (Int): 1995 - Specification with guidance for use.

This standard does not state specific environmental performance criteria. Rather, it is a system which organisations can use to implement, maintain and improve their own, specific code of conduct in relation to their impacts on the environment. Green Games Watch 2000 has already issued commentary on environmental management systems for the Olympics (Myer, 1996).

8. Factors determining indoor air quality

There are many sources of chemical, biological and physical indoor air pollutants. There are also many factors influencing whether these pollutants will cause a problem and whether other aspects of the indoor environment, such as temperature, are acceptable. These inter-related factors can be considered according to their source: from outside; from the building itself and its heating, ventilation and air-conditioning [HVAC] system; and, from inside (Table 8.1).

Table 8.1: Factors Influencing Indoor Air Quality

From outside the building	From the building & HVAC system	From inside the building
• Climate	• Building design	• Interior design
• Ventilation with & infiltration of outdoor air	• Structural building materials	• Interior building materials
• Infiltration of water	• HVAC design and operation	• Furnishings
		• Equipment
		• Occupant bioeffluence
		• Occupant activities
		• Consumer products
		• Pest management
		• Cleansing
		• Interior renovation and refit

8.1 Factors of influence: exterior

Exterior factors are important both as potential sources of pollutants to the indoor environment and because of their effects on building design and operation.

8.1.1 Climatic factors

Significant effects of climate on indoor air quality are air temperature and humidity. Irrespective of whether a building is air-conditioned or not, the further the outdoor temperature is from the desired indoor temperature, the more likely it is the building's ventilation rate will be reduced, either to keep heat in or keep heat out the building. In air-conditioned buildings, this ventilation reduction may occur automatically by use of external temperature sensors. High outdoor humidity may also result in increased use of air conditioning. In buildings using natural ventilation, or a simple air-conditioning system, the ventilation rate may be reduced by occupants closing doors and windows and even blocking vents. While these practices may lead to greater thermal comfort, and save energy, the lowered ventilation rate can lead to air pollutant build-up and may also produce uncomfortably low humidity conditions.

8.1.2 Ventilation with and infiltration of outdoor air

Ventilation systems deliberately introduce outdoor air to the indoor environment. Infiltration is non-designed entry of air from outside the building, through loose-fitting doors and windows, porous building materials, or cracks and crevices. Unless the intake air is especially cleaned, the quality of outdoor air can adversely affect air indoors.

Sources of pollutants from outdoors include: nearby industrial air pollutants; combustion particles and products, such as carbon monoxide and soot from motor vehicles, including those in underground carparks; and gases and odours from poorly located sewerage and building exhaust vents. Contaminants in soil or from hard surfaces outside may also be blown into buildings. Plants are another potential source of pollutants to indoor environments, particularly pollens from flowering plants, which can be allergenic to humans (Institute of Medicine, 1993).

8.1.3 Infiltration of water

Undesirable entry of moisture into a building, as a result of poor design and maintenance, can promote the growth of biological air pollutants. This can be a particular problem where the water infiltrates mechanised heating, ventilation and air-conditioning systems.

8.2 Factors of influence: building design, materials & HVAC systems

Building design affects indoor air quality through requirements for ventilation and specification of construction materials and methods. Heating, ventilation and air-conditioning [HVAC] systems control many aspect of indoor air environments, so clearly their design, operation and maintenance has an important affect on IAQ.

8.2.1 Building design

The most direct effect of building design on IAQ is whether the building can use natural ventilation or whether is must be augmented or completely replaced by a mechanised ventilation system. Fundamental aspects of the building, such as its depth, location and placement with respect to prevailing winds, determine whether natural ventilation is feasible or not.

Building design also impacts IAQ through specification of construction materials and methods, as described in the following section.

8.2.2 Structural building materials

The materials used for a building’s structure and envelope can out-gas toxic emissions, although the significance of this to indoor air quality is of lesser importance than out-gassing from materials exposed directly to the interior.

Levin (1989) states that structural and envelop materials of typical concern to IAQ are: wood preservatives; concrete sealers and curing agents; caulking; sealants; joint fillers and gaskets; glazing components and gaskets; and fire proofing and thermal and acoustic insulations.

The American Institute of Architects’ series *Environmental Resource Guide* (which began in 1992) considers the environmental impacts of numerous building materials, including their effects on indoor air quality. These “materials reports” are arranged according to the Construction Specifications Institute’s *CSI Masterformat*.

- **Brick & mortar** (American Institute of Architects, 1996, MAT04210)

No studies have indicated that brick and mortar contribute to indoor air pollution.

- **Concrete masonry units** (American Institute of Architects, 1996, MAT04220)

A United States’ Environmental Protection Agency [USEPA] study reported that various aromatic and halogenated hydrocarbons were emitted from concrete masonry units. Pre-insulated masonry blocks may contain polystyrene foam insulation. A USEPA study reported that polystyrene emits the following indoor air pollutants: ethyl benzene; styrene; aliphatic, aromatic and halogenated hydrocarbons.

- **Stone veneer** (American Institute of Architects, 1996, MAT04450)

Stone curtain walls are generally hung on the outside of buildings. Although they contain adhesive resins, most volatile organic compounds are released before installation.

- **Steel framing** (American Institute of Architects, 1996, MAT05410)

Steel framing does not out-gas so its impact on IAQ is negligible

- **Wood framing** (American Institute of Architects, 1996, MAT06110)

Wood framing enclosed in walls has little impact on IAQ unless it is very odorous. Softwoods generally have a stronger odour than hardwoods. Sensitive individuals may experience symptoms because of exposure to wood constituents, such as terpenes. Small traces of arsenic dust have been detected in rooms where pressure-treated timber has been used.

- **Thermal insulation** (American Institute of Architects, 1996, MAT07200)

Concerns associated with insulation include release of fibres and/or volatile organic compounds during installation and use.

Fibrous particulate matter, considered to be possibly carcinogenic to humans, may be introduced from fibreglass and mineral wool insulation. Cellulose particulates from cellulose insulation are not generally considered a problem for IAQ, however, chemical additives to improve fire retardancy, such as ammonium sulfate and boric acid, may result in emissions. Some foaming insulation materials may emit VOCs such as formaldehyde, xylene and toluene and, in some cases, CFCs. Removal of asbestos insulation during renovations and demolitions is of concern.

Because of its formaldehyde emissions, urea-formaldehyde [UF] foam insulation was previously a major concern in the USA, however, this insulation type is rarely used there now.

- **Asphalt shingles** (American Institute of Architects, 1996, MAT07310)

Asphalt is the result of petroleum processing that distils off VOCs, although some VOC residue may remain. In addition, modifiers such as styrene butadiene and the binder urea-formaldehyde are present in asphalt. Asphalt shingles are applied to the outside of the building, so emissions to interior spaces are not considered significant, although there may be health effects in sensitive individuals.

- **Glass** (American Institute of Architects, 1996, MAT08810)

Glass is inert and has virtually no impact on IAQ.

- **Sealants** (American Institute of Architects, 1992, July, TOPIC.I-7920)

Toxic emissions from sealants are of particular concern for the persons applying the material. The hazards from sealants vary widely, however, dependent on composition as well as curing time. Solvent-based acrylic sealants are reportedly more durable than latex sealants, but are less suited to indoor applications because of their xylene emissions. Butyl rubber and neoprene sealants emit aliphatic hydrocarbons, so limited use for indoors applications is recommended. Solvent-based synthetic rubber and nitrile sealants are reported as possible health hazards for indoors use.

8.2.3 Heating, ventilation and air-conditioning systems

HVAC systems control the following aspects of indoor air: temperature; humidity; "cleanliness" (including odour); and, air movement. Design of HVAC systems and their operation and maintenance clearly affects indoor air quality.

The poor management of and an increasing reliance on mechanised HVAC systems to maintain indoor environments has led to an increasing number of IAQ problems associated with these systems. A well known and extreme example of a health problem associated with evaporative water systems is Legionnaires' disease.

HVAC systems in buildings can:

- be the primary source of air contaminants;
- transfer contaminants from their source to people in the building;
- fail to adequately remove contaminants from their source in an occupied area (Bearg, 1993).

These contaminants may arise from:

- outdoors, entering via intentional outdoor air intake;
- outdoors, via unintentional intake [infiltration];
- within the HVAC system, such as contaminants in old air filters, microbes growing in the draining pans beneath cooling coils or from internal duct liners;
- the building itself, such as from the building occupants or maintenance activities (Bearg, 1993).

Levin (1992, July) states that HVAC system *materials* may, in themselves, be sources of air pollutant emissions; these materials include the duct insulations, duct sealants and chemical water treatments.

8.3 Factors of influence: interior

Interior materials are constantly exposed to the interior space, so clearly influence the quality of air in that space. The design of the interior, and the associated materials specifications, are therefore critical aspects of achieving good indoor air quality.

Building occupants strongly influence indoor air quality, both through their presence alone, as well as through their activities and the products and materials they use.

8.3.1 Interior design

The choice of construction materials, surface finishes, furnishings, location of office equipment and appliances, plants and partitionings affect the level of IAPs and the ventilation flow within interior spaces. Interior designers need to consider the IAQ impacts from the wide range of materials used in indoor spaces.

8.3.2 Interior construction & finishing materials

Choice of interior materials is critical because their surfaces are constantly exposed to the interior air. The principal issues are that materials can:

- emit substances which are toxic;
- emit substances which are unpleasantly odorous;
- adsorb gaseous pollutants and then re-emit them later (the materials are sinks); and
- collect dust and other particles and provide harbourage for nuisance micro-organisms, such as dust mites.

Levin (1989) gives the following categories of typical materials which are of concern in office building interiors:

• Subfloor	underlay (particleboard, plywood, chipboard)
• Flooring systems	flooring or carpet adhesive carpet backing or pad carpet or resilient flooring
• Ceiling systems	ceiling tiles panels
• Partitions	wall coverings adhesives paints, stains, wood preservatives paneling

The American Institute of Architects' *Environmental Resource Guide* series provides a detailed analysis of the environmental impact of numerous interior materials.

- **Plywood** (American Institute of Architects, 1993, January, TOPIC.1-6118)

The American Institute of Architects state that hardwood plywood is generally or more concern to indoor air quality than softwood plywood. Hardwood plywood is generally bonded with urea-formaldehyde adhesives, which can emit formaldehyde for months or even years after manufacture. Phenol-formaldehyde adhesives, generally used in softwood plywood, are more stable and have lower formaldehyde emissions. Softwood plywood is generally used in exterior applications.

- **Particleboard** (American Institute of Architects, 1992, TOPIC.1-6124)

Particleboard bonded with urea-formaldehyde adhesive is an issue for indoor air quality because of its formaldehyde emissions (see comments above for Plywood) and because it is often used in large quantities in modern buildings.

- **Glued laminated timbers** (American Institute of Architects, 1996, MAT06180)

Fully cured resorcinol-formaldehyde and phenol-resorcinol-formaldehyde adhesives, used in laminated timbers, release few emissions. Urea-formaldehyde adhesives can still release formaldehyde after curing.

- **Plastic laminates** (American Institute of Architects, 1996, MAT06240)

Plastic laminates are usually adhesive-bonded to a plywood or particle board surface, either before or during installation; these adhesives which may out-gas VOCs. No studies have detected emissions of formaldehyde or aliphatic, halogenated or aromatic hydrocarbons from plastic laminate directly. In fact, when all particleboard surfaces are covered with laminate, the laminate can reduce formaldehyde emissions from the board.

- **Plaster & lath** (American Institute of Architects, 1996, MAT09200)

Plaster surfaces are hard and stable when cured, so the plaster itself contributes few emissions. Materials added to plaster to effect its drying or decorative finishes may, however, be a source of significant emissions.

- **Gypsum board systems** (American Institute of Architects, 1996, MAT09250)

Gypsum alone is inert and extremely low in emissions but additives used to produce water-resistant board and fire-resistant board may out-gas VOCs such as formaldehyde, trichlorethane, xylene and undecane. The paper on each side of the gypsum board may contain chemical from previous uses, additive chemicals from the production of the paper itself or from specialty coatings. The USEPA concludes that gypsum board may contribute significant emissions. These emissions can be reduced by surface treatments such as painting or laminating, however these coatings may themselves contribute pollutants. There is some evidence that gypsum board acts as a sink for VOCs from other sources.

- **Ceramic tile** (American Institute of Architects, 1996, MAT09300)

Ceramic tile is an inert building material and does not emit toxic chemicals in use. Portland cement-based mortar and grout have not been shown to produce any toxic emissions. However, adhesives and non-cementaceous mortar (for example, latex-portland cement mortar or dry-set mortar) and grout (for example, epoxies, furans, and silicones) used to install tiles may be a source of emissions that affect IAQ.

- **Terrazzo** (American Institute of Architects, 1996, MAT09400)

After terrazzo has been poured and hardens, few materials remain that can evaporate into the indoor air environment. During use and maintenance, sealers used on terrazzo floors may release VOCs.

- **Acoustical ceiling systems** (American Institute of Architects, 1996, MAT09510)

Ceiling panels and tiles may act as sinks because of their large surface area. Some studies indicate that ceiling panels and tiles adsorb and desorb certain VOCs at significantly higher rates than carpet and pillow.

8.3.2.1 Finishes

- **Paper and flexible vinyl wall coverings** (American Institute of Architects, 1996, MAT09950)

A USEPA study indicated that wallpaper was a substantial source of emissions for formaldehyde, n-hexane, isohexane, toluene, xylenes, nonane, 1,2,4-trimethlbenzene, decane and undecane. Solvent-based inks are thought to be the source of some emissions. Adhesives used to attach wall coverings are also a source of VOCs. However, tests indicated that emissions from both wall paper and vinyl coverings decrease to trace levels during the first few weeks following installation.

- **Paints** (American Institute of Architects, 1993, January, TOPIC.1-9900)

Both solvent-based and water-based paints emit substances which may be irritating or toxic. Conventional water-based paints contain a small amount of volatile organic solvent. Most VOC emissions occur during application and while the paint is drying. Painters are particularly at risk from chronic exposure to these toxic compounds.

The American Institute of Architects also report that paint strippers frequently contain methylene chloride, a hazardous and volatile substance.

As part of the strategy to reduce ground-level ozone production and photochemical smog, the *Clean Air Act Amendments*, 1990, forced the reformulation of many organic solvent-base paints in the United States[8].

- **Stains & varnishes** (American Institute of Architects, 1996, MAT09930)

Emissions of volatile organic compounds occur predominantly during the application and drying phases of stains and varnishes. These initial emissions can be significant. As mentioned above, the US *Clean Air Amendments* lead manufacturers to reduce the VOC content of their stains and varnishes.

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[8] The Australian Paint Manufacturers' Federation has indicated the following VOC reductions could be achieved by the year 2001: architectural and decorative paints – 20%; industrial paints – 15% (Hambrook, personal communication, 24/1/97). While these reductions are proposed in response to the issue of photochemical smog, there are likely to be associated benefits for indoor air quality.

8.3.2.2 Floor coverings

- **Carpet systems** (American Institute of Architects, 1992, July, TOPIC.1-9681)

The three components of a carpeting system which are important to consider with respect to emissions of indoor air pollutants are the carpet itself, the carpet cushion and the installation adhesive. It is reported that carpets themselves have relatively low VOC emissions when compared with the associated carpet cushion and, especially, the installation adhesive. Carpet finishing treatments, such as protective coatings, and shampoos are also a source of VOCs.

Another important aspect of carpet and carpet cushion to indoor air quality is their propensity to act as sinks for VOCs. The large surface area and porosity of carpets give them a very high sink capacity.

Carpets that are not cleaned and properly maintained can harbour a build up of biological pollutants such as fungi, mites and bacteria.

- **Linoleum** (American Institute of Architects, 1996, MAT09651)

Linoleum is naturally antibacterial because of the continuous oxidation of linseed oil. There are various formulations so it is difficult to make generalisations about emissions. A USEPA literature review of linoleum reported several emissions including formaldehyde, toluene and butanol. Industry indicated that most of these VOC emissions come from solvent-based factory coatings. Installation adhesives may be a source of VOCs.

- **Vinyl flooring** (American Institute of Architects, 1996, MAT09652)

USEPA studies showed that the main emissions from vinyl flooring include aromatic, aliphatic and halogenated hydrocarbons. Emissions originate from the PVC resins, plasticisers[9], solvents, and contaminants or impurities in the raw materials used to manufacture the flooring. The EPA concluded that the adhesives used in installation are a greater sources of indoor air emissions than the actual flooring material.

8.3.3 Furnishings & furniture

Levin (1989) state that furnishings of typical concern with respect to indoor air pollutants emissions are textiles and other soft furnishing and furniture made from composite wood (particleboard, plywood, hardboard, chipboard). Some furniture and furnishings may also act as sinks for dust and introduce biological contamination.

Commentary on emissions from composite wood materials can be found in Section 8.3.2. Soft furnishings which contain urea-formaldehyde foam, such as chairs, sofas and bedding, are also of concern as they out-gas significant concentrations of formaldehyde.

Open shelving is a type of furniture of particular concern to indoor air quality because of the large surface area it provides for accumulation of dust and the difficulty in adequately cleaning such shelves.

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[9] Plasticisers have received considerable attention lately because of recent evidence regarding their role in endocrine disruption (Colborn *et alia,* 1996). Smith (1996) notes that the Swedish National Chemicals Inspectorate has recommended that emissions of plasticisers such as phthalates be reduced on the basis of human health risk, but their final decision is contingent on the findings of a current European Union risk assessment of these materials.

- **Wool and polyester fabrics** (American Institute of Architects, 1996, MAT12610)

The *Environmental Resource Guide* discusses wool and polyester in relation to their use as upholstery fabrics in office workstations. In such modular office furniture, these fabrics are frequently applied to vertical surfaces of partitions for acoustical and decorative purposes.

Fabrics, especially synthetic fabrics, can release noticeable amounts of VOCs into the indoor air. Upholstery treatments such as water repellents, mildew proofing, fire retardants, and stain guard, may also be a source of emissions. Moth-proofing agents for wool fabrics include naphthalene and paradichlorobenzene. Coatings on fabrics include vinyl acetate, vinylidene chloride and formaldehyde. Some individuals may be sensitive to fabric fibres.

8.3.4 Equipment & appliances

Some indoor air quality problems associated with equipment and appliances are the consumables or fuel used in the operation of equipment. Photocopiers and printers are examples of the former; these can also generate ozone gas during operation (WorkCover Authority, 1993). Unflued gas heaters and cookers and kerosene heaters are sources of nitrogen oxides and other polluting combustion products (USEPA & CPSC, 1988).

Improperly vented appliances, such as tumble driers and stoves, can cause undesirable moisture build-up (USEPA & CPSC, 1988).

Improperly maintained evaporation trays in humidifiers, air-conditioners and refrigerators can provide a breeding ground for microbial contaminants (USEPA & CPSC, 1988).

Some authorities also express concern over the possible dangers of radiation from televisions, computer monitors, microwave ovens and electrical equipment in general.

8.3.5 Occupant bioeffluence

Occupied spaces are always subject to gases, vapours and particles excreted by humans and their animal pets [bioeffluence]. The most important of these are: carbon dioxide, a product of respiration; water vapour, especially from sweating or panting and respiration; body odour, especially from microbial action in the region of apocrine glands but also in the mouth and oily parts of the skin surface, such as the scalp; skin flakes and animal dander (skin, scales and fluff); and odours associated with urine, flatulence and faeces. While body odours should not generally be regarded as pollutants, their presence in indoor spaces is a critical factor affecting peoples' perception of indoor air quality.

8.3.6 Occupant activities

Occupant activities which have a negative impact on indoor air quality can be broadly be divided into two types: activities which are purposely undertaken and activities which are neglected.

The most significant purposeful activity is smoking. The negative health impacts of tobacco smoking on both smokers themselves and other people in the vicinity – passive smokers – are very well documented. The term "environmental tobacco smoke" is used to describe the sidestream smoke and exhaled smoke (USEPA & CPSC, 1988) to which all occupants of a room or even a whole building can be subjected.

Other purposeful activities which can have a negative impact on indoor air quality are those which sometimes or always involve use of polluting products or processes, such as hobbies, cooking, home maintenance and work or study activities.

Neglecting certain activities can have a negative impact a building's air quality. Inadequate cleaning of furnishings and surfaces and incorrect operation of ventilation equipment are examples of negligent practice on the part of building occupants.

8.3.7 Consumer products

Consumer products[10] which can be source of indoor air pollutants include perfumes and other toiletries, cosmetics, stationery, incense and candles, tobacco, clothing (especially dry-cleaned clothing), and freshly printed matter (such as newspapers and magazines).

8.3.8 Pest management

Traditional pest control methods rely largely on the use of chemical pesticides (including, insecticides, herbicides, rodenticides) to manage pest problems. Commonly used chemical groups include organophoshates, synthetic pyrethroids and carbamates. As each pesticide formulation contains a mixture of chemicals, it is not only the active constituent which may contribute to IAP but all other formulated ingredients as well.

Indoor chemical pest control contributes to indoor air pollution through the release of VOCs during application and via residues left behind on surfaces or attached to dust particles post-treatment. Outdoor chemical treatments also contribute to IAP through the release of VOCs which can enter the building via windows, doors and ventilation ducting. Contaminated soil particles can also be blown indoors or enter attached to occupants' footwear.

Indoor pest infestations can, in themselves, be a form of indoor air pollution. For example, some asthmatics are sensitive to dust mite allergens and to the odour that infestations of cockroaches leave behind.

8.3.9 Cleansing

Good indoor air quality cannot be achieved without adequate cleansing activities. However, cleaning products in themselves can be a source of source of air pollutants.

Chemicals such as solvents, detergents, fragrances, surfactants, enzymes and antimicrobials are commonly used in cleaning products. These chemicals contribute to the chemical load in the indoor environment and some components evaporate and become IAPs.

Cleansing processes such as vacuuming can introduce particles to the indoor air. Cleaning specific areas such as ventilation ducts can introduce unwanted substances back into the indoor air environment.

8.3.10 Interior renovation and refit

Bearg (1993) points out that a refit will typically involve all new materials; this is when emissions are usually very high. This may have particular implications for renovations in the Village, for instance, where refits may occur while other parts of buildings are occupied.

One part of a building may be renovated while another part of the same building continues to be occupied. The people working on the actual refit, such as the builders and painters, should normally be provided with safety equipment which will protect them from dangerous emissions from, for example, wet products like paints and strippers, or dusts, from sanding back old paint. The regular building occupants, however, may not be protected under these unusual conditions.

[10] Goods which are ready for consumption and are not utilised in any further production.

Old buildings might contain hazardous substances, such as asbestos, lead paints, urea-formaldehyde or fibrous insulations, which may be disturbed or removed during a renovation or refit.

9. Managing indoor air quality - best practice

Best practice is the use of products, processes and services which go beyond their normal function by achieving the best possible indoor air quality and the lowest possible contribution of pollutants to the total air environment (Section 4.3).

Many IAQ management authorities state that it is more efficient to limit the use of polluting sources than it is to remove or clean polluted air (e.g., Levin, 1992 & Appleby, 1990). Mitigation is usually more demanding of energy than prevention[11]. Minimising the use of polluting sources is therefore preferable in the context of total – indoor and outdoor – air quality, so is a strategy strongly recommended for Olympics' facilities.

The priorities for restricting the use of a particular source will differ according to how much pollution that source contributes, the availability of non-polluting alternatives, trade-offs against other selection criteria, such as durability and cost, and the demand for specific reductions, be they consumer-driven or regulatory requirements.

Although natural materials are generally better than synthetic materials from an overall environmental [cradle-to-cradle] perspective, this is not necessarily true from the indoor air pollution perspective (Pilatowicz, 1995; Crowther, 1992). For instance, unless treated with special finishes, natural materials can be a more suitable habitat for microbial growth than synthetics. Each materials choice therefore needs to be made on a case-by-case basis.

While prevention is preferable to mitigation, obviously not all sources of indoor air pollution can always be avoided. For example, any occupied building will be subject to the human emissions of carbon dioxide. Spengler & Samet (1991) report mitigative measures for poor indoor air quality of five basic types: source removal, source modification, behavioural adjustment, increased ventilation and, air cleaning.

Preventive control measures for building materials, outdoor sources, furniture and textile sources (Table 9.1) are primarily the domain of architects and interior designers. Limiting pollutant sources for other pollutant emitting products, like cleaning products and tobacco smoke (Table 9.1), falls particularly to building managers and building occupants.

Effective management of processes like working or cooking involves both avoiding the use of polluting products and the provision of a ventilation system adequate to those processes (Table 9.1). For instance, clean operation of a photocopier might involve using low toxicity toner as well as locating the copier in a special room fitted with a local exhaust system.

In general, provision of ventilation systems adequate for building uses and to manage human bioeffluence is the responsibility of architects and HVAC engineers. Once a building is occupied, correct operation of the ventilation system is generally the responsibility of building managers and/or building occupants.

[11] The revised United States' Ventilation Standard may require "additional ventilation rates" to be added to the current minimum rates if the building designer does not minimise the pollutant sources in the building. The aim of this approach is to encourage the use of low-emission materials rather than increase the level of ventilation (State of the Environment Advisory Council, 1996).

Table 9.1 Management strategies for various sources of indoor air emissions

Modified from Levin (1992), which was, in turn, based on an earlier scheme devised by Anderson (1982).

Emission source category	Emission	Control strategy	Control method
Pollutant release	Building materials	Limit source	Preventive measures
	Outdoor sources		Preventive measures
	Furniture, textiles		Removal or restriction
	Consumer products		Removal or restriction
	Tobacco smoke		Removal or restriction
	Pesticides		Preventive or restriction
	Cleaning products		Preventive or restriction
Processes	Work (e.g., school, office, retail)	Ventilation	Local exhaust and dilution
	Food preparation		Local exhaust and dilution
	Laundry		Local exhaust and dilution
	Bathing & going to toilet		Local exhaust and dilution
Human metabolism	Water vapour	Ventilation	Dilution
	Carbon dioxide		Dilution
	Odours		Dilution
	Particles		Dilution

The management strategies summarised above (Table 9.1) are those recommended for Olympics' facilities. In keeping with the requirements of the *Environmental Guidelines for the Summer Olympic Games* (Sydney Olympics 2000 Bid, 1993), the subsequent discussion emphasises best practice for limiting the use of sources of indoor air pollution.

The majority of indoor air quality management literature is North American or European. There is limited information available on Australian conditions *per se*, although similar climatic conditions do exist in southern Europe and parts of the USA. A possible issue with using overseas information is that Australian building methods and materials, both in their composition and in the range available here, may be different. The extent to which any such differences could diminish the relevance of overseas findings is not known.

One locally produced publication, particularly aimed at management of large buildings and shopping complexes, is the Building Owners and Managers Association of Australia document *Managing Indoor Air Quality* (BOMAA, 1994).

9.1 Limiting material sources of indoor air pollutants

Limiting sources of indoor air pollution can be considered across a wide range of materials, including building and furnishing materials, appliances and consumer products (including tobacco).

9.1.1 Building and furnishing materials selection – general criteria

To achieve good indoor air quality, optimal selection criteria are for materials which:

- do not emit harmful levels of pollutants, respirable particles, dust or unpleasant odours (Pearson, 1989);
- after installation, emit any pollutants over the short- rather than the long- term (Levin, 1993);
- have low adsorption characteristics (Appleby, 1990), so do not act as sinks for pollutants from other sources;
- are resistant to micro-organisms such as bacteria, mould (Pearson, 1989) and dust mites;
- can be effectively cleaned using benign cleansers and processes;
- do not emit any harmful levels of radiation (Pearson, 1989);

- are safe during installation and under normal and extreme temperatures and during fires;

Levin (1993) gives useful guidance on how to determine which materials are important to focus on, how to identify and screen candidate products, how to get the required technical information on each product and how to evaluate candidate products prior to final selection. Materials which are likely to provide the greatest load of pollutants are those which are used in large quantities, have large surface areas and have high levels of volatile materials upon installation.

Materials safety data sheets [MSDSs] prepared by manufacturers provide information on the major ingredients in individual products. An MSDS also provides some information on health hazards associated with inhalation of a product, although this may only relate to short-term [acute] exposure to the product. Information should also be sought from the manufacturer on the effects of long-term [chronic] exposure to the product. In either case, the stated health effects from inhalation[12] will provide some guidance on a product’s possible impact on indoor air quality: if the stated effects are severe then the product should not be used, or used only sparingly and with appropriate precautionary measures. Because of issues of commercial confidentiality not all ingredients are disclosed on an MSDS. In addition, the stated health effects do not always relate to the formulated product but may only be relevant for active ingredients or ingredients that are in the greatest quantities. Material safety data sheets cannot therefore be used as the sole source of health data for products.

9.1.2 Surface finishes

An action required for improving air quality in Olympics’ buildings stated in the *Environmental Guidelines for the Summer Olympic Games* is that toxic fume emissions from paints, varnishes and polishes should be minimised (Table 6.1).

In addition to the general materials selection criteria (see 9.1.1), the following should be considered in selecting surface finishes:

- whether a surface finish is needed at all;
- the extent to which the finish is decorative rather than protective;
- that products need only be as durable as the specific application dictates;
- that products have the lowest possible content of toxic or irritating volatile organic compounds [VOCs];
- that the occupational hazards for the person applying the finish be minimised by selecting low toxicity paints and providing adequate ventilation during the painting process (see *Painters’ Hazard Handbook*, Holmes, 1990, for further detail).

[12] For example, the effects of inhalation stated on MSDSs for various cleaning products are remarks like “may cause weakness and dizziness”, “normal use is unlikely to cause toxicity” and “irritant and toxicant if inhaled excessively”.

9.1.2.1 Paints and varnishes

Anink *et alia* (1996), working in the Netherlands, categorise various building materials in terms of their environmental sustainability, based on a scale ranging from *not recommended* to *third*, *second* and *first preferences*. In assigning a minimum *basic selection* for each application, they consider the financial as well as environmental and health implications of each choice. Their recommendations for interior paintwork, shown with minimum basic selections (underlined), are:

Surface	**Not recommended**	**3rd Preference**	**2nd Preference**	**1st Preference**
• Interior wood	Conventional alkyd paint	Natural paint or High solids alkyd paint	Water-based acrylic paint	Untreated wax or Water-based natural stain
• Wood -concrete or Wood -stone or Wood-brick joints	Lead red lead[13]	Iron red lead or Alkyd resin primer	Water-based primer or High-solids primer	Natural preservative
• Wall preparation	Solvent-based[14] preservative	Water-based preservative	Natural preservative	No primer
• Interior walls	Conventional alkyd paint	Natural paint or Water-based acrylic paint	Mineral paint or Water-based natural stain	Whitewash
• Ferrous metal paintwork	Lead red lead or Epoxy-alkyds or Thermal galvanising	Conventional alkyd paint or Iron red lead	High-solids alkyd paint	Natural paint or Electrolytic powder coating

Anink *et alia* (1996) point out that all paints contain additives which are harmful to human and environmental health. They prefer high-solids alkyds over conventional alkyd paints because of their lower VOC solvent content.

Herbert Beauchamp (Toxic Chemicals Committee, Total Environment Centre), an industrial chemist with 35 years experience, commented to the authors that, except for surfaces subject to very high abrasion, water-based acrylic paints perform as well as high solids alkyd paints. In addition, water-based acrylic paints are preferable for indoor air quality and occupational health.

The American Institute of Architects (1993, January, TOPIC.I-9900) recommend that low-emitting and low-VOC paints are used and that, to allow vapours to dissipate, plentiful ventilation is provided during painting and for at least 72 hours following application. To minimise the need for preservative additions to paints (such as biocides added to prevent microbial growth in the paint containers), they also recommended that paints are made to order, for use at predetermined times.

A recent paper by the environment manager of the Australian division of ICI Dulux (Tepe, 1996) states that there are solvent-reduced or solvent-free products on the market for all decorative and almost all industrial applications[15].

Decorative finishes were avoided altogether on many of the surfaces in an environmental showcase home, built in Phoenix, Arizona (American Institute of Architects, 1996, PRO4). Extreme care was

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13 There is some confusion over what is meant by the term *lead red lead*. However, Lewis (1993, LDSOOO) gives *dilead (II) lead (IV) oxide* as a synonym for *lead oxide red*, so *lead red lead* is thought to be equivalent to lead oxide red. Herbert Beauchamp (Toxic Chemicals Committee, Total Environment Centre) indicated to the authors that paints with higher than 0.25% lead content are already banned from residential applications in Australia and that it is highly unlikely that lead oxide red would be an effective wood preservative.

14 The solvents referred to here are *volatile organic* solvents, rather than water, which is also a solvent.

15 No analysis of the costs, durability and application requirements for these paints is given, so it is not clear what is impeding wider use of these environmentally preferable products than currently occurs. Information on consumer attitudes to and perceptions of these products would also be useful in this regard.

necessary to ensure these components were installed without blemish, reportedly a difficult task because few tradespeople were sufficiently skilled to carry out such work. An alternate view from the "green" architect Ton Alberts is "to let the hand of the builder show", an aesthetic applied in the design and construction of a famous bank headquarters in Amsterdam (Vale & Vale, 1991).

No specific information on IAQ best practice for varnishes was found in time for production of these guidelines. However, the general materials selection criteria (9.1.1) apply; information provided for other wet products, such as paint, also give guidance on factors to be considered when choosing and applying varnishes.

9.1.3 Sealants

Based on a range of environmental and economic criteria, Anink *et alia* (1996), working in the Netherlands, give the following recommendations and basic minimum selections (underlined) for various sealants:

Application	Not recommended	3rd Preference	2nd Preference	1st Preference
• Sealing joints	Polyurethane [PUR] foam or PUR sealant	Elastomeric sealant with base filler	Mineral wool or Polyethylene [PE] tape or Ethylene propylene diene monomer [EPDM] seals	Coconut fibre or Felt or Sisal
• Sealing cracks	Polyvinyl chloride [PVC] tape or PUR tape	PE tape	[None given]	EPDM tape or Ethylene propylene terpolymer [EPT] rubber
• Elastomeric sealants	PUR sealant	[None given]	Polysulphide sealant	Silicone sealant
• Plastic sealants	Solvent-based acrylic sealant	Butylene sealant	Water-based acrylic sealant	Water-based natural sealants

Anink *et alia* (1996) disapprove of some sealants because of the ozone depletion associated with their manufacture as well as their inherent toxicity. However, they point out that in some applications, it is practically impossible to avoid using polyurethane sealants.

The American Institute of Architects (1992, July, TOPIC.I-7920) emphasises the need to protect the health of persons applying sealant indoors, by provision of adequate ventilation and protective devices. They also recommend the use of low-emission products; oleoresinous, acrylic emulsion latex, polysulphide, polyurethane, and silicone sealants are examples of these products cited.

9.1.4 Adhesives

In some applications, adhesives can be replaced with screws and bolts (Myer & Klymenco, 1994). Floor coverings can sometimes be fixed with nails or staples. An added advantage of avoiding adhesives is that the fastened materials may be more easily disassembled and need less preparation for future re-use.

Where adhesives cannot be avoided, low-emission products should be used.

Hays *et alia* (1995) state that, in general, liquid polymers and water-based emulsions have fewer emissions than solid polymers and solid rubbers because the former do not dry by the release of VOCs. They report the following findings from research into emissions from resin-based adhesives:

- natural resins (vegetable-, animal-, oil- and tar- based) are generally low emitters;
- synthetic solid polymers/rubbers generally contain high levels of VOCs, so are high emitters;
- emulsions are generally low emitters;

- liquid polymers are generally low emitters;
- hot melt resins are typically low emitters; and
- pressure sensitive resins are typically low emitters.

9.1.5 Timing application of wet materials

Wet materials, such as paints, varnishes, adhesives, caulks and sealers, tend to out-gas a large amount of volatile organic compounds during their initial drying periods. This tendency can be used to minimise adsorption of these VOCs onto fleecy surfaces and other sinks, by carefully timing the application of wet materials in relation to installation of the adsorptive surfaces. For instance, gyprock walls, which are quite adsorptive, should be sealed or painted before floors are varnished. Appropriate timing of the application of wet materials should therefore be included in building work plans.

9.1.6 Insulation

The *Environmental Guidelines for the Summer Olympic Games* require use of insulation as a key criteria for energy conservation in Olympics' buildings (Table 6.1).

In selecting an insulation material, the general criteria (9.1.1) apply, with special attention to be paid to its propensity to support microbial growth, its formaldehyde content and the possibility of loose fibres escaping from the insulation, either during installation or use.

The American Institute of Architects (1996) rank magnesium silicate, cotton and perlite as some of the best insulating materials with respect to indoor air quality (Table 9.2).

Table 9.2 American Institute of Architects rankings for insulation materials

Information summarised from American Institute of Architects (1996, App2). Although not explicitly stated, it is assumed these rankings were based on insulating products available in the USA, which may differ in composition from comparable products available in Australia.

Material	Performance with respect to IAQ	Comments on IAQ implications
• Fibreglass	Poor – Reasonably good	Needs to a be barrier between insulation and space
• Mineral wool	Poor – Reasonably good	" " "
• Cellulose	Reasonably good – Good	Mould and mildew risk. Dust and fibres a risk if poorly installed
• Extruded polystyrene	Good	Generally no problems, except for individuals with chemical sensitivities
• Expanded polystyrene	Good	" " "
• Polyisocyanurate	Good	" " "
• Polyurethane	Good	" " "
• Phenolic foam	Good	Possible out-gassing, but probably not a problem
• Open-cell isocyanuarate	Good	Unknown, but any emissions probably out-gas quickly
• Magnesium silicate	Good	Considered one of the safest materials from the IAQ standpoint
• Cotton	Good	Considered safe
• Perlite	Good	No known concerns
• Vermiculite	Poor	May contain asbestos

Baggs & Baggs (1996), Australian-based authors, assess the performance of many insulating materials across a range of environmental and functional criteria. While they do no specifically isolate indoor air quality effects, they give overall toxicity ratings as follows:

- worst [very disadvantageous] – mineral wool (glass, rock fibre), polystyrol, urea formaldehyde, polyurethane;
- bad [disadvantageous] – cellulose (recycled paper), vermiculite, perlite;
- neutral – straw and clay mix, woodwool, sawdust or shavings with bark, strawboard, cork (baked), coconut fibre, foam glass, foamed lime or cellulose, clay bead.

Insulation can provide an ideal medium for microbial growth, so should be installed carefully to ensure that it remains free of moisture in use.

9.1.7 Plywood and wood panels

The American Institute of Architects (1993, January, TOPIC.I-6118) recommends using low-formaldehyde plywood and using higher than normal ventilation rates for up to one year after installation of urea-formaldehyde [UF] bonded plywood.

The American Institute of Architects (1992, July, TOPIC.I-6124) recommends the use of low-emission UF bonded particleboard wherever practical or the use of phenol formaldehyde bonded product. They also recommend sealing or encapsulating large areas of unfinished UF particleboard, such as might be used as subflooring.

Industry representatives indicated to the authors of these guidelines that the vast majority of Australian-made particleboard, MDF and plywood already achieve formaldehyde emission limits of 10 mg (or less) per 100 g of product. Clearly, some manufacturers are making product further below the 10 mg limit than others. This limit should therefore be used as a benchmark by which specifiers can judge the IAQ impacts of wood boards and panels from various suppliers.

9.1.8 Floor coverings

The *Environmental Guidelines for the Summer Olympic Games* states that toxic fume emissions from carpets should be minimised in Olympics' facilities (Table 6.1).

Flooring coverings should be installed without polluting adhesives by, for example, use of stretching and tacks, or using very low toxicity adhesives.

9.1.8.1 Hard floor coverings

Environmentally preferable resilient floor coverings recommended by Dutch authors Anink *et alia* (1996) are linoleum or ceramic tile; they reject vinyl on the basis of its PVC content. Linoleum is made from natural and renewable raw materials and is sufficiently durable for most applications. Ceramic tiles are inert and highly durable (American Institute of Architects, 1996, MAT09300) but may be too hard for prolonged standing and do not reduce noise as much as softer floor coverings (Crowther, 1992).

The American Institute of Architects (1996, App5) state that the total VOC emissions from linoleum, due to its linseed oil content, may be higher than vinyl flooring. However, it is suggested that VOC emissions from vinyl are more likely to be toxic than those from linoleum, which are odorous rather than toxic. In either case, if adhesives are used for installation, these are very likely to be a significant source of toxic VOCs. On the basis of indoor air quality concerns alone, linoleum and vinyl are ranked about equal; across a full range of environmental performance criteria, however, linoleum ranks well ahead of vinyl (American Institute of Architects, 1996, App5). As the EGSOG recommends avoiding the use of polyvinyl chlorides (Table 6.1), vinyl flooring is not a suitable option for Olympic's facilities.

The American Institute of Architects (1992, April) suggest that linoleum (TOPIC.I-9651) and vinyl flooring (TOPIC.I-9625) be installed using low-emission adhesives and that installation should not occur over uncured concrete [because of out-gassing from the concrete] or on below-grade slabs [because of potential damp problems].

9.1.8.2 Carpet

A big advantage of carpet is its sound-absorbing properties (Crowther, 1992). Unlike many other interior components, however, carpet has implications for indoor air quality long after its installation. Carpet and carpet underlay provide ideal harbourage for dust mites, tend to collect dust and dirt and act as a sinks for many chemical pollutants. An ongoing source of chemical pollution associated with carpet is protective coating treatment.

Carpet should therefore only be installed where it is certain that appropriately frequent, thorough and environmentally benign cleansing will be carried out. For this reason alone, minimal use of fitted carpets in the residential components of the Olympics' development is recommended.

9.1.9 Furnishings and furniture

A key IAQ strategy for furnishings is to reduce the amount of fleecy materials, such as padded and upholstered furniture and partitions and drapes, thus providing less surface area for adsorption of volatile air pollutants from other sources. These fleecy surfaces also often provide ideal harbourage for dust mite, so their reduction is also advantageous from this perspective. Special attention needs to be paid to adequate cleansing of fleecy furnishings and furniture.

Reducing the amount of furniture, especially new furniture, made from glued wood products, such as particleboard and MDF, reduces sources of formaldehyde emissions. However, where alternative solid wood, glass or metal products are uneconomic, glued wood products should be sealed with benign water-based products or plastic laminate. Crowther (1992) recommends off-site curing of new furnishing materials.

Cupboards and wardrobes are preferable to open shelves or clothes racks because of the propensity of the latter to gather dust.

9.1.10 Re-use and recycling of materials

In keeping with *Environmental Guidelines for the Summer Olympic* Games (Table 6.1), general materials selection should include recycled materials.

Recycled materials may be a source of a source of indoor air pollutants because:

- they may contain high levels of micro-biological contaminants such as bacteria and fungus (Institute of Medicine, 1993);
- they may be contaminated with chemicals, such as pesticides or lead, from previous uses (Baggs & Baggs, 1996); and
- their preparation for re-use may expose or introduce new, pollutant-emitting surfaces.

However, recycled materials may be beneficial to IAQ as they are generally well-cured and out-gas fewer volatile emissions than new materials (Baggs & Baggs, 1996). Suppliers of recycled materials should provide adequate evidence that a given batch of material is free from chemical contamination. Recycled materials may generally be cheaper than new ones, so the cost of conducting pre-purchase safety tests can be justified.

9.1.11 Appliances

The two aspects of household appliances which are most critical with respect to indoor air quality are, firstly, the combined heat and moisture they can produce and, secondly, the combustion by-products that fuel burning appliances produce.

The general strategy in either case is that the appliance is flued or vented to the outside of the building. This is particularly important for gas stoves, gas heaters, including water heaters, and tumbler driers.

Localised exhaust is also recommended for office appliances of concern, such as photocopiers and printers. This means careful consideration and planning should be given to office layout in Olympics' facilities. Sufficient flexibility should be built into the HVAC system to allow a reasonable level of changing usage patterns in office spaces to occur without detrimental affect on office air quality.

9.1.12 Consumer products

Tobacco smoking is of great concern for indoor air quality because of its effects on both the smoker and other building occupants. To ensure good indoor air quality, smoking can either be prohibited in indoor spaces or allowed only in designated and specially ventilated rooms. The latter strategy is out of keeping with the energy conservation policy promoted for the Sydney Olympics' development, so prohibition from smoking indoors is recommended. If outdoor smoking spaces are deemed necessary, to prevent influx of tobacco smoke, these should be in designated areas, located well away from building openings.

In general, occupant education will be the key for limiting use of other polluting consumer products. It is recommended that information on this aspect of indoor air pollution be included in plain English operating manuals written for the residential components of the Olympics' development.

9.1.13 Outdoor sources

While outdoor sources of pollutants have a lesser impact on indoor air quality than sources located inside, best practice includes consideration of the following factors.

9.1.13.1 Placement of building and building openings

A principal concern in placement of the building and its openings (doors, windows and vents) is that the surrounding air used for ventilation may be polluted. Some strategies for avoiding these problems are mentioned in the Section 9.3.1.2.

9.1.13.2 Avoiding plant allergens

Plants produce substances that can be allergenic to humans, in particular, pollens from flowering plants. These can enter indoors via ventilation air or by transportation on people and their clothing (Institute of Medicine, 1993). Consideration should therefore be given to the types of vegetation planted around buildings to minimise pollen transferral indoors. In particular, plantings around and downwind of windows, doors and ventilation ports should involve minimal use of known allergen-producing plants. The Asthma Foundation of NSW recommends use of bird or insect pollinated plants rather than wind pollinated plants (Tovey, no date). The Foundation also produces a pamphlet *The Low Allergy Garden.*

9.2 Building management for good indoor air quality

9.2.1 Pest management

The *Environmental Guidelines for the Summer Olympic Games* specify that a criteria for sustainable development be “implementation of non-chemical pest control at Olympic sites”. Compliance with the guidelines specifies the “use of building techniques and interior design that minimise the need for chemical pest control and maximise opportunities for integrated pest management”(Table 6.1).

Integrated pest management (IPM) is defined by Olkowski *et alia* (1991) as an approach to pest control that utilises regular monitoring to determine if and when treatments are needed and employs physical, mechanical, cultural, biological and educational tactics to keep pest numbers low enough to prevent intolerable damage or annoyance. Least-toxic chemical controls are used as a last resort.

The range of Olympic facilities is vast. Successful integrated pest management at these sites will depend on strategies, developed to suit each building, that address factors such as design, use and management of the facilities. An integrated pest management expert should be consulted to provide detailed programs for Olympic facilities.

Potential pest problems requiring management in Olympics’ facilities can be separated into: structural pests such as termites, wood boring beetles and fungal decay; nuisance pests such as cockroaches, ants, flies, mosquitoes, fleas and rodents; and weeds.

9.2.1.1 Structural pest management

Non-chemical structural pest management needs to be considered at the design stage of the building process. Australian Standard AS 3660.1: 1995 *Protection of buildings from subterranean termites – Part 1 – New buildings,* specifies procedures to be implemented prior to, and in association with, building practices and physical barrier systems. Physical barriers systems detailed in this standard include stainless steel mesh, graded stone, and concrete slabs barriers.

Minimum termite resistant (MTR) design strategies, suitable for the Australian environment, are detailed by Verkerk (1990). Key components of MTR design include: building site management; design elements such as material selection, ventilation of subfloor and cavity spaces, inspection access to structural timbers; construction processes; and landscaping. Minimum termite risk design may also incorporate the use of physical barriers.

A pest management programme is an essential component of successful non-chemical management of structural pests and should be established upon completion of each structure. The programme should specify inspection regimes and establish important building maintenance procedures to minimise risks which encourage infestations. Regular inspection enables infestations to be identified at an early stage and maximises the opportunity for implementation of integrated pest management control strategies if required.. Regular maintenance procedures, such as minimising the build-up of moisture sources and maintaining seals on timber for example, will reduce the risks of structural pest infestations (Verkerk, 1990).

9.2.1.2 Nuisance pest management

Urban environments include many types of buildings and micro-environments which may be exploited by a range of nuisance pests (Hadlington & Gerozisis, 1988). The particular uses of a building will determine whether a particular animal species is a pest or not. For example, in a commercial kitchen, a cockroach infestation is a public health issue, while in an office, it may be merely a nuisance factor.

The potential for buildings to establish nuisance pest infestations is influenced by quality of finishing, design aspects, and the subsequent use and maintenance of the building. A range of integrated control strategies for nuisance pest infestations are detailed by Verkerk (1990) and Olkowski *et alia* (1991).

To minimise the creation of entry points and favourable harbourage areas for nuisance pests, finishing details which require attention include minimising gaps around electricity conduits, plumbing pipes, and ventilation ducting and careful sealing around doors and windows (Verkerk, 1990; Olkowski *et alia,* 1991).

Examples of interior design features which require consideration by designers, building occupants and managers include:

- location of and access around appliances such as stoves, dishwashers, fridges, computers and photocopiers – appliances are associated with heat and moisture and, often, food scraps, which provide ideal conditions for cockroaches and rodents;
- seals around cupboards and sinks – gaps and voids provide harbourage areas;
- storage facilities – warm, dark and possibly dank conditions, coupled with little disturbance, can foster animal pest infestation, for example, cockroaches and silverfish;
- fitted carpet – difficult to clean adequately, so can provide harbourage for dust mites and fleas.

As recommended for structural pest management, an integrated nuisance pest management programme should be established for each building. For nuisance pests, more attention should be focussed on building use, maintenance and occupant activities than for structural pests, as these factors significantly impact on nuisance pest establishment.

9.2.1.3 Weed management

Outdoors weed management is not a primary source of indoor pollution, however, the use of chemicals to control weeds [herbicides] may become a source of IAP if they enter indoors through ventilation ports or are tracked in by occupants. For this reason, non-chemical control of weeds is recommended as a strategy relevant to IAQ management at Olympics' facilities.

Non-chemical weed suppression techniques include indirect methods – landscape design/redesign (e.g., fences, paths, flower beds); habitat modification (e.g., manipulating soil fertility, mulching) and horticultural controls (complementary plantings, competitive planting) – and direct methods – physical (e.g., cultivation, mowing, soil solarisation) and biological (e.g., herbivorous insects, pathogens, fish) controls (Olkowski *et alia,* 1991).

9.2.2 Cleansing

The *Environmental Guidelines for the Summer Olympic Games* specify that compliance with the guidelines requires "the selection wherever practicable of materials and processes that are non-toxic in use such as...solvents and cleaning products" (Table 6.1).

Good indoor air quality cannot be achieved without adequate cleaning protocols, however the choice of cleaning products and processes can be a significant source of indoor air pollution and need to be adequately managed.

There are a large variety of cleaning products available for different cleaning applications. The level of cleanliness required (sterilisation, disinfection or sanitation) will, to a large extent, determine the choice of cleaning products and processes.

Some cleaning products may contain ingredients such as hazardous synthetic solvents and fragrances. These products should generally be avoided in cleansing processes for Olympics' facilities. There are now several manufacturers producing cleaning agents based on plant chemistry, such as citrus extracts. These products are generally considered less hazardous in terms of worker safety and hazardous VOC emissions and may be a suitable choice.

The recently introduced NSW *Occupational Health and Safety (Hazardous Substances) Regulations* 1996 sets out the legal obligations on employers and employees concerning the use of hazardous substances in the workplace. The legislation defines a hazardous substance as "any substance which has the potential to harm the health of the persons in the workplace, when used at work". The *Regulations* address storage, protective clothing and use of hazardous substances in the workplace. For example, it is now a mandatory requirement for employers to provide employees with material safety data sheets for chemicals. It is envisaged this legislation will minimise incidences of intentional chemical mis-use, or mis-use through lack of education.

Berry (1993) provides the following best practice cleansing guidelines, which have been modified for the purposes of these guidelines. Building managers and cleaning contractors should ensure:

• that cleaning procedures are carried out primarily for the purpose of protecting health and that cleaning for the sake of appearance is of secondary importance	– determine how clean the environment needs to be based on the building's function and human safety needs – examine all cleaning operations with regard to their consequences for human health and the environment – use safe cleaning products which minimise the introduction of indoor air pollutants – avoid exposing occupants and cleaning staff to pollutants being removed during cleaning processes;
• that the safety of all occupants and cleaning staff is provided for throughout cleaning operations	– occupants should know in advance when and what cleaning procedures will be performed – occupants and cleaning staff should be provided with material safety data sheets [MSDSs] to inform them about the products being used – safety signs and procedures should be used during cleaning processes – cleaning procedures should comply with government safety rules and regulations;
• that minimise chemical, particulate and moisture residue	– use water as a primary solvent in cleaning procedures to minimise hazardous solvents – ensure water residues are cleaned up as they may facilitate the development of indoor air pollution problems associated with moisture – deep clean to remove hazardous small particles – monitor temperature, moisture and ventilation during cleaning;
• that minimise human exposure to contaminants, cleaning chemicals, and cleaning residue	– cleaning chemicals should be used strictly according to label direction – adequate ventilation should be used during cleaning procedures – chemical waste should be disposed of properly – chemical residues should be minimised;

• that maximise the extraction of pollutants from the building envelope	– use effective, appropriate equipment that extracts and captures pollutants and residues (such as vacuum cleaners fitted with High Efficiency Particulate Air [HEPA] filters and externally vented, centralised vacuuming systems) – dispose of the extracted substances appropriately – seek out and clean up cleaning residues.

As dust mite allergen is known to be a major indoor air pollutant in coastal Australia, cleansing procedures to reduce accumulation of allergen should be implemented in Olympics' facilities. The Asthma Foundation outlines dust mite controls for domestic premises in the pamphlet *Asthma – Dust, Mites, Pollens & Pets* (Asthma Foundation, 1996). Cleansing recommendations include: regular dusting of all surfaces with a damp cloth 2-3 times a week; regular vacuuming, at least 2-3 times a week, of carpeted areas and soft furnishings, with a vacuum cleaner fitted with a good filter system or that is ducted outside; and, washing of all bedding at least once in month in 55°C water.

Specific cleansing programs, with strict purpose-written contracts, should be established with service providers to ensure the required level of cleansing is performed with the least hazardous materials and processes available. Cleaning guidelines should be provided to post-Olympic occupants of the Athletes' Village in order to facilitate the ongoing maintenance of indoor air quality in those facilities.

9.2.3 Management of HVAC systems

The availability of sophisticated air-handling and air-cleaning technologies should be not be used as an excuse for not reducing sources of indoor air pollution.

Rolloos (1993) gives the following guidelines for sound air-conditioning practice:

- Identify contaminant sources to be certain they are appropriately controlled. This must be done during design and construction and periodically throughout the life of the building.
- Provide the necessary outside air, thermal control and illumination when and where needed.
- Provide for proper installation, balancing and commissioning. Make the plant accessible for the measuring and checking instruments, which must be used during commissioning trials.
- Operate and maintain the building according to the (changing) activities and needs of the building occupants.

9.3 Ventilating for good indoor air quality

The *Environmental Guidelines for the Summer Olympic Games* recommend natural ventilation as a key criteria for energy conservation in Olympics' buildings (Table 6.1).

Natural ventilation may have advantages additional to energy conservation. Appleby (1990) reports that, even though naturally ventilated buildings generally have worse indoor air quality than air-conditioned buildings, the incidence of Sick Building Syndrome is lower. Appleby also states that investigations have shown that a perception of inadequate fresh air is frequently associated with factors which include the inability to open windows.

The State of the Environment Advisory Council (1996) says that Australia has no specifications for minimum ventilation rates in residential buildings. Presumably this is because the current Australian Standard which covers ventilation for acceptable indoor air quality (AS 1668.2: 1991) only considers mechanically ventilated buildings, whereas residences generally use natural ventilation[16]. The status of codes of practice for natural ventilation may, however, change in the next few months[17].

9.3.1 Energy conservation and adequate ventilation

The *Environmental Guidelines for the Summer Olympic Games* states that building design should "maximise indoor air circulation, without compromising energy saving features" as a key criteria for improving air quality in Olympics' buildings (Table 6.1).

There is a potential conflict between requirements for energy efficiency and satisfactory indoor air quality. All occupied indoor spaces need some form of ventilation with outdoor or otherwise "fresh" air. Provision of "fresh" air can be energy-demanding because:

- it may be colder or warmer than is comfortable for the space;
- it may be polluted and need cleaning prior to use; and/or
- it is distributed by use of mechanised air-handling systems.

Best practice with regard to energy conservation and adequate ventilation are therefore those strategies which minimise the need to expend energy for heating, cooling, air cleaning or air distribution purposes. Following is a discussion of some of these strategies.

9.3.1.1 Minimising the heating and cooling demands of ventilation

Baggs & Mortensen (1995) discuss the energy-conserving advantages of buildings with high thermal mass, for example, those with thick walls. These buildings alternately store both warmth and "coolth" [the opposite of warmth] within their thermally massive structural components. For such buildings they recommend flush ventilation – flushes which are short and sharp but achieve a large air exchange. They state that, in contrast to lightweight structures, using this ventilation strategy will result in a relatively small loss of warmth or "coolth" from thermally massive buildings.

A similar strategy is used for summer cooling of the NMB Bank's famous Amsterdam headquarters, in which the massive concrete structure is flushed with cool night air in readiness for the warmer days (Vale & Vale, 1991).

Air quality sensors may be useful for reducing the heating and cooling demands of ventilation air, by only activating ventilation when air quality drops below acceptable limits.

Vale & Vale (1991) report that the winter ventilation strategy of Spectrum 7, a novel light industrial premises in the UK, involves the use of carbon dioxide CO_2 sensors. The sensors respond to CO_2 in the occupants' exhalations and bring in fresh but cold air only when needed. This strategy is simplistic because occupants' perceptions of indoor air quality are certainly affected by factors other than CO_2 concentration, such as body odour (Appleby, 1990). To be effectively fully automated, a battery of different air quality sensors would be needed. More realistically, occupants probably need the ability to override automated systems of this type (see Case Study 10.4).

Heat-recovery ventilators (also called air-to-air heat exchangers) use the outgoing exhaust air to heat or cool the intake air.

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[16] *Natural ventilation* is also frequently termed *passive ventilation*.

[17] As indicated in Section 7, the draft of *AS 1668.2* has expanded coverage, and includes both natural and mechanical ventilation systems. In addition, as previously indicated, it is likely that NSW will adopt the new performance-based *Building Code of Australia* in mid-1997.

9.3.1.2 Minimising the introduction of polluted ventilation air

The location of outdoor air intakes affects the quality of that air. Special care must be taken with building relying solely on natural ventilation, as there is little opportunity for air filtration in such buildings (Gelder, 1996).

Anink *et alia* (1996) discuss the refurbishment of an apartment building located on a busy city street in Amsterdam. Ventilation air was taken from the rear of the building, where the air was cleaner. They also report the noise-reduction advantages of this strategy.

A large underground carpark in the NMB headquarters, in Amsterdam, is ventilated with air drawn from the indoor gardens which run the length of the building’s ground floor (Vale & Vale, 1991). An additional reported advantage is that the air inlets are hidden amongst the greenery.

Garages attached to houses are also a concern because of the combustion by-products that idling vehicles produce (USEPA & CPSC, 1988). For this reason, garages should either be separate from house living quarters, or appropriately sealed off.

9.3.1.3 Minimising energy demands of supplying and removing air

Providing the outdoor intake air is sufficiently clean, natural ventilation will generally be the most energy-efficient means of distributing air throughout a building. The depth of the building, the size, number and placement of opening windows, vents and doors, and the location of internal partitions and walls are all factors which affect the feasibility of using natural ventilation.

The activities that take place in the building will also affect whether natural ventilation strategies will suffice or whether additional mechanised systems, such as local exhaust, will be needed in particular areas. For example, to ensure that moisture does not build up in houses, Wrzeski (1991) recommends that bathrooms have ventilators which are controlled by a timer set for 30 minutes or more.

For energy conservation reasons, the *Environmental Guidelines for Summer Olympic Games* also requires that mechanical ventilation systems are designed so that they can be turned off in unoccupied spaces (Table 6.1). Timers and motion sensors may be useful devices in this regard.

9.4 Air-cleaning for good indoor air quality

9.4.1 Bake-out & flush-out

Bake-out and flush-out are strategies which are used to accelerate out-gassing of volatile pollutants from new but unoccupied building interiors.

Bake-out involves sealing a building and heating the interior to hotter than normal temperatures (up to 38°C) to accelerate curing of new materials (American Institute of Architects, 1996, MAT12610). The heating phase is followed by full flushing of the building with fresh air. Bake-out may lead to cracking and damage to seals (Gelder, 1996), is energy-demanding and may not ultimately achieve cleaner indoor air conditions (American Institute of Architects, 1996, MAT12610). However, further investigation of bake-out techniques is recommended because of their potential to improve air quality in new and newly refurbished buildings.

A less dramatic material curing technique, flush-out, involves full flushing of the building with outside air, 24 hours per day, for several weeks (American Institute of Architects, 1996, MAT12610).

These techniques may be useful both at completion of Olympics' facilities, and also mid-construction, between installation of high-emitting components, such as varnishes, and absorptive components, such as carpets.

9.4.2 Mitigative effects of plants

The ability of plant leaves to absorb chemicals from the environment and biodegrade them has been demonstrated in many studies. Common varieties of interior foliage plants have the capacity to reduce the concentrations of various trace organic chemicals such as formaldehyde, benzene and trichloroethane (Wood & Burchett, 1995).

Plants which will grow in typical indoor conditions tend to be varieties that do not flower or have only limited flowering, so do not generally introduce pollens (Institute of Medicine, 1993). These varieties should be preferred for interior areas.

Plants which have been shown to reduce indoor air pollutants and can typically be grown inside include Chinese evergreen, madonna lily, warenkii, mother-in-laws tongue, heart leaf, corn plant, English ivy, pothos and Madagascar dragon tree (WorkCover Authority, 1993).

The maintenance of indoor plants can contribute to indoor air pollution and should be considered. The use of pesticides and fertilisers containing polluting ingredients, including aerosols, should be avoided. Plants should be carefully inspected for insects to minimise the chances of introducing pests indoors (for example, ants and silverfish) which may in turn require treatment indoors.

9.5 Occupant education

Occupants, including building managers and non-expert occupants, need to understand the importance of maintaining good indoor air quality. There needs to be an awareness of the systems in place to maintain indoor air quality and an understanding of any personal responsibilities to limit unnecessary indoor air pollution. For example, occupants need to be shown how to operate ventilation systems, and told who to inform if the HVAC system is not working satisfactorily. Occupants also need to understand how their own activities and the materials they use to carry out these activities can contribute to indoor air pollution.

For this reason, it is recommended that protocols be written which describe how to effectively operate the ventilation system in each type of Olympics' building. So that these protocols can be understood and implemented, special attention should be paid to the level of expertise of the target occupants. Because operational details will vary from building to building, these protocols should form part of the contract conditions for delivery of each Olympic facility; adequate time should be allowed for testing that the protocols work and that they can be understood by the relevant occupants.

9.6 Measuring indoor air quality in Olympics' facilities

Special effort will be made to make Olympics' facilities energy-efficient, so it is particularly important that air quality measurements are undertaken at appropriate intervals in these facilities to ensure that indoor air quality is not compromised.

For the non-workplace components of the facilities, indoor air quality should at least meet the indoor air quality goals recommended by the NHMRC (Section 14). Workplaces are covered by the more rigorous occupational health and safety exposure standards (see Section 7). Indoor air quality monitoring findings should be included in the Olympic Co-ordination Authority's annual *State of Environment Report* (OCA, 1995, p10).

Scientific assessment of air quality in Olympics' facilities in comparison to conventional buildings will provide important benchmarks for the future design and operation of ecologically sustainable building developments, both in Australia and overseas. For this reason, it is recommended that the Olympic Co-ordination Authority encourage research bodies, such as cooperative research centres, to undertake deductive, scientific assessment of indoor air quality measures undertaken in Olympics' facilities.

9.7 Indoor air quality design and the tendering process

Indoor air quality considerations should form part of the design of Olympics' products and services, as well as its structures. This requirement needs to be made explicit in tender documents and briefs issued by OCA, SOCOG and other organisations responsible for the delivery of Olympics' facilities.

All stages of the building process and occupation have a potential impact on indoor air quality. Responsibilities for management of indoor air quality should therefore be clearly defined for and between each of these stages.

Olympics' tendering organisations and contractors who are certified to or follow *AS/NZ ISO 9001: 1994 Quality systems – model for quality assurance in design, development, production, installation and servicing* should systematically conduct and demonstrate such design processes. The standard requires protocols for design planning, input, output, review, verification, validation and variation, outlined in its Design Control element.

The fact that a tendering organisation or contractor has an accredited quality assurance system does not absolve OCA and SOCOG (or their agents) from a need to audit those suppliers to ensure that the required indoor air quality specifications are actually met.

10. Case studies

10.1 A user-healthy day nursery, Sweden

The following case study is an edited version from *Healthy buildings*: *a design primer for a living environment* (Holdsworth & Sealey, 1992). In Sweden, as a result of the growing demand for child care facilities in the 1970s, there was a rapid increase in the number of nurseries built using fast-build methods. By the 1980s some 30% of the nurseries exhibited indoor air quality problems. All the buildings had been designed to the appropriate Swedish standards, considered state of the art in many countries at the time.

The common problems found were:

- Gases and micro-organisms such as formaldehyde, 2-ethyl-hexanol and/or mildew were found in quantities great enough to constitute a health hazard.
- Moisture, and building material that released easily volatilised pollutants.
- High indoor temperatures, resulting in low relative humidity.
- Air-tight structures, heat recovery and low air-change rates; inadequate HVAC systems.

To limit IAQ problems, features for the user-healthy nursery, located in Stockholm, included:

- Design of the foundation and other features to avoid risk of moisture penetration and/or water damage
- Design of the ventilation system to incorporate heat exchangers that cannot transfer volatile pollutants from the exhaust air to the incoming air, and incorporating good air quality filters, together with provision for allowing air flows to be increased above the required minimum values

- Selection of homogeneous materials in preference for layered materials, and using screws and nails in preference to gluing, unless alternative "healthy" materials are available
- Avoidance of materials and designs which gather dust, or are difficult to clean
- Avoidance of materials that can release pollutants such as hydrocarbons, formaldehyde and fibres into the air
- Limitation of surplus heat from passive radiation by means of projecting roofs
- Documentation of type and manufacturer of materials, paints, glues, mastics, etc., used in the building

The main differences in the choice of materials in relation to those used in standard day nurseries were:

- Stained wood panels on walls in the children's areas and corridors instead of painted glass-fibre fabric
- High-pressure laminates in wet rooms instead of wall-grade plastic covering or woven glass-fibre with extra coats of paint for water resistance
- Grade E1 flooring chipboard (maximum 0.01% free formaldehyde[18]) under linoleum. Grade E1 was also wanted for cupboards , but the cost for this project was considered too high and 0.04% free formaldehyde was used instead

The authors (Holdsworth & Sealey, 1992) report the costs were not so much higher than the norm. The small increase in costs led to reduced operating and maintenance costs, as well as to benefit in running and energy costs. The project was considered an essential model for the development of any healthy building code and materials specification.

10.2 A new house for chemically-sensitive clients, Canada

Drerup (1991), a building contractor, describes how the special air quality needs of a client highly sensitive to many building materials, were met in the design and construction of a small house. Drerup's background was mainly building for energy conservation. While the client's needs were extreme, salient features included the need to:

- thoroughly check the composition of even apparently benign building materials, because it was found they could contain intolerable but unlabelled additives;
- build the house to be extremely water-tight, to reduce the opportunity for mould growth;
- provide a special room to house a mechanised ventilation system, which would run continuously, under negative pressure relative to the rest of the building;
- not use any plywood in the house construction, because of the client's sensitivity to formaldehyde;
- use concrete made without the addition of water-reducing agents;
- seal off all intolerable but mandatory or otherwise unreplaceable building components from the house interior.

Drerup (1991) explains the building methods used to achieve these requirements in further detail.

While extreme sensitivity to chemicals might appear irrelevant to the bulk of the population, the experiences of chemically sensitive individuals are a useful source of information for professionals seeking "clean" products and work methods.

10.3 Recycling of an old gas company building, California

The American Institute of Architects (1996) describe how a gas company recycled its 35-year old building, into an Energy Resource Centre. Reported is the fact that new materials and products used

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[18] Equivalent to formaldehyde limits in Australian/New Zealand draft standards DR96380 and DR96381.

in the Centre were chosen with the aim of optimising the indoor environment. At the *start* of the design phase, the project's environmental consulting firm prepared a catalogue of several hundred low-toxicity materials and products. Materials used in the Centre included "non-toxic paint, and floor sealers free of VOCs and other solvents; linoleum flooring; non-toxic adhesives; furniture panels treated with anti-microbial agents; special linings in ducts to minimise mould and bacterial growth". An indoor air quality consultant, who verified that the design specification was adequate, was also employed on the project.

10.4 Personalised control in office buildings

Pilatowicz (1995) describes the use of "personal environment workstations" in an office building in Wisconsin. Through use of controls located on each desk, the occupants can individually control temperature and airflow within their own spaces through vents and radiant heaters built into their furniture. To save energy, motion sensors are included, which detect whether the space is occupied or not. Independent research conducted in the building showed that when the personal workstations were randomly switched off, productivity dropped.

The University of Sydney's Architecture Building (Wilkinson), City Road, Darlington, is a local example of a building which provides occupants with personalised control over the HVAC system. A suite of seven rooms used as offices are ventilated through windows and doors which can be adjusted as required by the occupants. The rooms are equipped with reverse cycle refrigerated fancoil units which can be used as supplementary cooling and heating under direct occupant control. Temperature set point, fan speed and direction of air supply are independently adjustable in each room. Background heating is available during winter months from hot water panel radiators also under direct occupant control. Over a twelve month study period from August 1995 to July 1996 it was reported that energy consumption was a quarter of what would be expected if climate control were provided by ducted air conditioning (Rowe *et alia*, 1997)

11. Progressing indoor air quality management

There is a lack of systemically compiled and detailed information on the potential of Australian materials and products to contribute to indoor air pollution. This poses a significant obstacle for architects, designers, specifiers and the general community when addressing indoor air quality issues. Several tools, mentioned below, may be helpful in advancing such systematic compilation of the necessary data.

In Australia, at present, management strategies for indoor air quality are fragmented. An integrated management framework will require more emphasis on factors such as source reduction of pollutants, new standards and industry codes of practice.

11.1 Decision-making tools

There a numerous indoor air pollutants and numerous potential sources of these pollutants. When selecting materials, designers and specifiers therefore need appropriate decision-making tools to help them sort of the "vital few" from the "trivial many".

11.1.1 Decision trees

In the early 1990s, a major undertaking of the United States' Environmental Protection Agency was comprehensive, systematic compilation of information on building materials and products as potential sources of indoor air pollution (Stockton *et alia*, 1991). The first document, a catalogue, was to list these materials, together with their chemical compositions and pollutant emission rates (Stockton *et alia*, 1991). The first volume of the *Catalog* was published in 1993 (see Hays *et alia*, 1995, p247-248 and Section 13 of this document).

The publication of a further volume, a handbook which would help the user make sound materials choices, was proposed (Stockton *et alia*, 1991). The proposed format of this handbook included a series of decision trees for building materials, furnishings and consumer products which generally influence indoor air quality, such as particleboard, vinyl flooring, sealants and household pesticides (Stockton *et alia*, 1991). Due to funding cuts, it is believed that production of this handbook only reached prototype stage (White, *personal communication*, 23/12/96).

A prototype decision tree is reproduced below (Figure 11.1). Presumably, the intention was that each tree would be accompanied by explanatory text and data which would show how materials choices at each step could more or less contribute to indoor pollutant emissions. The authors of these guidelines believe that further development of IAQ decision trees would be very useful for addressing indoor air pollution control in Australia. Such decision trees would be most effective if based on Australian conditions, building practices and materials, furnishings and consumer products available here.

Figure 11.1:

Sample decision tree from US EPA's prototype *Handbook on Material Sources of Indoor Air Emissions*

Prototype decision tree relates to floor coverings, showing floor covering options which may influence indoor air quality. Read from left to right, each vertical line indicates a range of materials options for each item. For example, carpet flooring options include a stain-guarded, wool rug and a wall-to-wall, stained-guarded, synthetic carpet, fitted with tacks.

Slightly modified from Stockton *et alia* (1991).

Floor coverings	Wood floors	Hardwood Softwood	Stain Sealer Oil-based paint Latex paint			
	Stone/ slate floors	Brick Slate Marble	Sealer			
	Carpet	Wall-to-wall	Wool Synthetic	Stain guard	Installed with adhesive Installed with tacks	
		Area rug	Wool Synthetic	Stain guard Uncoated		
	Resilient floors	Vinyl	Sheet	Uncoated No wax	Wax Sealant	Installed by adhesive backing Installed by stretching/heat treatment
		Linoleum	Tile			

11.1.2 Life cycle analysis

Life cycle analysis is another approach which is a potential tool for helping architects and specifiers make sound materials choices across a range of environmental criteria, including any indoor air quality impacts from the materials. The American Institute of Architects' (1996, Appendix A) *Environmental Resource Guide* gives a methodology for life cycle analysis of building materials which includes IAQ impacts. Also included in the 1996 edition of the *Guide* are full life cycles for many building materials. One local example of life cycle analysis of Australian building products is Partridge & Lawson's (1996) *Building Material Ecological Sustainability Index*[19].

Where life cycle analysis is used in the design of remaining Olympic's facilities it is recommended that it include full consideration of the indoor air quality impacts of building materials.

11.2 An integrated framework for indoor air quality management

An integrated framework is essential for effective management of indoor air quality across all building types. In Australia, at present, management strategies for indoor air quality are fragmented, and information relevant to Australian conditions is difficult to access.

The NHMRC have established interim national goals for some indoor air pollutants. These goals are useful tools in establishing and monitoring indoor air quality, however, do not address the causes or provide solutions to indoor air quality problems.

A great deal of emphasis is currently placed on mechanical ventilation strategies for maintaining good indoor air quality. The proposed changes to the Australian ventilation standard may better address the issue of natural ventilation, which is particularly important in residential and low-energy buildings.

To provide a benchmark for sound management of air filtration systems, the NSW Department of Public Works and Services are producing a *Filtration Standard for Indoor Air Quality* (Wesley, *personal communication*, 24/1/97).

A new Australian Standard for indoor air quality has also been proposed. It is envisaged the standard will provide guidance to building owners and managers, contractors, employers and employees on emission standards, risk management procedures and guidance on remediation techniques for degraded indoor environments (Begg, *personal communication*, 31/1/97).

These new standards are likely to advance indoor air quality management in Australia. Areas that need more attention include: reducing pollutant sources, education and awareness programmes and, a more concerted effort on the part of industry to minimise any negative impacts of their products and activities on indoor air quality.

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[19] The index considers Resource Depletion, Inherent Pollution and Embodied Energy associated with 31 building materials. Within Inherent Pollution, the "environmental impacts of materials during building use" are considered but are not given great overall emphasis.

12. References

Note: Some standards, guidelines and codes of practice are referenced fully in Section 7, so are not repeated in this reference list. Australian Standards are published by Standards Australia, Homebush, NSW.

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13. Resource list

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United States Environmental Protection Agency's *IAQ INFO Clearinghouse*, Homepage: http://www.epa.gov/iaq/iaqinfo.html.

14. Appendix A: Interim national IAQ goals recommended by NHMRC

Pollutant	Interim goal (expressed as an upper limit)	Measurement criteria	Note	NHMRC Session at which recommended
• Carbon monoxide (CO)	10 000 µg.m^{-3} *or* 9 ppm	8 hour average not to be exceeded more than once a year	1	98th (Oct 1984)
• Formaldehyde (HCHO)	120 µg.m^{-3} *or* 0.1 ppm	Not to be exceeded	2	93rd (Jun 1982)
• Lead (Pb)	1.5 µg.m^{-3}	Three month average		88th (Oct 1979)
• Ozone (O_3)	210 µg.m^{-3} *or* 0.10 ppm	Maximum hourly average not to be exceeded more than once a year	3	119th (Jun 1995)
	170 µg.m^{-3} *or* 0.08 ppm	Four hour average		119th (Jun 1995)
• Radon (Rn)	200 Bq.m^{-3} *or* 5.4 nCi.m^{-3}	Annual mean	4	109th (May 1990)
• Sulfates	15 µg.m^{-3}	Annual mean		104th (Nov 1987)
• Sulfur dioxide (SO_2)	700 µg.m^{-3} *or* 0.25 ppm	Ten minute average	5	120th (Nov 1995)
	570 µg.m^{-3} *or* 0.20 ppm	One hour average	5	120th (Nov 1995)
	60 µg.m^{-3} *or* 0.02 ppm	Annual mean	5	106th (Nov 1988)
• Total suspended particulates (TSP)	90 µg.m^{-3}	Annual mean	6	92nd (Oct 1981)
• Total volatile organic compounds (Total VOC)	500 µg.m^{-3}	Hourly average	7	115th (Jun 1993)

Notes:

Goal limits are expressed at 0ºC and 101.3 kPa.

1 This period of measurement is not to be confused with that for Threshold Limit Values.

2 Within domestic premises and schools. **The Formaldehyde goal is a final goal.**

3 A public warning is to be given if ozone levels are expected to rise above 500 µg.m^{-3} (0.25 ppm).

4 Action level for simple remedial action in Australian homes. Where the concentration exceeds this level, householders should consult the appropriate State authority for advice. **The Radon goal is a final goal.**

5 "CAUTION: At these levels, there still may be some people (for example, asthmatics and those suffering chronic lung disease) who will experience respiratory symptoms and may need further medical advice of medication [sic]".

6 TSP goal to read in conjunction with annual SO_2 goal.

7 A single compound shall not contribute more than 50% of the total.

(Source: Sightly modified from Heiskanen, *personal communication*, 23/12/96)

15. Glossary & acronyms

BRI Building related illness (for definition, see Section 5.2)

CFC/s chloroflurocarbon/s

ESD ecologically sustainable development

GGW2000 Green Games Watch 2000. A coalition of major environment groups working towards achieving an environmentally responsible Olympic Games in 2000.

HVAC heating, ventilation and air-conditioning [system within a building]

IAP/s indoor air pollution (see Section 4.1) or indoor air pollutant/s

IAQ indoor air quality (see Section 4.1)

IPM integrated pest management (see Section 9.2.1)

LCA life cycle analysis

Mechanised ventilation A ventilation system which uses electrical energy or fossil- or carbon-based fuels to run, as opposed to *natural* or *passive* systems. Note, Australian Standard *AS 1668.2: 1991* does not classify ceiling fans and free-standing fans as *mechanised* systems. However, for the purposes of these guidelines, these electrically run fans are regarded as mechanised.

MSDS/s material safety data sheet/s, which provide information on the ingredients in and health hazards associated with individual products, available to consumers on request from manufacturers.

Microenvironment/s a term used to distinguish varying spaces or areas within a wider space or area. For example, indoor microenvironments include bathrooms (high humidity with hard, smooth surfaces), bedrooms (tend to high proportion of fleecy materials), roof spaces, crawl spaces, photocopy rooms, etc.

MTR Minimum termite risk, used to describe building strategies which help prevent termite infestation in buildings (see Section 9.2.1.1 for further detail).

Natural ventilation A ventilation system which runs without use of electrical energy or fossil fuel or carbon-based fuel, as opposed to *mechanised* ventilation system.

NHMRC National Health & Medical Research Council

OCA Olympic Co-ordination Authority. A NSW State Government authority, formed in 1995, to provide most venues and facilities for the Sydney Olympics in 2000 and to manage re-development of Homebush Bay.

Out-gassing the process where volatile substances in a material or product gradually migrate to its surface and vaporise into the surrounding air.

Passive ventilation synonym for *Natural ventilation*.

SBS Sick building syndrome. Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building (Bearg, 1993). The World Health Organisation defines this syndrome on the basis of frequently reported symptoms including skin, eye, nose and throat irritation, dizziness, headaches, mental fatigue, asthma-like symptoms and unpleasant odour and taste sensations (Godish, 1995).

Sick building syndrome see *SBS*

Sink a surface or material that becomes a reservoir of particles and gas molecules that deposit, condense or otherwise attach to it from the surrounding air (Levin, 1992, July). For example, carpets and other fleecy materials can act as sinks for indoor air pollutants. The problem with sinks is not that they adsorb pollutants but that they re-emit at a later time (Sparks, 1991). Re-emissions from sinks increase the time necessary for IAQ control and they can change a local IAQ problem into a whole building problem (Sparks, 1991).

Smoke Free Olympics Taskforce A coalition of major health groups, including the Cancer Council, the National Heart Foundation and ASH.

SOCOG Sydney Organising Committee for the Olympic Games

SPOC Sydney Paralympic Organising Committee

UF Urea-formaldehyde; a resin glue often used in the manufacture of particleboard and other reconstituted wood products, plywood and other building materials.

UFFI Urea-formaldehyde foam insulation; a type of thermal insulation, containing UF resin, that is mixed and sprayed on-site.

US EPA the United States' Environmental Protection Agency

VOC/s volatile organic compound/s. "Volatile" refers to the fact these substance have boiling points in the range 50-100°C to 240-260°C (Appleby, 1990). In comparison to very volatile organic compounds [VVOCs], which have a boiling point of less than 50-100°C, VOCs take up to several years to be liberated in typical indoor environments (Appleby, 1990). "Organic" refers to the fact these substances are carbon-containing compounds.

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