Indoor Environmental Quality of Preparatory to Year 12 (P-12) Educational Facilities in Australia: Challenges and Prospects

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Abstract Climate change is leading to increased frequency, intensity and duration of heatwaves not only in Australia but globally. Children are among those who are most physically vulnerable to the changing climate. Schools buildings and facilities are critical infrastructure which are at risk of the adverse impacts of extreme weather conditions, particularly to the schools' indoor environments. This chapter reviews the diverse policies on cooling and ventilation in educational facilities across Australia and brings together a multidisciplinary appraisal which can provide starting points for designers, building scientists and policy makers on:

- Impact of building energy efficiency measures on the thermal comfort, IAQ and ventilation of educational facilities.
- Health, educational outcomes and economic impacts of thermal comfort, IAQ and ventilation within educational facilities.
- Australian and best practice international policies, standards and practices applicable to the thermal environment, IAQ and ventilation within P-12 educational facilities.

1 Introduction

While other chapters in this book look at building energy and sustainability performance, this chapter explores indoor environment performance of school buildings by looking at national and international standards, design guidelines and policies on indoor environmental quality (IEQ) for Australian Preparatory to Year 12 (P-12) educational facilities.[1] This examines the relationship between the IEQ parameters

[1]See Chapter "University Buildings: the Push and Pull for Sustainability" for a discussion on sustainability in university buildings in Australia.

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of thermal comfort, indoor air quality and ventilation and educational outcomes for the P-12 group. Knowledge gaps exist in this area with limited research undertaken in Australia to establish potential benefits of indoor environmental quality improvements in schools. This chapter establishes the need for a study grounded on addressing the absence of clear documentation on the state of indoor environments in educational facilities in Australia backed by measurements and surveys of temperature, comfort conditions, indoor quality and the relationship between these aspects of indoor environments and academic performance of students.

2 Indoor Environmental Quality in Educational Facilities

Extremely hot weather conditions are becoming more commonplace and severe in Australia[2] [12]. It is projected that by 2070, Adelaide, Sydney and Melbourne can expect to experience at least twice as many days with extreme temperatures, while residents of Darwin could find 35 °C days occurring for up to two-thirds of the year [61, 72]. In Melbourne, the long-term annual average number of days above 35 °C is 10 but rose to 13 during the decade 2000–2009 [11]. The number of hot days is likely to increase to 15–26 days by 2070 [13]. The increasing number of hot days will impact on public health, mortality rates, energy demand and economy of Australia [43, 61, 76].

With significant increases in the frequency of extreme temperatures in the country [62], public concern about the adverse effects of school indoor environments in Australia has increased in recent years [18, 70, 71]. School buildings, as with much of the country's critical infrastructure and facilities, are vulnerable to poor performance during extreme weather. Poor indoor air quality (IAQ) and thermal conditions are known to decrease productivity and cause dissatisfaction for building occupants [44, 79]. However, much of the research on indoor environments focuses on adult workers in offices [22]. There is limited information on the relationship between indoor environments and the learning performance and behaviour of children in school buildings [47, 75].

In 2016, there were 344,726 children aged four or five years enrolled in a preschool (early childhood development) program in Australia [2], where 43% attend preschools and 51% long day care (LDC) centres. These preschoolers attend for 15 hours or more per week or up to 645 hours in a school building annually. Students in Years 1 to12 receive at least 25 hours of instruction per week [68] or spend up to 1075 hours indoors in school buildings annually. Australian students will spend up to 12,900 hours of their lives in school buildings from Preschool to Year 12—which

[2]Chapter "Urban Climates in the Transformation of Australian Cities" provides a discussion on the changing climate trends in Australia.

would be up to 25% of their waking lives to the completion of their schooling [17]. With the number of hours spent in classrooms, the conditions of indoor environmental quality factors in school buildings and their impact on children's health,[3] well-being, comfort and learning ability remain a subject area of concern [25, 74].

3 Indoor Environmental Quality (IEQ)

The terms *indoor environmental quality* (*IEQ*) and *indoor air quality* (*IAQ*) have different meanings. Both terms refer to environmental qualities within a building, and they are used especially in relation to the health and comfort of building occupants. However, IEQ is a broader concept that includes IAQ as one of the indoor quality elements [8], including (1) thermal comfort, (2) indoor air quality and ventilation, (3) lighting levels and (4) acoustics and noise. However, this chapter focuses on thermal comfort, IAQ and ventilation as they are the dominant factors to achieve an overall comfort (or a high level of IEQ) among the indoor elements. Acoustics and noise, lighting quality and levels (including daylighting), odour quality (olfactory) and visual perception are not included in this review.

Much research has been conducted on thermal comfort, IAQ and ventilation [20, 27, 58]. Thermal comfort and IAQ affects an occupant's well-being, health, perception of IEQ and productive performance [8, 21]. This general statement applies to children's health and learning achievements in school buildings. An extensive body of knowledge on thermal comfort and IAQ has informed the development of international standards and guides for the design and management of the indoor environments of buildings. Australian standards, guides and codes of practice typically follow international developments.

3.1 Thermal Comfort

The primary environmental factors that determine thermal comfort are [37] air temperature, radiant temperature, humidity and airspeed. The primary personal parameters are clothing and activity level. Discomfort can be minimised in various ways. In a warm or hot environment, the amount of clothing or level of physical activity can be reduced, or an environment that is more conducive to increased heat loss can be created (see also Chapter 'Thermal Environments in the Construction Industry: A Critical Review of Heat Stress Assessment and Control Strategies'). Conversely, in a cool or cold environment, the responses could include increased clothing, increased activity, or seeking or creating an environment that is warmer [10]. While thermal

[3] Although this chapter mainly focuses on the student requirements for indoor environmental quality of school facilities, the authors acknowledge that the same indoor conditions would affect the teaching and administration staff.

comfort is essentially a subjective response and may be influenced by contextual and cultural factors (i.e. psychological adaptation) [29], a person's sense of thermal comfort is primarily a result of the body's heat exchange with the environment.

The development of international thermal comfort standards has largely been based on studies of healthy, fit and sedentary office workers across a range of climate zones: temperate, hot and humid, cold and hot-arid [30]. However, research indicates that adult-based thermal comfort standards are not directly applicable to children in school buildings [48, 65, 66]. Teli et al. [65] suggest this may be due to children's higher metabolic rate (per kg of body mass); their limited ability to adapt to the indoor thermal environment by controlling heaters, coolers, windows, blinds, etc., in the classroom, or by changing their clothing; and/or possibly their strong relationship with the outdoor climate since their daytime schedule includes outdoor activities and play, unlike office workers.

3.2 Indoor Air Quality (IAQ) and Ventilation

Indoor air quality directly impacts occupant health, comfort and work performance. People in buildings frequently report building-related health symptoms and sometimes develop building-related illnesses. Research has shown these health and comfort effects are associated with the characteristics of buildings, HVAC systems and the indoor environment [20, 63]. The *American Society for Heating, Refrigerating and Air-Conditioning Engineers* (ASHRAE), *International Organization for Standardization* (ISO) and the *European Committee for Standardization* (CEN) have developed standards and guides for indoor air quality and ventilation and the criteria and recommendations in the international standards have been adopted as normative references by Australian national standards, guidelines and codes of practice [23, 24, 59, 60, 77]. In contrast to the specifications for thermal environments, it has not been possible to agree on a method for specifying the level of indoor air quality in buildings. Instead, required ventilation rates are specified for different types of space and occupancy [54].

4 Design Guides and Best Practice Standards

Design guides and standards on the approaches to cooling and heating, thermal comfort and ventilation in educational facilities in Australia follow *ASHRAE Standards 55* [9] and *62.1* [7] in North America and *ISO 7730* [42], *CIBSE Guide A* [19] and *CR 1752* [14] in Europe. Although the methodologies underpinning these standards differ, a deterministic stimulus-response approach based on laboratory methods is used in *EN ISO Standard 7730* while a holistic person–environment systems approach based on field research is used in *ANSI/ASHRAE Standard 55* [27]—both evaluate the general thermal state of the body based on a heat balance analysis. These thermal

Table 1 Recommended indoor temperatures and relative humidities for general use (*Sources* ASHRAE Standard 55 [9], EN ISO 7730 [42] and CIBSE Guide A [19])

Standard	Thermal comfort criteria
ASHRAE Standard 55[a]	Winter: Temp 19–26 °C Summer: Temp 23.5–28 °C (graphical method)
ISO 7730[a]	Winter: Temp 20–24 °C; RH 30–70% Summer: Temp 23–26 °C; RH 30–70%
CIBSE Guide A[a]	Temp 22–24 °C, RH 30–60%

[a] Light, mainly sedentary activity

Table 2 Recommended indoor temperatures for Australia and Victoria (*Sources* Comcare Australia and Community and Public Sector Union [24], WorkSafe Victoria [77, 78])

Standards, guides and codes	Thermal comfort criteria
Comcare Australia and Community and Public Sector Union [24] [a]	Summer: Temp 23–26 °C
WorkSafe Victoria [77][a]	All year: Temp 20–26 °C; Airspeed 0.1–0.2 m/s

[a]Mainly sedentary work

comfort standards prescribe numeric and descriptive criteria for comfort primarily for mechanically conditioned spaces (19.7–26.7 °C, 20–60% RH). For free-running (non-conditioned) buildings and during warm weather, 25 °C is an acceptable indoor design temperature.

4.1 *Criteria for Thermal Environments in Educational Facilities*

International standards and guides specify environmental conditions for acceptable thermal comfort in terms of indoor temperatures and humidities (Table 1) or predicted mean votes (PMV) [42]. These have been adopted into guides and codes for offices in Australia (Table 2). The Victorian Trades Hall Council (VTHC) endorses these recommendations and circulates them as part of occupational health and safety (OHS) information for the education sector in Victoria [69]. Environmental conditions and the level of thermal comfort expected in a building depend on the type of building and its occupants. Conditions for educational facilities are recommended by ASHRAE [6] (see Table 3).

Table 3 ASHRAE recommended indoor temperatures and humidities for educational facilities (*Source* ASHRAE Handbook—HVAC Applications [6, Tables 1 and 6, pp. 7.1–7.4])

Category	Occupancy	Humidity criteria[a]	Temperature (°C)[a]	
			Winter	Summer
Preschools	Infant, toddler, and preschool classrooms	30% RH	20.3–24.2	23.8–26.7
		40% RH	20.0–23.9	23.1–26.7
		50% RH	20.3–23.6	22.8–26.1
		60% RH	19.7–23.3	22.8–25.8
	Administrative areas, offices, lobbies and kitchens	RH 30–60%	20.3–23.3	23.3–25.8
K-12 schools	Classrooms, laboratories, libraries, auditoriums and offices	30% RH	20.3–24.2	23.3–26.7
		40% RH	20.0–23.9	23.1–26.7
		50% RH	20.3–23.6	22.8–26.1
		60% RH	19.7–23.3	22.8–25.8

[a]Based on EPA [35] and ASHRAE Standard 55 [4] for people wearing typical summer and winter clothing, at mainly sedentary activity

4.2 Criteria for Indoor Air Quality (IAQ) and Ventilation in Educational Facilities

Standards and guides prescribe minimum ventilation rates as a means of achieving acceptable indoor air quality [39]. The relationship between indoor air quality, in terms of CO_2 concentration levels and ventilation rates is shown in Table 4. Standards and reference guides include *ASHRAE Standard 62: Ventilation for Acceptable Indoor Air Quality* [7], European Standard *EN 13779: Ventilation for non-residential buildings—Performance requirements for ventilation and room-conditioning systems* [15] and the technical report *CR 1752-1998: Ventilation of buildings—Design criteria for the indoor environment* [14].

The prescriptive method of *ASHRAE Standard 62.1* adds the minimum ventilation rate per person to the minimum ventilation rate per square metre of floor area. The person-related ventilation accounts for pollution from people and the ventilation rate based on floor area accounts for emissions from building materials, furnishings, HVAC system, etc. [54]. A similar approach is used in *CR 1752*. However, only person-related ventilation is required if it is assumed the building does not emit pollution [54]. Ventilation rates for education facilities prescribed by *ASHRAE Standard* 62.1 and CR 1752 are compared in Table 5.

Table 4 Classification of indoor air quality (IDA) according to EN 13779 (*Source* Olesen [54, p. 22])

Category	Description of indoor air quality	Classification parameter	Ventilation rate (outdoor air)	
		CO_2 level above outdoors (ppm)	Non-smoking (l/s per person)	Smoking (l/s per person)
IDA 1	High	≤400	>15	>30
IDA 2	Medium	400–600	10–15	20–30
IDA 3	Acceptable	600–1000	6–10	12–20
IDA 4	Low	>1000	<6	<12

Categories of indoor air quality as specified in EN 13779 [15, p. 19]

Ventilation requirements for educational facilities in the Australian Standard *AS 1668.2-2012: The use of ventilation and air conditioning in buildings—Mechanical ventilation in buildings* [59] align with *CR 1752* (see Table 6).

4.3 Interactions Between Thermal Comfort and Indoor Air Quality (IAQ)

IAQ directly impacts occupant health, comfort and work performance. Providing superior IAQ can improve health, work performance and school performance, as well as reduce health care costs, and consequently be a source of substantial economic benefits [16, 79].

Temperature is recognised as a key factor for human comfort. However, less attention may have been given to the importance of humidity [50, 67]. Recent studies on the direct impact of temperature and humidity on human perception of IAQ found that acceptability of air decreased with increasing air temperature and humidity levels [36, 57]. Changing the air temperature or humidity of the indoor environment may change IAQ by significantly affecting the emission source strength of materials in a space and the perception itself of air due to change in chemical composition [41]. Maintaining dry and cool indoors as opposed to humid and warm may improve both the perceived air quality and ventilation requirement. For example, in a study by Fang et al. [36], reducing the ventilation rate from 10 to 3.5 L/s per person in an office space can be compensated for by reducing the air temperature and humidity from 23 °C and 50% RH to 20 °C and 40% RH, so as to avoid deteriorating perceived air quality. IAQ is typically addressed through compliance with minimum ventilation requirements in building regulations, which are based on industry consensus standards such as the *ANSI/ASHRAE Standard 62.1* [5]. The increased interest and attention on the impact of IAQ in buildings saw the publication of two guides which present best practices for design, construction and commissioning of buildings and provide information and guidance on IAQ-related issues in schools [3, 8, 35]:

Table 5 Recommended ventilation rates in educational facilities according to ASHRAE 62.1 and CR 1752 (*Source* Olesen [54, Appendix 2, p. 26])

Room type	Occupancy (person/m^2)	Category of indoor air quality	Minimum outdoor airflow rate (l/s per person)		Additional ventilation for building emissions (l/s per m^2)			Total (l/s per m^2)	
			ASHRAE	CR	CR low-polluting building	CR *Not* low-polluting	ASHRAE (R_a)	CR Low-polluting	ASHRAE
Classroom	0.5	A	3.8	10	1.0	2.0	0.3	6	2.2
		B	3.8	7	0.7	1.4	0.3	4.2	2.2
		C	3.8	4	0.4	0.8	0.3	2.4	2.2
Kindergarten	0.5	A	5.0	12	1.0	2.0	0.9	7.1	3.4
		B	5.0	8.4	0.7	1.4	0.9	4.9	3.4
		C	5.0	4.8	0.4	0.8	0.9	2.8	3.4

Category refers to the quality level of indoor air and corresponds to the percentage of dissatisfied: Class A—15% dissatisfied, Class B—20% dissatisfied, Class C—30% dissatisfied

Table 6 Minimum ventilation rates for educational facilities according to AS 1668.2 (*Source* AS 1668.2-2012 [59, Appendix A, p. 61])

Occupancy type	Net floor area per person[a] (m^2)	Minimum outdoor airflow rate (l/s per person)
Classrooms serving persons up to 16 years of age	2	12.0
Classrooms serving persons over 16 years of age	2	10.0
Laboratories	3.5	10.0

[a] Applies when number of occupants is not known. Where the occupancy is not indicated, the actual occupancy shall be determined during the design of the room

5 Policies and Protocols for Educational Facilities in Australia

No unified set of policies and guidelines exist for air conditioning (heating, cooling and ventilation) of Preparatory to Year 12 (P-12) educational facilities in Australia. While international standards such as *ASHRAE Standards 55 and 62.1* and guides such *CIBSE Guide A* are referenced, each state has its own unique set of policies and guidelines. These are summarised in Table 7. Climate zones form the basis of the cooling policy of Victoria [32, Sect. 5.8, p. 89]. Schools are cooled if they are located in NatHERS[4] Zones 20 or 27. These zones are hot and dry during the summer, with the mean maximum air temperature exceeding 30 °C during January. This is similar to New South Wales' policy of providing cooling for schools in locations where the mean maximum air temperature during January exceeds 33 °C, although New South Wales also accounts for the effect of building design on cooling demand by allowing 'hot spots' classrooms to be cooled when the mean maximum temperature is 30–33 °C. The Relative Strain Index (RSI) used in Western Australia is also a location-based cooling policy. The Cooler Schools zones in Queensland are likewise based on the climate map of the state. In contrast, the cooling policy of South Australia does not specify geographical locations. The state's policy takes a performance-based approach to cooling by specifying indoor air temperature requirements. Adopting a performance-based approach to cooling in educational facilities would objectively meet the appropriate requirements of young students.

Summarising the cooling policies of the five (5) Australian states, without critique, the climate conditions of NatHERS Zones 20 and 27 currently adopted by the Victorian Department of Education and Training and the Victorian School Building Authority [32] loosely corresponds to those in the geographical locations of Zones 4 and 6 of the National Construction Code—Building Code of Australia (NCC-

[4] Nationwide House Energy Rating Scheme (NatHERS) is a star rating system in Australia that rates the energy efficiency of a home, www.nathers.gov.au. See Chapter "The Built Environment and Energy Efficiency in Australia: Current State of Play and Where to Next" for a discussion on the energy efficiency regulatory frameworks in Australia.

Table 7 Australian policies and protocols on air conditioning (heating, cooling and ventilation) in schools

Policies and protocols
Victoria (VIC) The Building Quality Standards Handbook [32] of the Department of Education and Training and the Victorian School Building Authority provide guidance on the policy requirements on thermal comfort, cooling, heating and ventilation: • Cooling systems are provided to schools on the basis of their location within the Nationwide House Energy Rating Scheme (NatHERS) – Zones 20 and 27. All schools in these areas receive full air conditioning to their entitled spaces under the space and area guidelines. The remaining schools are not provided with cooling systems except in limited number of circumstances, e.g. information technology server rooms [32, Sect. 7.8.2, p. 97] • Air conditioning is provided to all special development schools regardless of location and all relocatable buildings. [32, Sect. 7.8.2, p. 97] • Thermostat setting for cooling should not be lower than 26 °C, for heating should not be higher than 18 °C [32, Sect. 7.8.4, pp. 101-102] • No cooling system should be installed until an energy target has been established and the performance of the proposed system compared with that target, and revised if necessary. [32, Sect. 7.8.2, p. 98] • Ventilation conforms to the BCA requirement on a minimum area proportional to the occupied room floor area. Fixed or opening devices must be 5% of the total floor area [32, Sect. 7.7]
New South Wales (NSW) The Air Cooling Policy of the NSW Department Education and Communities [52] ensures that: • Schools with a mean maximum January temperature of 33 °C or above are provided with air cooling to all habitable spaces • Schools with a mean maximum January temperature between 30 and 33 °C are eligible to apply for air cooling of 'hot spots' classrooms • Air cooling is provided to all demountable classrooms and libraries in NSW public schools • The department is developing a Thermal Comfort and Resource Efficiency Framework that aims to maximise the performance of existing buildings through passive design measures (such as roof insulation and sunshades) complemented where necessary by mechanical systems to meet extreme heating and cooling requirements. [53]
South Australia (SA) The Air Conditioning Protocol (SV001) of the SA Department of Education and Child Services [31] provides guidance on the policy requirements for the provision of air conditioning in public schools: • Learning areas in schools and children's centres shall have heating and cooling equipment capable of maintaining temperatures within the range of 20–26 °C when the outside temperature is between 6.5 and 37 °C (for Adelaide). When the outside temperatures fall outside these 'design temperatures', then room temperatures may be below 20 °C in winter and above 26 °C in summer • General learning areas, learning support areas and administration areas in schools and children's centres are to have temperatures maintained within the range of 20–26 °C on a Design Day as per comfort conditions detailed by ASHRAE Standard 55. This identified comfort conditions are being where there is a dissatisfaction rate of less than 10% • For the Adelaide metropolitan area, the 'design temperatures' are 6.5 °C for winter and 37 °C for summer. For design temperatures for other parts of South Australia refer to Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH) Application Manual DA9-Air Conditioning Load Estimate • The minimum ventilation rate in learning areas shall be 10 litres per second per student and assuming a maximum capacity of general learning area (GLA) classrooms of 30 students • Students are dismissed at 12.30 pm on days when the forecast maximum is 38 °C or higher, or up to one hour before normal dismissal time when the estimated maximum temperature is to be at least 36 °C

(continued)

Table 7 (continued)

Policies and protocols
Western Australia (WA) The WA Department of Education uses the redefined 25-day Relative Strain Index (RSI) line and extended 20 day RSI as the boundary for the 'Air Cooling Zone' [70]: • All new schools within the 20 day RSI boundary will be provided with air cooling/air conditioning to the extent required • All existing schools within the 20 day RSI boundary will be eligible to have air cooling/air conditioning into classrooms and offices where air cooling has not previously been installed • The 20 day RSI line is to be considered a general guide (rather than a fixed demarcation line) that allows schools east and north of the line to qualify for air cooling/air conditioning
Queensland (QLD) The Queensland Government introduced the 'Cool Schools' program in 1996 and 'Cooler Schools' in 1998 [55]. These programs: • Assist both state and private schools in North Queensland to assess their building stocks and provide some cooling strategies, where needed • Recommend cooling classrooms only when the indoor temperature exceeds 27 °C • Implement passive cooling techniques/strategies, such as replacing sliding windows with louvers, installation of insulation. • Have no temperature limit for dismissing students [18] The Design Standards for DETE Facilities [34] states: • Schools located in the Cooler Schools zones are provided with air-conditioning systems. It is the intention that air conditioning is used only during the hot summer periods, and natural ventilation is used for the remainder of the year • The provision of natural ventilation in rooms that are not air-conditioned: Rooms designed for use by more than 15 occupants shall have external windows/doors/skylights with a minimum open-able area of 10% of floor area. Open-able windows and doors to be located on opposite sides of a room where possible [34, Sect. 3.2.1, p. 14] • Air supply rates for kindergarten and prep spaces should meet the higher rate of 12 l/s per person specified in AS 1668.2 applies [34, Sect. 3.5.1, p. 32] The Schools Standard Air Conditioning Specification [33] specifies the following air-conditioning design and performance parameters (Sect. 2.3.1, p. 31): • Summer: 26 °C ± 1 K DB, 55% RH (not controlled) • Winter: 21 °C ± 1 K DB, 55% RH (not controlled)

BCA) Climate Zones [1], characterised by hot, dry zone with average January maximum temperature of above 30 °C. New South Wales' policy of air cooling for schools with mean maximum January temperatures of 33 °C or above and 'hot spots' classrooms for 30–33 °C, likewise approximately correspond to Zone 4 locations in the NCC-BCA Climate Zones [1]. With reference to Western Australia's cooling policy which follows the RSI index, the geographical locations of the 20- and 25-day 0.3 RSI line correspond to those within Zones 4, 3 and 1 of the NCC-BCA Climate Zones. The cooling policies in South Australia and Queensland do not specify geographical locations but have outlined the conditions of occupied school spaces which require the provision of air conditioning.

6 Indoor Environmental Quality (IEQ) and Educational Outcomes

Reviews on research findings on the relationships of US school facility conditions to student achievement and behaviour indicate that the following thermal comfort factors correlate with positive educational outcomes (McGuffey 1982 cited in [75, 82]:

- A significant relationship between the thermal environment of a classroom and student achievement and behaviour.
- There was a consistent pattern of higher achievement in air-conditioned schools.
- Achievement was greater in facilities that allowed for individual preferences for heat.
- Excessive temperatures caused stress in students.
- Solar heating through glass is a major contributor to overheated classrooms.

However, limited data and inadequate clear documentation are available on the effects of poor indoor environments, particularly of thermal effects and indoor environmental quality on the performance of schoolwork by students. Because little research has been reported on these relationships for children in schools, much of the information have assumed that influences of indoor settings on adults have relevance to the influences of school environments on children [79, 81].

6.1 Recent IEQ Research

A recently completed study in Europe is the Schools Indoor Pollution and Health: Observatory Network in Europe (SINPHONIE) project [40]. It was the first pilot project to monitor the school environments in 25 European countries in parallel. The SINPHONIE project established a scientific/technical network to act at the EU level with the long-term perspective of improving air quality in schools and kindergartens to reduce the risk and burden or respiratory diseases among children and teachers due to outdoor and indoor air pollution. The SINPHONIE results were mainly on the causal relationships between exposure and health effects. However, the final report outlined that the most striking results overall are those that underline the relevance of IAQ in schools as a societal problem with clear impacts on the health, quality of life and learning performance of European schoolchildren [25].

The thermal comfort studies of New South Wales' schools undertaken by the NSW Department of Education and Communities in collaboration with the University of Sydney's Faculty of Architecture, Design and Planning Indoor Environmental Quality (IEQ) Laboratory and NSW Public Works [51] show that about 22.5 °C operative temperature was found to be the students' neutral and preferred indoor temperature, which is generally cooler than expected for adults under the same thermal environmental conditions [28]. Despite the lower-than-expected thermal neutrality, the school children demonstrated considerable adaptability to indoor temperature variations, equating to approximately 4 °C operative temperature. This comfort study was part of the department's *Thermal Comfort Framework* program and primarily aimed to maximise the performance of existing public school buildings through passive design measures complemented where necessary by mechanical systems to meet extreme heating and cooling requirements [52, 53]. It was anticipated that the benefits of this approach to thermal comfort, among others, will increase the number of learning spaces that provide comfortable learning environments and reduction in electricity consumption. However, based on available information, although the study includes environmental monitoring of the schools, the effects on school performance and educational outcomes were not assessed.

In Victoria, a study on a selection of schools primarily in Melbourne confirms that schools reflect poor air quality, ventilation and comfort control [45, 46] and the findings indicate that CO_2 concentration levels (>2,700 ppm), ventilation rates and air temperatures in classrooms during winter are non-compliant with the standards.

6.2 Student Performance

Mendell and Heath [47] carried out a review of research into the factors that influence student performance. The review highlighted that the direct association of thermal conditions of higher temperature [56] and lower relative humidity (Green 1974 cited in [47] on performance or attendance are significant in the decrease in beneficial outcomes. Schoer and Shaffran [56] found a general advantage for performance tests in the cooled environments (22.5 °C), with a consistent tendency for greater, statistically significant benefits for more complex performance tests. Mendell and Heath [47] were not able to assess the relationships between HVAC thermal control systems and performance or attendance due to unavailability of findings from studies. Although the findings of McNall and Nevins (1967 cited in [47]) were characterised as '*non-persuasive*' (p. 35), the study's comparison between one air-conditioned school and several non-air-conditioned schools in Florida (USA) found trends in favour of higher academic achievement in the air-conditioned school. However, these studies are decades old and updated research is required to validate these findings.

The most recent field study carried out in school classrooms was conducted by Wyon and Wargocki [80] in Denmark. The study sought to determine whether classroom air quality affects schoolwork. These field experiments show that reducing moderately high classroom air temperatures in late summer from the region of 25 to 20 °C by providing sufficient cooling and increasing effective outdoor supply rate from 5 l/s per person to 10 l/s per person, improved the performance of numerical and language-based tasks resembling schoolwork [80].

While inadequate ventilation is often suspected to be an important condition leading to reported health symptoms [38, 63, 64], ventilation rates have rarely been measured in schools [26, 47]. *ASHRAE Standard 62.1* recommends a minimum ventilation rate of 6.7–8.6 l/s per person for educational facilities. In a 1984 study of

11 randomly selected Danish schools, the reported ventilation measurements ranged from 1.8 to 15.4 l/s per person with an average of 6.4 l/s per person. European standards—*CR1752* and *CIBSE Guide A* recommend a minimum ventilation rate of 10–12 l/s per person. A more recent study on the ventilation rates of four naturally ventilated secondary schools in the UK was conducted during the heating season 2005–2006 [49] and found measurements that ranged from 3.9 to 10.5 l/s per person.

7 Conclusions and Research Imperatives for Educational Facilities

The primary objectives of this chapter were to review IEQ design guides, standards and policies for Australian P-12 educational facilities, survey the literature related to the relationship between educational outcomes and thermal environment and indoor air quality for the P-12 group and identify findings of applicable IEQ research.

7.1 Standards and Design Guides on Thermal Comfort, Indoor Air Quality (IAQ) and Ventilation

The review of design guides and standards on the approaches to cooling and heating, thermal comfort and ventilation in educational facilities indicated that most guidelines, policies and protocols follow the American *ASHRAE Standards 55* and *62.1* and the European *ISO 7730, CIBSE Guide A* and *CR 1752*. The thermal comfort standards (*Standard 55*, *ISO 7730*, *CIBSE Guide A*) prescribe numeric and descriptive criteria for comfort primarily for mechanically conditioned buildings—19.7 to 26.7 °C, 20 to 60% RH. The guidance provided for naturally ventilated spaces by *Standard 55* applies only to conditions where the mean monthly outdoor temperature ranges from 10 to 35 °C, and occupants must be able to open and adjust operable windows. Whereas *Standard 55* does not provide specific guidance for naturally conditioned spaces, *CIBSE Guide A* prescribes summer design temperatures and over-heating criteria for free-running buildings, where 25 °C is an acceptable indoor temperature. The criteria and recommendations in the international standards have been adopted as normative references by Australian national standards, guidelines and codes of practice.

Indoor air quality (IAQ) standards pertain to reducing the quantity of indoor air contaminants by providing criteria for ventilation rates. CO_2 concentrations are often used as a surrogate of the rate of outside supply air per occupant, and indoor CO_2 concentrations above about 1000 ppm are generally regarded as indicative of ventilation rates that are unacceptable with respect to body odours [26]. The international standards (*ASHRAE Standard 62, European standards EN 13779* and *CR 1752*) provide both the prescriptive and analytical methods to calculate the ventilation rates. The regulatory actions related to IAQ in Australia are limited, and there is a lack of information on the emissions rates of and exposure levels to pollutants in specific building categories. As an alternative to calculating the concentration levels, exposure to pollutants and actual monitoring, using the ventilation rates, for example those prescribed for educational facilities, is deemed to adequately address the achievement of the required IAQ for a space or building. The ventilation requirements in the *Australian Standard AS 1668.2* for educational facilities (10–12 l/s per person) align with those prescribed in the international standards.

7.2 Policies on Thermal Comfort, Indoor Air Quality (IAQ) and Ventilation for Educational Facilities

In the review of the policies to cooling and ventilation in educational facilities, it is observed that two streams of approaches are typically adopted. General requirements for teaching and learning spaces in North America and the UK are to comply with the recommended performance standards for school buildings where the prescribed indoor temperature or temperature range, ventilation rates and CO_2 concentration levels are met using the standards. In Australia, the states of South Australia and Queensland follow this approach and have outlined the conditions of occupied school spaces which require the provision of air conditioning. The states of Victoria, New South Wales and Western Australia specify the requirement for cooling based on geographic locations and external (climatic) conditions rather than prescribing the indoor conditions (temperature, air quality) of school spaces.

7.3 Indoor Environmental Conditions and Educational Outcomes

Information on indoor environmental conditions in Australian schools is very limited. Few data and scientific studies on measurements of school environments, particularly on thermal conditions and IAQ are available. Moreover, majority of the studies summarised in this review have been conducted in the northern mid-latitudes. This lack of knowledge poses a concern considering that children, unlike adults, are much more vulnerable, are required to perform work that is not optional and would almost always be new to them [26, 47, 73].

The prescribed conditions and temperature limits recommended by the standards were based on studies which did not take peoples work performance into account. Available peer-reviewed literature and studies on the effects of classroom thermal conditions and air quality on student performance are likewise very sparse. However, the findings of the few research studies summarised in this chapter suggest that increased classroom temperatures can have negative effects on the performance of schoolwork by children. These studies indicate that air quality and temperature were improved by increasing ventilation and cooling. However, assumptions that the results of these studies can be generalised to other developed countries where the climate, classroom conditions, level of education and educational approach are similar to those in the northern mid-latitudes will have to be validated by replicating them in temperate, subtropical, tropical and humid climates.

This chapter establishes the need for a study grounded on addressing the absence of clear documentation on the state of indoor environments in educational facilities in Australia backed by measurements and surveys of temperature, comfort conditions, indoor quality and the relationship between these aspects of indoor environments and student performance. The minimisation of temperature extremes within school buildings and IAQ-related impacts may yield significant educational learning outcomes to Australia's P-12 education sector but as yet there is little evidence to back this proposition.

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