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A Review of IAQ Standards and Guidelines for Australian and New Zealand School Classrooms

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Abstract: Information on indoor environmental conditions in Australian and New Zealand school classrooms is limited. The indoor environments in schools are less studied compared to other building types such as offices. Limited data and scientific studies on measurements of school environments, particularly on thermal conditions and indoor air quality (IAQ) are available. Moreover, majority of the studies have been conducted in the northern mid-latitudes. This lack of knowledge poses a big concern considering that children, unlike adults, are much more vulnerable, and are expected to perform work that is not optional and would almost always be new to them. This paper reports on the findings of a literature review that explores thermal comfort, particularly indoor air quality and ventilation requirements for Australia and New Zealand school classrooms. The objectives of the review are to identify national and international standards and guidelines associated with the provision of thermal environments and indoor air quality in educational facilities, to examine current knowledge on the relationship between indoor conditions and educational outcomes and identify findings of applicable indoor environmental quality (IEQ) research.

Keywords: Indoor air quality (IAQ); indoor environmental quality (ieq); school classrooms.

1. Introduction

Indoor air quality (IAQ) is recognized as one of the top five environmental hazards by the United States Environmental Protection Agency (US EPA). Numerous studies found that indoor pollutants may be 2 to 5 times, and occasionally more than 100 times higher than the outdoor (US EPA, 1993). Inadequate IAQ conditions have been found to be a cause for absenteeism and poor performance in both office and school environments (Daisey et al., 2003). Poor IAQ is also the source of respiratory and other health related issues (Csobod et al., 2014). Although there are other pollutants and agents which characterise IAQ conditions (Stranger *et al.*, 2008), indoor carbon dioxide (CO_2) concentrations and ventilation rates are commonly used as surrogates and indicators for air quality of indoor environments. Concentration levels exceeding 1,000ppm is an indication of insufficient ventilation and unacceptable conditions in relation to odours removal. Poor ventilation also result in unhealthy learning environments (Ferreira and Cardoso, 2014) and along with poor IAQ, are responsible for acute and chronic health effects (Annesi-Maesano *et al.*, 2013), particularly respiratory health issues in young children (Taptiklis and Phipps, 2017).

An orientation of the literature suggest that there is no unified policies and guidelines for heating, cooling and ventilation in Australia, where each state has its own unique set of policies and guidelines and the provision of mechanical ventilation system is based on climate zones (Andamon *et al.*, 2013). Furthermore, the IAQ regulatory framework in Australia is limited and there is insufficient information on the concentration levels of and exposure to pollutants in specific buildings types. In New Zealand, schools often endured poor IAQ with high indoor CO_2 concentrations and relative humidity, particularly in winter (Taptiklis and Phipps, 2017). Taptiklis and Phipps (2017) has also indicated that IAQ in New Zealand preschools is greatly under-researched. Information on the correlations between indoor environments, health and educational outcomes are sorely limited in both New Zealand and Australia.

2. IAQ in Schools

The scope of this review includes the best-practice standards and practices applicable to indoor air quality (IAQ) and ventilation within educational facilities in Australia and New Zealand. Other indoor environmental quality factors relating to thermal comfort, lighting quality (including daylighting), acoustic quality, odour quality (olfactory quality) and visual comfort are outside the scope of this review.

The method for undertaking the literature and policy review includes standard desktop searches of peer-reviewed publications, using online and scientific electronic databases including ScienceDirect, PubMed, Google Scholar, SAI Global, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and relevant guidelines from the New Zealand Ministry of Education.

Using a variety of search algorithms and combinations of key words, publications, policy documents, design guides and standards related to indoor environments, learning and school performance, educational outcomes, absenteeism or health were sought. In addition, other articles and papers were reviewed as appropriate to provide background information on current conditions in education facilities. This paper reports on the key findings of a literature review that explores thermal comfort, particularly in indoor air quality and ventilation requirements for Australian and New Zealand public school classrooms.

3. Defining the Requirement for IAQ

As building designs trend towards energy efficiency to meet increasing demands of reduced energy consumption in buildings, the importance of indoor environmental quality (IEQ) is potentially being neglected. Poor IEQ in buildings is known to cause Sick Building Syndrome (SBS) and often related to indoor air quality (IAQ). Astolfi and Pellerey (2008) have identified IAQ satisfaction as the most important parameter in determining overall satisfaction with IEQ. ASHRAE (2016) defined acceptable IAQ as air with no known contaminants at harmful concentration levels, and in addition, 80% of the occupants do not express dissatisfaction, in terms of odours. Prescription of ventilation rates in standards and guidelines are deemed sufficient for acceptable IAQ. However, studies have shown these requirements are often not met (Daisey et al., 2003).

3.1. Indoor air pollution parameters

IAQ in a building is not constant and it is influenced by changes in building operation, occupant activity and outdoor climate. Indoor quality may be controlled by a combination of source control and ventilation. The standards for indoor air quality pertain to reducing the quantity of indoor air contaminants that are odorous, potentially irritating, and/or harmful to the comfort and well-being of occupants by providing the criteria for ventilation rates. The quality of indoor air is attributed to the amount of pollutants present in the indoor environment (Table 1). Bluyssen (2009) maintains that the concentration of these pollutants is dependent on:

- The emission rate of pollutants in the space;
- The ventilation rates of the space;
- The concentration of the pollutants in the ventilation air.

Exposure to these indoor pollutants can be affected by parameters such as ventilation rates, air velocity, temperature, relative humidity, and activities happening in the observed indoor space. Among these pollutants, carbon dioxide (CO_2) concentration levels are most commonly used as a surrogate and indicator for IAQ in many air quality related research and studies. Carbon dioxide is a simple and non-intrusive predictor is estimating ventilation rates, especially in high occupancy buildings such as schools and kindergartens (Hänninen, 2012).

Table 6: Main groups of indoor air pollutants (Source: adapted from Bluyssen 2009, p69)

Groups	Subgroup	Examples
Chemical	Gases and vapours	Inorganic: CO, CO_2, NO_X, SO_X, O_3 Organic: volatile organic compounds (VOCs), formaldehyde
	Particulate matter	Fibres: asbestos (natural fibres), mineral wool (synthetic), ceramic (vitreous and crystalline structures) Respirable suspended particles (RSP_S), PM10 Particulate organic matter (POM): biocides, polycyclic aromatic hydrocarbons (PAH_S)
	Radioactive particles/gases	Radon and its daughters
Biological		Micro-organisms, mould, fungi, mycotoxins, bioaerosols pollen, mites, spores, allergens, bacteria, airborne infections, droplet nuclei, house dusts.

3.2. Indoor carbon dioxide (CO_2)

The normal outdoor carbon dioxide (CO_2) levels range between 300 to 500ppm, and typical indoor CO_2 concentration levels range between 500 to 1,500ppm (Seppänen, 2006). Previously, ASHRAE Standard 62.1 (1989) recommended absolute values for indoor CO_2 concentration levels, minimum of 1,000ppm and a maximum of 2,500ppm. This 1989 guideline values were based on an assumed ventilation air rate (outdoor) of 7 Ls^{-1} per person and an outdoor baseline CO_2 concentration of 300ppm. CO_2 poses no health concerns at the concentration levels generally found indoors. However, a study by (Satish *et al.*, 2012) found cognitive ability diminished at 1,000ppm CO_2 concentration levels. Exposure to high concentration levels also have health implications; occupants exposed to CO_2 concentration levels at 800ppm or more can suffer from tightness of chest and suffocation (Bluyssen, 2009).

The measurement and analysis of indoor CO_2 concentration levels often assist to understand ventilation conditions within an indoor environment. Seppänen et al. (1999) suggest that the control of the ventilation is equivalent to control of CO_2 concentration levels in the same indoor space. Many studies have found classrooms with high indoor CO_2 concentration levels are potentially under- ventilated. Classrooms with ideal ventilation are typically where CO_2 concentration levels range between 600 to 800ppm (Figure 1).

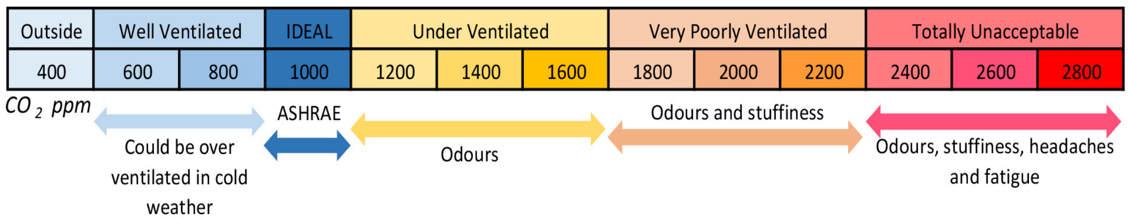

Figure 21: Carbon dioxide as an indicator of classroom ventilation. (Source: adapted from New Zealand Ministry of Education 2007, p16)

3.3. Ventilation

Ventilation is an effective measure to control indoor air pollutants, and is essential for the provision of thermal comfort of occupants, humidity control and odour removal in indoor environments. Although ventilation has no direct impact on occupants' health, inadequate ventilation rates can affect indoor environment conditions and cause SBS (Seppänen *et al*., 1999). Furthermore, Sun *et al*. (2011) also found that inadequate ventilation can encourage the spread of infectious diseases and cause other undesired health issues.

Ventilation may also be the reason for high indoor humidity and dampness, which could result in microbial growth and consequently bring discomfort to occupants (Seppänen, 2006). Poor ventilation is a prevailing issue in schools as observed by the Schools Indoor Pollution and Health Observatory Network in Europe (SINPHONIE) study (Csobod *et al*., 2014). This extensive study of 114 schools in 23 European countries, found that 86% of values for ventilation rates were less than the desirable value of 4 Ls^{-1} per child. High indoor CO_2 concentrations (above 2,700ppm) were found in classrooms in Australia due to inadequate ventilation (Luther and Atkinson, 2012). In New Zealand, ventilation rates were found to be 16 times lower than the recommended value of 8 Ls^{-1} fresh air per person specified in Standards New Zealand 4303:1990 (Wang *et al.*, 2016).

4. Standards and Guidelines

Although indoor air quality (IAQ) has been widely researched, there has been no agreement on a common standard (Olesen, 2004). International standards such as ASHRAE Standard 62.1 is the most commonly used guide for indoor air quality and ventilation (Olesen, 2004), and is used as the normative reference of many national standards (Standards New Zealand, 1990; Standards Australia, 2012). These standards are essentially for the design of ventilation systems in order to meet health and comfort requirements of the built environments (Olesen, 1997).

A comprehensive standard that outlines the mechanical requirements of the ventilation systems is ASHRAE Standard 62.1 which specifies the minimum ventilation rates that is required to achieve indoor air quality suitable for human occupancy with the least negative health impacts. The previous 1,000ppm guideline value for CO_2 recommendation of ASHRAE (1989) was a guideline for comfort acceptability relating to odour removal and not a ceiling value for air quality. Although the 1,000ppm value was revised in the 1999 version of Standard 62.1, it is still widely adopted by numerous studies on IAQ, CO_2 and ventilation rates (Daisey *et al.*, 2003; Shendell *et al.*, 2004; Bakó-Biró *et al.*, 2012). The 2016 and current version of ASHRAE Standard 62.1 (2016) specifies a revised steady state CO_2 concentration level of no greater than 700ppm (p40) above outdoor air levels, along with specified ventilation rates (Table 2).

Table 7: Minimum ventilation rates in Educational Facilities per ASHRAE 62.1-2016. (Source: adapted from ASHRAE 2016, p13)

Occupancy Category	**People Outdoor Air Rate** L/s person	**Area Outdoor Air Rate** L/s m^2	**Default Values**	
			Occupant Density #/100m^2	**Combined Outdoor Air Rate** L/s person
Classrooms (ages 5-8)	5.0	0.6	25	7.4
Classrooms (age 9 plus)	5.0	0.6	35	6.7
Lecture classroom	3.8	0.3	65	4.3
Lecture hall (fixed seats)	3.8	0.3	150	4.0
Art classroom	5.0	0.9	20	9.5
Computer lab	5.0	0.6	25	7.4

The benchmark of 1,000ppm is also adopted by Standards New Zealand NZS 4303:1990. The NZ standard recommends a fresh air requirement of 8 Ls^{-1} per person in a class of 30 occupants, as cited in *Designing Quality Learning Spaces: Ventilation & Indoor Air Quality* (Ministry of Education, 2007). It also recommends more fresh air rate of 10-13 Ls^{-1} per person for non-sedentary teaching spaces, such as gyms, where occupants are active. The NZ Standard prescribes ventilation based on the type of space and the number of occupants in the space, but does not indicate the area of the space (Table 3).

In comparison, the Australian Standard AS 1668.2 (2012) sets out design requirements for mechanically ventilated buildings, based on the need to control odours, particulates and gases, to achieve acceptable IAQ. AS 1668 advocates minimum outdoor airflow rate between 10-12 Ls^{-1} per person, and in addition, specifies a minimum floor area requirement per occupant. For example, 12 Ls^{-1} per person and minimum floor area of 2m^2 per person in classrooms serving persons up to 16 years of age. There is little information on CO_2 or other indoor air pollutants exposure levels, minimum CO_2 concentration levels or emission rates in the specific building categories.

Table 8: Minimum ventilation for teaching spaces. (Source: New Zealand Ministry of Education 2007, p8)

Type of space	**Number of people**	**Fresh air requirement** (litres per second per person)
Classroom	30	8
Laboratories	30	10
Art, design and technology rooms	30	10
Libraries	20	8
Multi-purpose halls	150	8
Gyms	30	10-13

5. Current Conditions in Schools

Children spend the second largest portion of their time in schools and are a more vulnerable group due to their developing immune system (Csobod *et al.*, 2014; Taptiklis and Phipps, 2017). Classrooms in the US, Canada and Sweden were also reported to have CO_2 concentration levels exceeding 1,000ppm, and high CO_2 concentrations at 1,000ppm is associated to risen absenteeism (Shendell *et al.*, 2004). A study of UK classrooms reported that occupants were exposed to unacceptable air conditions of CO_2 concentration of up to 5,000ppm (Bakó-Biró *et al.*, 2012). Another study in Portugal across 51 elementary schools similarly reported high CO_2 concentrations of close to 2,000ppm (Ferreira and Cardoso, 2014). Fadeyi *et al.* (2014) also reported inferior IAQ of exceedingly high CO_2 concentration levels (> 1,600ppm) found in elementary classrooms in United Arab Emirates. In New Zealand, Wang *et al.* (2016) have measured high levels of CO_2 concentrations (exceeding 3,500ppm) in classrooms during school hours. Luther and Atkinson (2012) likewise found high CO_2 concentrations (> 2,700ppm) in Australian classrooms during winter, and concluded that poor IAQ is common in schools world-wide. Mendell and Heath (2005) have identified that students' attention and performance are linked to ventilation rates. It is evident that deficient ventilation has direct impacts on health and students' performance, yet IAQ and ventilation rates are rarely measured in schools (Daisey *et al.*, 2003). Taptiklis and Phipps (2017) has indicated that IAQ in NZ preschools is greatly under-researched.

Standards for indoor environment conditions have been developed based on studies conducted with healthy and fit adults, and often in a workplace or office settings. School populations are much denser than offices; 4 times as many occupants per square metre as a typical office building (Chatzidiakou *et al.*, 2012), with active children engaging in learning and non-sedentary activities. Furthermore, children are a more vulnerable group to poor IAQ conditions than adults. Thus, the application of IAQ requirements for offices is not appropriate for school environments. Moreover, in naturally ventilated schools, ventilation in classrooms largely depends on the opening of windows. Although well-placed cross ventilation strategies can offer effective ventilation (Luther and Atkinson, 2012), windows may not be open frequent enough, especially in cooler winter months, to avoid heat loss and thermal discomfort. This would result in high indoor CO_2 concentration levels (> 800ppm) (Taptiklis and Phipps, 2017). Whereas, a well ventilated space of CO_2 concentrations between 600 to 800ppm is considered conducive for learning (Kajtár and Herczeg, 2012).

This review outlines that current indoor air quality guidelines are informed by studies on working environments in office buildings and there is limited guidance to specific building occupancy types, particularly school facilities. Moreover, although some guidance have been provided by authorities such as the National Health and Medical Research Council (NHMRC) and the National Occupational Health and Safety Commission (NOHSC), the regulatory actions related to indoor air quality in Australia in particular are limited (Brown, 2006). Furthermore, the selection of IAQ guidelines for the educational building categories should consider the protection of the sensitive population in this sector. The prescribed conditions and limits recommended by the standards often do not consider the impact on student performance. Limited data and inadequate clear documentation is available on the effects of poor indoor environments on the performance of schoolwork by students that much of the information have assumed that influences of indoor settings on adults have relevance to the influences of school environments on children (Wyon, 2004; Wyon and Wargocki, 2013). This knowledge gap presents opportunities to address the absence of quantitative studies on the current state of IAQ in schools. This review establishes the need for studies grounded on addressing the lack of clear documentation on the state of indoor environments in Australian and New Zealand school facilities backed by measurements and the relationship between aspects of indoor environments and student performance.

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