

WESTERN SYDNEY
UNIVERSITY



COOL SCHOOLS

September 2018

AUTHORS

Anisah L. Madden¹
Vanicka Arora¹
Kathryn A. Holmes²
Sebastian Pfautsch³

¹Institute for Culture and Society

²School of Education

³School of Social Science and Psychology

This report was produced with financial support from the Office of the Deputy Vice Chancellor (Research and Innovation). The authors acknowledge endorsement from Western Sydney University's Research Themes Education and Aspirational Change, Environment and Sustainability and Health and Wellbeing.

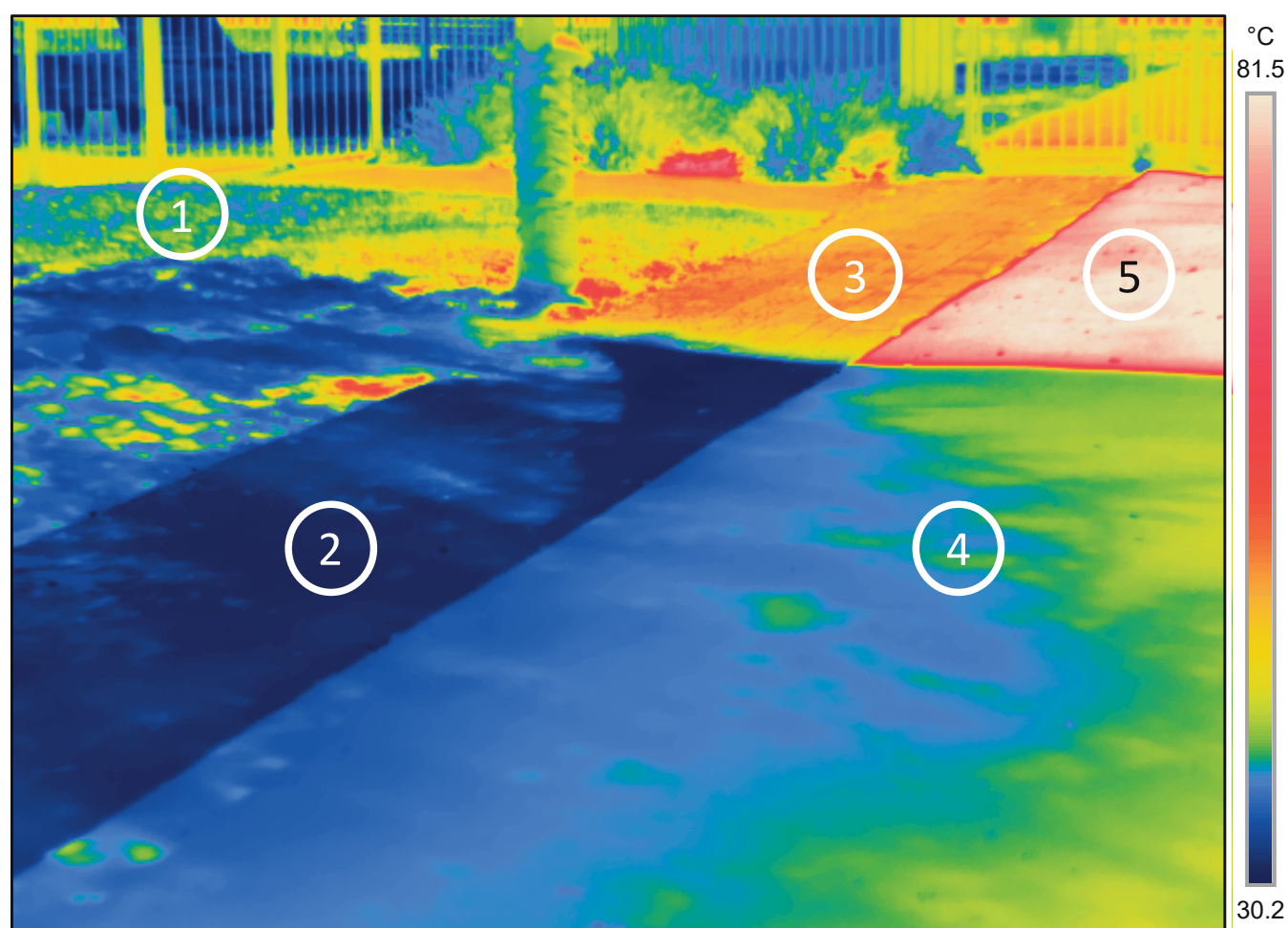
With respect for Aboriginal cultural protocol and out of recognition that its campuses occupy their traditional lands, Western Sydney University acknowledges the Darug, Tharawal (also historically referred to as Dharawal), Gandangarra and Wiradjuri peoples and thanks them for their support of its work in their lands (Greater Western Sydney and beyond).

This document can be cited as:

Madden, A.L., Arora, V., Holmes, K.A., Pfautsch, S. 2018.
Cool Schools. Western Sydney University. 56 p.
<http://doi.org/10.26183/5b91d72db0cb7>

©Western Sydney University

HEAT IMPACTS SCHOOL CHILDREN IN MANY DIFFERENT WAYS.



Keeping indoor and outdoor school space cool in summer is important. The thermographic image shows the temperature variation of different surface materials in a typical school yard.

1. Sun-lit grass (40 °C).
2. Shaded concrete bricks (32 °C).
3. Sun-lit concrete bricks (52 °C).
4. Shaded soft fall (40 °C).
5. Sun-lit soft fall (83 °C).

The image was taken in the early afternoon of a warm summer day where ambient air temperature was 31 °C. The apparent variation in surface temperature of 50 °C within a small area demonstrates the importance to consider thermal characteristics of materials when designing outdoor space in schools. Thermal characteristics of building materials used in schools have a large influence on air temperatures experienced in outdoor and indoor learning space.

Image © S. Pfautsch.

CONTENTS

ABBREVIATIONS	6	PART 2. INFRASTRUCTURE	24	PART 3. COOLING SCHOOLS	36
LIST OF FIGURES AND TABLES	7	3. PLANNING AND CONSTRUCTION OF SCHOOLS IN NEW SOUTH WALES: LEGISLATION AND POLICY	25	5. TRENDS FOR SCHOOLS IN NSW	37
RATIONALE	8	3.1 NSW DEPARTMENT OF EDUCATION	26	SECTION HIGHLIGHTS	37
PART 1. THERMAL COMFORT	10	3.2 THE EDUCATION FACILITIES STANDARDS AND GUIDELINES (EFSG)	28	5.1 MODULAR CLASSROOMS FOR SCHOOLS	37
1. THERMAL COMFORT IN INDOOR AND OUTDOOR ENVIRONMENTS	11	3.3 NSW PLANNING AND ENVIRONMENT DEPARTMENT	31	5.2 HIGH-RISE SCHOOLS IN NSW	38
SECTION HIGHLIGHTS	11	3.4 NATIONAL CONSTRUCTION CODE OF AUSTRALIA	31	5.3 AIR CONDITIONING IN NSW SCHOOLS	39
1.1 DEFINING AND ASSESSING THERMAL COMFORT	11	4. STANDARDS AND CERTIFICATIONS FOR SUSTAINABLE BUILDING PLANNING AND DESIGN	33	5.4 COVERED OUTDOOR LEARNING AREAS (COLAS)	40
1.2 APPROACHES TO THERMAL COMFORT IN INDOOR ENVIRONMENTS	12	SECTION HIGHLIGHTS	33	6. PASSIVE DESIGN STRATEGIES FOR LANDSCAPING IN SCHOOLS	42
1.2.1 VENTILATION AND AIR QUALITY	14	4.1 GREEN STAR CERTIFICATION	33	6.1 PLANTING TREES FOR SHADE	42
1.3 STUDENT THERMAL COMFORT IN AUSTRALIAN CLASSROOMS	15	4.2 THE NATIONWIDE HOUSE ENERGY RATING SCHEME (NaTHERS)	33	6.2 SITE PLANNING: GEOMETRY AND LAYOUTS	42
1.4 INDOOR ENVIRONMENTS: HEAT, VENTILATION, STUDENT LEARNING AND WELL-BEING	15	4.3 NATIONAL AUSTRALIAN BUILT ENVIRONMENT RATING SYSTEM (NABERS)	34	6.3 OUTDOOR SHADING	44
1.5 APPROACHES TO THERMAL COMFORT IN OUTDOOR ENVIRONMENTS	16	4.4 BREEAM AND LEED CERTIFICATIONS	34	6.4 OUTDOOR PAVING, SURFACES AND GREENING	44
1.5.1 OUTDOOR THERMAL COMFORT INDICES	17	4.5 STANDARD EN15251	34	7. PASSIVE DESIGN STRATEGIES FOR SCHOOL BUILDINGS	45
1.6 STUDENT THERMAL COMFORT IN OUTDOOR PLAY SPACES	18			7.1 INSULATION AND GREEN FACADES	45
1.7 EFFECTS OF HEAT STRESS ON STUDENT OUTDOOR LEARNING AND WELL-BEING	21			7.2 CEILING INSULATION, COOL AND GREEN ROOFS	45
2. SUSTAINABILITY AND ENVIRONMENTAL EDUCATION	22			7.3 WINDOWS, DOORS, VENTILATORS AND GLAZING	45
2.1 SUSTAINABILITY EDUCATION IN AUSTRALIAN SCHOOLS	22			8. INNOVATIVE COOLING SOLUTIONS	46
2.2 SUSTAINABILITY AND ENVIRONMENTAL EDUCATION IN NSW	22			SECTION HIGHLIGHTS	46
				8.1 COOLING PROJECTS IN WESTERN SYDNEY	47
				9. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS	50
				REFERENCES	52

EXECUTIVE SUMMARY

The Western Sydney University Cool Schools Initiative (CSI) was launched in 2018 to develop interdisciplinary research programs for heat-resilient primary and secondary school environments and design of heat-resilient curriculum. This report summarises current research in health and environmental sciences, planning policy, legislation and standards, sustainability education, and innovative design trends. Its purpose is to inform future research into student thermal comfort and cooling solutions for schools in Western Sydney and NSW.

Rising temperatures and the increasing frequency of extreme heat events across NSW and Australia pose significant health and safety risks to children, yet little is known about thermal comfort of students and teachers in Australian schools. Climate-responsive cooling technologies are increasingly employed in cities to mitigate urban heat effects, and there are a host of policies and standards pertaining to thermal comfort inside classrooms. However, no explicit legislation or policies for “heat-smart” schools and curricular activities currently exist. Thermal properties of school outdoor play spaces are conspicuously absent. The impact of heat on learning outcomes in Australian schools is largely undescribed. These unknowns demand urgent attention and collaborative efforts of diverse sectors and agencies – particularly in light of the announcement by the NSW Government to invest \$6 billion in new schools and upgrades between 2018 and 2022 to meet the needs of a rapidly growing population.

Part I of this report contains two sections. Section 1 reviews methods for defining and assessing thermal comfort, and gives an overview of relevant research on thermal comfort in both indoor and outdoor school environments. Section 2 outlines efforts to incorporate sustainability and environmental education into Australian school curriculum, considering the potential future impacts of rising temperatures on children’s outdoor learning activities.

Part II contains two sections – 3 and 4 – that address issues related to legislation, policy, funding frameworks and standards which relate to thermal comfort of school environments in NSW, detailing areas of responsibility at state and national levels, and how their respective areas of responsibility intersect.

Part III elucidates emerging trends and innovations. Section 5 outlines modular and hi-rise schools, air-conditioning, and the removal of trees in favour of artificial shade structures. Sections 6 and 7 summarise passive cooling design strategies for landscaping and school buildings respectively, briefly touching on site planning, factors in ventilation, as well as greening approaches and use of cool materials. Section 8 highlights current research and practice to mitigate urban heat island effects in Sydney, noting the need for cross-sector collaboration to increase the effectiveness in battling urban heat.

Section 9 concludes this report, suggesting four areas for future research: development of school- and child-specific thermal comfort models and research methods; investigation of the direct and indirect impacts of rising temperatures on children’s activity, health, and learning; the need to address trends in school built environments and the testing and implementation (into policy and planning) of best practices for cooling; and strategies to facilitate inter-agency collaboration and coordination across all of these areas.

ABBREVIATIONS

ABCB: Australian Building Codes Board	MENEX: Man-Environment Heat Exchange
AAEE: Australian Association for Environmental Education	NABERS: National Australian Built Environment Rating System
AESA: Australian Education for Sustainability Alliance	NatHERS: Nationwide House Energy Rating Scheme
ASHRAE: The American Society of Heating, Refrigerating and Air-Conditioning Engineers	NCC: National Construction Code
ATC: Adaptive Thermal Comfort	NSW: New South Wales
BCA: Building Codes Australia	NSW DoE: New South Wales Department of Education
BREEAM: British Building Research Establishment Environmental Assessment Method	NSW DE&H: New South Wales Department of Environment and Heritage
CET: Corrected Effective Temperature	NSW DP&E: New South Wales Department of Planning and Environment
COAG: Council of the Australian Government	OPS: Outdoor Play Spaces
COLA: Covered Outdoor Learning Area	PCA: Plumbing Codes Australia
CSI: Cooling Schools Initiative	PMV-PPD: Predicted Mean Vote-Predicted Percentage Dissatisfied
Efs: Education for Sustainability	PSI: Physiological Strain Index
EFSG: Education Facilities, Standards and Guidelines	PST: Physiological Subjective Temperature
HVAC: Heating Ventilation and Air Conditioning	RTC: Rational Thermal Comfort
ISO: International Organization for Standardization	UTCI: Universal Thermal Climate Index
LEED: Leadership in Energy and Environmental Design	UHI: Urban Heat Island
	WBGT: Wet-Bulb Globe Temperature
	WSUD: Water Sensitive Urban Design

LIST OF FIGURES AND TABLES

Figure 1: 2017: Australia's Year of Heat Records.	10	Figure 14: A sample 'performance solution scenario' shared by the ACBC for reference on the performance design processes undertaken by building practitioners.	32	Table 1: Daily maximum temperatures in recent years in Sydney CBD, Parramatta and Penrith.	10
Figure 2: Provision of openable windows/doors and ventilators for natural ventilation requirements as described in Australian Standard 1668.2.	14	Figure 15: Sample BASIX Certificate with different indicators evaluated.	34	Table 2: Fanger's 6 key factors in determining thermal comfort.	12
Figure 3: A framework for outdoor thermal comfort assessment.	17	Figure 16: Artists rendition of design for new high-rise Ultimo Public School from Wattle Street (top) and proposed rooftop play areas (bottom).	36	Table 3: Thermal Comfort Standards in Classrooms.	13
Figure 4: The Human Heat Budget.	18	Figure 17: Modular classroom sample with solar powered roofs, thermal insulation in glazing and universal access.	38	Table 4: Mean temperatures (°C) of surface materials in kindergarten outdoor play spaces.	20
Figure 5: Surface temperature images of children's playgrounds in Arizona photographed with Infrared Thermography (IRT).	19	Figure 18: View of high-rise Arthur Philip High School in Parramatta.	39		
Figure 6: Outdoor play spaces in three Western Sydney childcare centres.	19	Figure 19: Number of air conditioned classrooms in NSW Schools. .	40		
Figure 7: Sustainable Schools NSW Flyer .	23	Figure 20: COLA at a School in Sydney, Australia.	41		
Figure 8: Thermal images showing surface temperatures of different building materials.	24	Figure 21: Strategies on location of planting with respect to the built fabric as prescribed the EFSG Guidelines PS504.01.	43		
Figure 9: Framework of policy and legislation for schools in NSW.	25	Figure 22: Spatial distribution maps of the Greater Sydney Area.	47		
Figure 10: Sectors or Units within the Department of Education.	26	Figure 23: Urban design strategies for cooler cities..	49		
Figure 11: Forecast permanent primary classroom deficit at 2031.	27				
Figure 12: Identification of zones in NSW based on mean maximum January isotherms.	29				
Figure 13: Resources available for reference on the EFSG website.	30				

RATIONALE

IMPACT OF POPULATION GROWTH ON SCHOOL INFRASTRUCTURE

The population of NSW, and particularly of Greater Western Sydney is growing rapidly, generating pressure on the existing education system. It is predicted that in the next decade the number of school-aged children in NSW will increase by 41% (The Urban Developer, 2018). By 2031 an additional 164,000 public school spaces will be required to accommodate this trend. The NSW Government is responding to this pressure by investing \$6 billion in new and upgraded school infrastructure between 2018 and 2022 (NSW Department of Education, 2018a) as a first measure. This investment represents the largest single spending commitment on school infrastructure in the history of the state.

RISING TEMPERATURES

Average global temperatures over the past five years (2013-2017) have been the highest on record for any five-year period in the 138-year global temperature archive (Steffen et al., 2017). In Australia, temperature records get broken year after year. 2017 was Australia's third hottest year on record; it was Sydney's hottest summer on record, and on February 11th 2017, NSW's average maximum temperature reached 44 °C, the hottest February day in the state on record (Steffen et al., 2017). In the Greater Sydney Region, heat is particularly pronounced in the west, where the average number of days over 35°C is up to five times greater compared to the eastern suburbs (Table 1). It is predicted that Western Sydney will experience an additional five to ten extremely hot days (above 40 °C) by 2030 (Sydney Water, 2017).

Table 1: Daily maximum temperatures in recent years in Sydney CBD, Parramatta and Penrith. Source: WSROC (2018).

	YEAR					AVERAGE FOR
	2013	2014	2015	2016	2017	ALL YEARS OF DATA
SYDNEY (OBSERVATORY HILL)						1859 - 2017
Annual number of days above 30°C	19	18	23	28	30	14.8
Annual number of days above 35°C	5	2	7	6	12	3.1
Annual number of days above 40°C	2	0	1	0	0	0.3
PARRAMATTA						1967 - 2017
Annual number of days above 30°C	58	49	47	55	29	43.1
Annual number of days above 35°C	14	9	15	16	18	10.9
Annual number of days above 40°C	3	2	1	1	8	1.5
PENRITH						1995 - 2017
Annual number of days above 30°C	81	71	73	82	79	69.5
Annual number of days above 35°C	24	21	23	22	38	20.1
Annual number of days above 40°C	5	4	2	4	16	4.2

Extreme heat events and increased overall summer temperatures pose health and safety risks as well as placing significant demands on energy supply. In 2017, peak energy use in Sydney increased by almost 100% with temperature increases from 20° C to 40 °C, and energy consumption for cooling purposes were up to 100 % higher in Western Sydney compared to Eastern Sydney (Sydney Water, 2017). Across the Greater Sydney Region, maximum air temperatures are expected to increase by up 2 °C by 2070. The NSW Department of Environment and Heritage (NSW DE&H) predicts that new urban developments, which are replacing forested areas and grasslands in the north-west and south-west of Sydney, may double this predicted rise in temperature (NSW DE&H, 2015).

RISKS OF RISING TEMPERATURES TO CHILDREN

Between 2005 and 2015, extreme heatwaves in NSW resulted in a 10% increase in both deaths and ambulance callouts (Jegasothy et al., 2017). With temperatures reaching more extreme levels in Sydney's west compared to the eastern suburbs, there may be up to three times as many heat related deaths in western suburbs (Sydney Water, 2017; Australian Water Association, 2018). It is well-known that children are more vulnerable to heat stress than adults, as children have a greater body surface area-to-mass ratio, less developed body regulating systems, and higher heart rates and metabolic activity than adults,

all of which makes them more sensitive to extreme temperatures (Xu et al., 2012). Xu and colleagues further noted that children spend more time outdoors and engage in more vigorous activities than adults, accelerating the risk. Finally, children, especially young children, are dependent on others to protect them from unsafe situations. Extreme heat events poses additional risks. For example, a study of health risks during heatwaves in Adelaide between 1993 and 2009 showed a marked increase in hospital admissions, emergency department presentations and mortality in young children (Nitschke et al., 2007, 2011). Comparable data is not available for Sydney, but it seems reasonable to expect similar trends. Increasing heat will expose children to significant health and safety risks, which urgently need to be addressed.

COOL SCHOOLS INITIATIVE

Recognising the lack of knowledge around the impacts of heat on school learning, infrastructure and design gave rise to the Cool Schools Initiative (CSI) of Western Sydney University. The CSI provides a canopy under which researchers, industry and Government organisations can meet to jointly identify important knowledge gaps in curriculum and infrastructure of primary and secondary schools and design research projects to fill these gaps. This co-design process will help to form new partnerships and strategies that can increase heat-resilience and sustainability of learning environments for children in NSW. Addressing both indoor and outdoor

environments, and understanding the interrelatedness of education, health and environmental sciences, sustainable design and infrastructure planning, the CSI takes a novel, interdisciplinary approach to research and innovation.

Western Sydney scientists bring bring skills and knowledge in the following fields of research to the CSI:

1. Environmental Monitoring: Assessing thermal environments in and around schools to provide evidence-based data to inform heat-smart design strategies.

2. Infrastructure Design: Development and field-testing of innovative building and school yard designs that support physical and cognitive development while providing cooling benefits.

3. Healthy Learning: Investigating patterns of physical activity in children through smart technology such as electronic textiles, GPS trackers, and smart water-bottles.

4. Education for Sustainability (EfS): Implementing EfS frameworks to help conserve waste, water, and energy, and generate health and environmental benefits.

5. New Curriculum: Designing new curricular activities that help dissolving the legacy of separating indoor learning and outdoor play.

PART 1.

THERMAL COMFORT

2017: AUSTRALIA'S YEAR OF HEAT RECORDS



CLIMATECOUNCIL.ORG.AU

| crowd-funded science information

Figure 1: 2017: Australia's Year of Heat Records.

1 THERMAL COMFORT IN INDOOR AND OUTDOOR ENVIRONMENTS

SECTION HIGHLIGHTS

- Many different approaches and techniques exist to define and assess thermal comfort. However, current building design standards are based on thermal comfort models that do not reflect the real-life dynamism of indoor and outdoor environments, nor the adaptive agency of users.
- Very few studies exist that assess thermal comfort of children. Less than 10% of all published articles on thermoregulation involve children (Vanos, 2017), and of these, few have considered the specific characteristics and needs of students (e.g. higher metabolic and physical activity than adults, preference for cooler temperatures, higher sensitivity to high temperatures and heat stress, less autonomy than adults over adaptive strategies).
- Thermal comfort studies performed inside schools do not account for a) thermal microvariations in classrooms, b) their effects on children (proximity to solar radiation entering through windows; drafts, etc.), or c) adaptive strategies employed by teachers to restore thermal comfort – which may or may not reflect children's needs and preferences.
- Very few thermal comfort studies have been carried out in Australian schools. Of these, none investigate the outdoor thermal school environment and the impact of rising temperatures on student thermal comfort, safety, health, learning, and activity patterns.

1.1 DEFINING AND ASSESSING THERMAL COMFORT

In principle, there are three different approaches to defining thermal comfort: psychological, neuro-physiological, and an approach based on heat balance of the human body (Höppe, 2002).

The psychological approach reflects the subjective character of comfort, demonstrated in the ASHRAE Standard 55 (2013) definition of thermal comfort as "a condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" (Rupp et al., 2015). ASHRAE (1992) defines the zone of thermal comfort as a) the span of conditions where 80% of sedentary or slightly active persons find the environment thermally acceptable; b) acceptable ambient temperatures are 23-27 °C in summer and 20-25 °C in winter.

In indoor environments, perceptions of thermal comfort are influenced by a variety of factors, such as types of building materials and furnishings, (e.g. visible metal or wood, the presence or absence of floor coverings, material colour), time of year, and outdoor weather. Thermal comfort related to outdoor weather is dependent on current conditions, but also on seasonal variation. A cool rainy day after weeks of hot sun will affect perceptions of thermal sensation differently than a month of cool rain (Potter and de Dear, 2000). The psychological approach therefore reveals a wide inter-individual and contextual variation in perceptions of comfort, presenting a challenge for how such variation should be accommodated (Höppe, 2002). As subjective measures are usually assessed through questionnaires and interviews, existing methods may not be suitable for use with

children, especially young children, who have different capacities compared to adults to recognize and communicate preferences and sources of discomfort.

The neuro-physiological approach uses measurements of skin and body core temperature to capture an objective measure of thermal sensation. As humans do not sense temperature directly, firing rates of temperature sensitive neurons, or thermoreceptors, which are found throughout the body, serve as proxy (Kingma et al., 2012). This approach has been useful in designing high-performance buildings to both optimize energy costs and maximise thermal comfort. However, the need for specialised equipment and the logistics of measuring thermoreceptors for each individual makes this a potentially costly and impractical approach for deriving data on children on a large scale over time.

Finally, Fanger's heat balance model suggests that thermal comfort is achieved when there is a balance between heat flows to and from the human body¹ and skin temperature² and sweat rate fall within a comfortable range (Höppe, 2002; Epstein and Moran, 2006). Fanger's model assumes that a person is most comfortable in a thermal neutral environment (i.e. neither warm nor cool). This model has been subject to criticism for various reasons, leading to the development of an adaptive model (see subsection 2.2, also refer to Kingma et al., 2012; Rupp et al., 2015). In addition, the heat balance model may be particularly unsuitable for assessing children's thermal sensation and preferences, given that it does not consider the specific physiological characteristics of children (subsection 2.2 below provides further details).

¹ Defined by Fanger as a body core temperature between 36.5 - 37.5 °C (Epstein and Moran, 2006).

² Mean skin temperature comfort limits defined by Fanger are 30 °C for extremities and 34-35 °C for core and head (Epstein and Moran, 2006).

These three approaches, along with a variety of adjuncts and derivatives, have been used to develop more than 150 indices available to measure and assess thermal comfort (e.g. Parsons, 2003; Epstein and Moran, 2006). Different indices are used for a variety of environments and applications, and due to the number and complexity of interacting factors and microclimatic variations, there is no definitive system for rating or measuring heat stress. In addition, indices have been subject to a number of classification schemes. De Freitas and Grigorieva (2015) classify 162 thermal indices into eight primary classes – possibly the most comprehensive classification scheme published to date. Thermal comfort approaches are selected according to a variety of factors: study rationale, number of variables, complexity of measuring equipment and capacity of researchers and resources available to them, and the type of environment: outdoor, semi-outdoor, or indoor (De Freitas and Grigorieva, 2015; Rupp et al., 2015).

1.2 APPROACHES TO THERMAL COMFORT IN INDOOR ENVIRONMENTS

There are two approaches to defining indoor thermal comfort: the classic steady-state model developed by Fanger in the 1970s (Rupp et al., 2015) – also sometimes referred to as the Rational Thermal Comfort (RTC) model – and the Adaptive Thermal Comfort (ATC) model (Zomorodian et al., 2016).

Fanger’s approach uses six key factors to predict thermal sensation and dissatisfaction with the thermal environment in air-conditioned space (Table 2). It uses the Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) indices. PMV³ is the basis for two commonly used international thermal comfort standards: ISO 7730 (ISO, 2005) and ASHRAE Standard 55. These, along with EN15251 (CEN, 2007), which is based on the ATC model, inform design guidelines for acceptable indoor temperature ranges (Rupp et al., 2015), including classrooms (Table 3). Fanger’s method was developed from studies in climate-controlled environments, leading to criticisms that it was not reflective of the dynamism of real-life conditions, and also modelled people as passive occupants of environments and not as active agents (Zomorodian et al., 2016). Rather than a heat balance model, which seeks to provide ‘cool, dry, still indoor air’, there is growing interest in the energy saving potential, health benefits, and higher degree of comfort of dynamic uniform environments (de Dear, 2011; Kingma, 2012).

Table 2: Fanger’s 6 key factors in determining thermal comfort. Source: Epstein and Moran (2006).

	parameter	symbol	also
Environmental	1. Dry-bulb temperature $T_a = 0.5(T_r + MRT)$ $(T_r \approx 2/3 T_a + 1/3 T_{cl})$	(T_a)	T_o
	2. Black-globe temperature $MRT = (1 + 0.22 V^{0.5})(T_g - T_a) + T_a$	(T_g)	MRT
	3. Wind velocity	(V)	
	4. Wet-bulb temperature	(T_{w})	rh: VP
behavioral	5. Metabolic rate	(M)	met
	6. Clothing Insulation	(clo)	
	Moisture permeability	(i_{cl})	

The conversions in this table are based on Shapiro and Epstein²⁰.
rh=relative humidity, VP=vapor pressure, met=a metabolic rate unit (1 met=50 kcal/h/m²). T_o = operative temperature, an index of the combined effects of dry bulb and radiant temperature; first degree estimate for a sunny clear day is: $T_o = T_a + 5$ (°C).
(For further information on terminology and units, the interested reader is referred to the Glossary of terms for thermal physiology⁴⁵)

³ PMV is calculated through the six variables of metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity (Rupp et. al, 2015)

The second approach, the ATC model, has been used in field studies in naturally ventilated buildings (Nicol and Humphreys, 1973; Auliciems, 1981; de Dear et al., 1997; de Dear and Brager, 1998; Nicol and Humphreys, 2002), and is based on the idea that if a change occurs in the environment to produce thermal discomfort, people will respond to restore comfort (e.g. opening or closing windows or window shades, removing or adding clothing). The key distinction between Fanger's model and the adaptive model is that the former sees bodies as passive respondents to thermal changes and seeks to maintain a "steady-state" environment, whereas the latter sees people as actively adapting to their environments. The adaptive model also recognizes that there is a range of temperatures people can adapt to in a given environment and still experience thermal comfort, moreover, this range is different for different people according to a variety of factors (i.e. age, gender) in different climates and geographical locations (de Dear et al., 1998; Rupp et al., 2015). Although Fanger's steady-state model forms the basis for current thermal comfort standards, the ASHRAE Standard 55 has shifted from a rational (2004) to an adaptive approach (2010) (see Table 3).

Table 3: Thermal Comfort Standards in Classrooms.
Source: Zomorodian et. al (2016).

Standard	Thermal comfort approach	Operative temperature winter (°C)	Operative temperature summer (°C)
ISO 7730 (2005)	Rational $-0.5 < PMV < +0.5$ PPD < 10%	20–24	23–26
ASHRAE 55 (2004)	Rational $-0.5 < PMV < +0.5$ PPD < 10%	20.5–25.5	24.5–28.0
EN- 15521 (2007)	Adaptive	$T_{in} = 0.302TRMT + 19.39$; $TRMT > 10$ $T_{in} = 22.88$; $TRMT \leq 10$ $T_n = 0.31T_o + 17.8$	
ASHRAE 55 (2010)	Adaptive		

TRMT: Running Mean Temperature.

T_o: Outdoor Temperature.

T_n: Neutral Temperature.

PMV: Predicted Mean Vote.

1.2. VENTILATION AND AIR QUALITY

Ventilation commonly refers to the supply of clean outdoor air to a building. Ventilation to indoor spaces is a significant element of thermal comfort, and also provides a number of other functions, including the provision of oxygen; dilution or removal of airborne contaminants (e.g. odours, volatile organic compounds, allergens); ensuring the correct operation and safety of combustion appliances; and smoke control or clearance (Australian Building Code Board (ABCB) 2018a).

Natural ventilation is achieved through leaks in the building envelope and as a consequence of natural airflows through open windows and doors. Where natural ventilation is inadequate to meet minimum ventilation rates, mechanical ventilation systems use fans to take in and distribute outdoor air. Hybrid and mixed-

mode ventilation systems use a combination of natural and mechanical ventilation in an integrated system or as two independent systems with control integration only (mixed-mode; ABCB, 2018a). The type, features, and efficiency of heating, ventilation and air conditioning (HVAC) systems can themselves play a role in ventilation rates and air quality (Sundell et al., 2011). Current trends in ventilation for both active and passive systems are detailed in sections 5 and 7.

A widely used ventilation standard in the United States specifies a minimum ventilation rate for classrooms of approximately 7 litres per second (L s^{-1}) or 15 cubic feet per minute (cfm) per occupant at a default occupant density. The European standard specifies a minimum ventilation rate of 8 L s^{-1} (17 cfm) per occupant for moderate indoor air quality and 12.5 L s^{-1}

(29 cfm) per occupant for medium indoor air quality (Haverinen and Shaughnessy, 2015).

The Australian Standard 1668 (2015/2012) on the use of ventilation and air-conditioning in buildings sets out the standards for design, construction, installation of mechanical smoke control, air handling and natural ventilation systems. It directs ventilation rates of 10 L s^{-1} per occupant, with reductions permitted in scenarios where odour and particulate matter filters are used. An excerpt from the standard indicating floor area percentage requirements for openable openings and natural ventilation is shown in Figure 2.

Figure 2: Provision of openable windows/ doors and ventilators for natural ventilation requirements as described in Australian Standard 1668.2. Source: https://www.airah.org.au/Content_Files/Advocacy/Compliance/Appendix-1-section-3-AS1668.2-2002.pdf

PERCENTAGE FLOOR AREA REQUIRED AS OPENABLE OPENINGS FOR OCCUPANT- AND BUILDING-RELATED CONTAMINANTS

Use of enclosure	Average adjusted metabolic rate Watts/occupant	Net floor area per occupant (m^2) (use highest applicable value)			
		<2	2 to 5	Over 5 up to 15	>15
Low activity	Up to 160	7.5%	5%	5%	2.5%
Medium activity	161-200	7.5%	5%	5%	2.5%
High activity	201-340	10%	7.5%	5%	5%
Very high activity	Over 341	15%	10%	7.5%	5%
Class 1 Class 2 Class 4	Any	5%			
Classroom (students under 16 years old)	Any	Multiply the percentage floor area required by 1.25			
Smoking not prohibited	Any	Multiply the percentage floor area required by 2.0 (does not apply to Class 1, Class 2 and Class 4 buildings)			

1.3 STUDENT THERMAL COMFORT IN AUSTRALIAN CLASSROOMS

Given that school children spend more than one-third of their time inside school buildings, evaluation of how indoor environments influence health and academic performance of children is justified (Vanos et al., 2015). As in other indoor environments, design values for classrooms are determined by current thermal comfort standards *ISO 7730*, *EN 1525*, and *ASHRAE Standard 55* (Table 3). However, a review of thermal comfort studies in educational buildings in a variety of different climates (over 40 peer-reviewed papers from 1969 – 2015) concluded that neither Fanger's 'rational' model, nor the adaptive model were able to accurately predict individual student's thermal comfort levels (Zomorodian et al., 2016). Several studies have demonstrated that the PMV-PPD model does not consider the warmer thermal sensations expressed by children, and their preferences for cooler environments (de Dear, et al., 2015).

A survey of Australian primary and secondary school children across three distinct subtropical climate zones was conducted in a mixture of air conditioned, evaporative cooled, and naturally ventilated classrooms during summer to investigate acceptable temperature ranges (de Dear et al., 2015). The study showed that students' preferred temperature was about 22.5°C, generally cooler than expected for adults under similar conditions. The study suggested that children have slightly lower, but comparable thermal sensitivity to adults. The greatest range of adaptability of thermal conditions was observed in students exposed to a wide range of indoor and outdoor thermal environments.

Not only do students tend to prefer cooler environments, they are more sensitive to high temperatures and the effects of heat stress than adults (Vanos et al., 2016; Zomorodian et al., 2016; de Dear et al., 2015; Kim and de Dear,

2018). However, adaptive strategies to restore thermal comfort such as removing or adding clothing or adjusting environmental conditions require a degree of autonomy that students may not have in classrooms. Classroom conditions may therefore reflect teacher preferences or habit rather than children's requirements. Kim and de Dear (2018) analysed 4866 surveys from primary and secondary school classrooms across Australia to better understand student's perception of thermal comfort and related behaviours. They confirmed that teachers are the primary active agents modifying ambient conditions inside the classroom. A study in South East Queensland, which examined the impact of retrofitting six classroom buildings between 2012-14, concluded that examining the range of adaptive actions undertaken by teachers to reduce feelings of discomfort from heat was a critical aspect of research (Kuiiri, 2016).

Although the thermal condition inside a building directly relates to its architectural and constructional characteristics. Zomorodian et al. (2016) noted that most classroom-based field studies have not taken these into account or related them to students' thermal perceptions. The researchers further noted that most studies considered classrooms as uniform thermal zones, not accounting for micro-variations produced by factors such as solar radiation entering through windows, drafts, and the diverse thermal radiant fields caused by windows, walls, and radiators. Based on these and other findings, they suggest that *ISO 7730*, *EN 15251*, and *ASHRAE Standard 55* are inappropriate for the assessment of classroom thermal environments⁴. The authors conclude that micro-level thermal comfort studies are needed to address these gaps. In addition, development of spatial and temporal thermal comfort metrics could support classroom design evaluations. Finally, to assess and design appropriate learning environments, children and young people's activity and clothing levels,

thermal background, body surface area-to-mass ratio, less developed body regulating systems, and higher heart rates and metabolic activity than adults should all be recognised (Xu et al., 2012).

1.4 INDOOR ENVIRONMENTS: HEAT, VENTILATION, STUDENT LEARNING AND WELL-BEING

A variety of factors are related to student learning, including socioeconomic status (SES) variables such as education of parents, family income, ethnicity (Sirin, 2005); teacher qualifications (Rivkin et al., 2005; Nye et al., 2000; Sanders and Rivers, 1996); classroom composition, peer relations, and personal qualities including intelligence, academic inclination, and motivation (Haverinen-Shaughnessy et al., 2011). Prominent environmental conditions that can negatively affect student learning include noise, temperature, air quality, ventilation and lighting (e.g. McNamara and Waugh, 1993; Keep, 2002; Earthman, 2004; Higgins et al., 2005).

The Better Placed Design Guide for Schools issued by the NSW Government Architect's Office (2018a) acknowledges that "air quality, natural lighting, thermal comfort and acoustic performance have been shown to have a profound impact on teacher wellbeing and student attentiveness, attendance and overall performance" (p. 9). However, in reality low school energy inefficiencies, high temperatures and low air supply rates in classrooms are common (Zomorodian et al., 2016).

A literature review conducted by Fisk (2017) investigated the evidence for claims that increased classroom ventilation rates improve student performance, reduce negative respiratory health effects and reduce student absence rates. The paper represents the first comprehensive review of a) ventilation rates and CO₂ concentrations in schools, b) their associations with health and performance

⁴ See Rupp et al. (2015) for a detailed review of papers assessing these standards and their shortcomings. .

of occupants, and c) their effects on energy consumption. It revealed that ventilation rates in American classrooms often fall short of the minimum ventilation rates specified in standards. Fisk found strong evidence that increased ventilation rates (a few percent to as much as 15 percent) improved student performance.

A study in the United States identified a strong linear relationship between classroom ventilation rates and students' academic achievement (Haverinen-Shaughnessy et al., 2011). Of the 100 classrooms studied, 87 had ventilation rates below recommended guidelines based on *ASHRAE Standard 62* (2004). Their study found that for every unit ($1 \text{ L s}^{-1} \text{ person}^{-1}$) increase in the ventilation rate, the proportion of students passing standardised test (i.e., scoring satisfactory or above) increased by 2.9 % for math and 2.7 % for reading. A follow up study that tracked indoor temperature (T), relative humidity (rH), and carbon dioxide (CO_2) in 70 elementary schools in the southwestern United States found a statistically significant association between ventilation rates and mathematics scores (Haverinen-Shaughnessy and Shaughnessy 2015). This study also indicated that mean mathematics scores increased 12-13 points per each 1°C decrease in temperature within a $20\text{--}25^\circ\text{C}$ range. Effects of similar magnitude but greater variability were found on reading and science scores. The study concluded that maintaining adequate ventilation and thermal comfort in classrooms could significantly improve academic achievement of students.

Mendell et al. (2013) investigated the relationship between ventilation rates and illness absence in 28 schools in three California school districts. All schools had median ventilation rates of $4 \text{ L s}^{-1} \text{ person}^{-1}$ (below the $7.1 \text{ L s}^{-1} \text{ person}^{-1}$ California standard). Their

findings suggest that increasing classroom ventilation rates to the state standard could decrease illness absence by 3.4 %.

The negative relationship between hot classrooms and learning outcomes has recently been demonstrated in a comprehensive study from the US (Goodman et al., 2018). Also, de Dear et al. (2015) note that some studies indicate that warmer temperatures (above 24°C) can negatively affect academic performance. However, given the adaptability of people to their environments, study results may be dependent on the climatic zones in which the research was conducted – and comparable research in Australian classrooms is needed. Further, there is little information on whether children perform better in air conditioned or naturally ventilated environments, and existing findings are inconsistent (de Dear et al., 2015).

In summary, research has demonstrated the negative effects of poor ventilation and high indoor temperatures on student learning, academic performance, and health. However, there is little information on whether children perform better in air conditioned or naturally ventilated environments. Most indoor studies do not account for the range of adaptive responses available and accessed by teachers and students to modify their environments.

1.5 APPROACHES TO THERMAL COMFORT IN OUTDOOR ENVIRONMENTS

Outdoor environments present more dynamic conditions and are subject to wider microclimatic variations than indoor environments (Nikolopoulou, 2011; Nikolopoulou et al., 2018). Meteorological factors such as solar radiation, humidity, and wind direction and speed are moderated by the specific character of any given environment to produce highly localized and dynamic

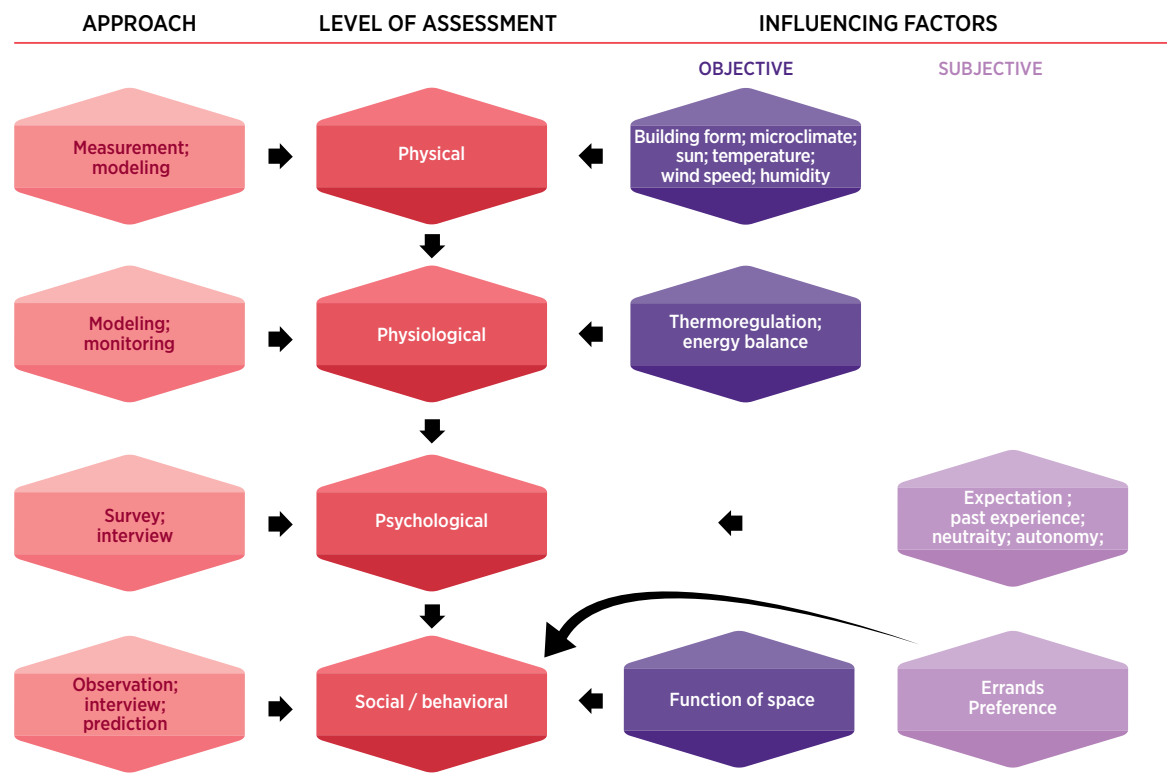
thermal conditions (Rupp et al., 2015). These effects on human thermal comfort are further complicated by individual characteristics such as age, gender, and clothing (Chen and Ng, 2012).

People's sensation of thermal comfort is perceived differently outdoors than indoors, being influenced by the local microclimate (Chen and Ng, 2012) as well as psychological expectations: in summer, people expect and are relatively more prepared for warmer weather, and situational factors: one study showed that when on holiday, people's tolerance for warmer thermal conditions was shown to increase (Potter and de Dear, 2000). Other psychological factors include naturalness, past experience, perceived control, time of exposure, and environmental stimulation (Nikolopoulou and Steemers, 2003). Adaptive behaviours in outdoor spaces include removing or adding clothing, as well as decisions to leave an environment to restore thermal comfort (Chen and Ng, 2012)⁵. Chen and Ng (2012) have proposed a general framework for assessing outdoor thermal comfort based on behavioural aspects (Fig. 3).

However, when considering children, particularly younger children, psychological assessment factors may need to be modified or entirely reassessed. Children's high degree of sensitivity to ambient climate conditions, their relatively less-developed capacity to perceive and communicate discomfort or its cause, and their high degree of dependence on adults make their needs unique and vulnerability significant (Vanos, 2015; Vanos et al., 2016).

⁵ For a comprehensive review of recent research on outdoor thermal comfort and outdoor activities in urban environments see Chen and Ng (2012).

Figure 3: A framework for outdoor thermal comfort assessment. Source: Chen and Ng (2012).



1.5.1 OUTDOOR THERMAL COMFORT INDICES

As previously noted, there are over 150 human thermal indices, along with a variety of classification schemes (de Freitas and Grigorieva, 2015). Although some indices are clearly designed for specific environments (i.e. indoor or outdoor), some approaches overlap and are combined with others related to human parameters such as clothing or physiological characteristics, making for a large suite of possible assessment options. Given the scope of this report, it has not been possible to comprehensively review the literature on outdoor indices and their potential suitability for assessing student thermal comfort. However, we make some general observations

on outdoor indices and summarise key points relevant to children’s outdoor thermal comfort.

A number of outdoor indices are based on Fanger’s heat-balance model of the human body, which was developed in climate-regulated indoor environments. These have been classified in the literature as “rational” (Epstein and Moran, 2006) or energy-balance “strain” or “stress” indices (de Freitas and Grigorieva, 2015). However, there are several problems with using heat-balance models in outdoor environments. They do not consider the dynamic, non-steady-state nature of outdoor environments, which become even more complex during physical activity due to the resulting variation in human-environment heat exchanges; although there are a number

of well-validated indoor thermal comfort models, these are based on sedentary activity and not appropriate for activity levels outside (Vanos et al., 2017). Moreover, heat-balance models do not adequately account for human adaptive responses; and indicators – such as skin temperature – are impractical to monitor on active children in outdoor environments. Finally, a number of these indices require biometeorological and physiological knowledge, making them somewhat inaccessible to non-specialists (Chen and Ng, 2012). Given these limitations, some researchers consider thermal comfort models based on indoor environments and standards unsuitable by for use in outdoor environments⁶ (e.g. Potter and de Dear, 2000; Höpfe, 2002; Vanos et al., 2017).

⁶ However, refer to Jendritsky et al. (2012) for an overview of how indoor heat-balance models have been revised and adapted to outdoor environments, yet a fundamental standard for assessing the thermal environment remains elusive.

Another category of indices is identified as “empirical” (Epstein and Moran, 2006), or “proxy” indices (Freitas and Grigorieva, 2015). Such indices are based on observed reactions of the human body to thermal stress and subjective perceptions of strain (e.g. physiological strain index (PSI); physiological subjective temperature (PST) index; corrected effective temperature (CET) index). PSI, PST, and related indices were developed from the man-environment heat exchange (MENEX) model, which considers heat exchange between the human body and its environment (Jendritzky et al., 2012; Fig. 4).

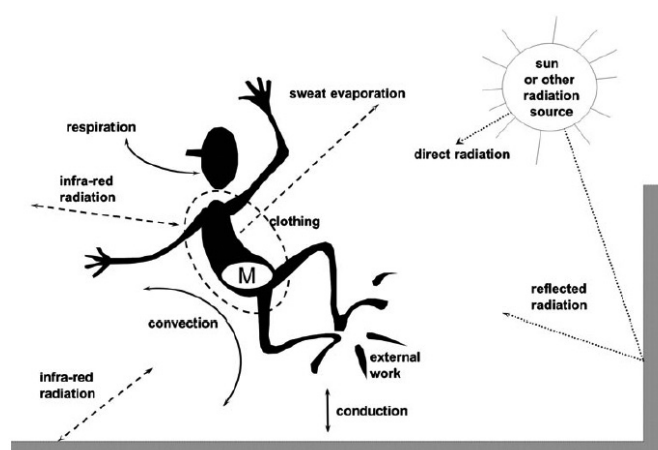


Figure 4: The Human Heat Budget. Physiological models such as this example are based on adult physiological characteristics, and do not consider important physiological differences of children. Source: Jendritzky et al. (2012).

Other kinds of indices use simulation devices for integrated measurement (e.g. wet globe temperature; kata thermometer), single parameter measurements (e.g. dewpoint temperatures, wet-bulb temperature) or are based on algebraic or statistical models (e.g. Humidex, wet-bulb globe temperature (WBGT)⁷, discomfort index (DI)); reviewed by de Freitas and Grigorieva, (2015). These have also been classified as “direct” indices (Epstein and Moran, 2006) and are based on generalized measurements of basic environmental variables (e.g. wind chill, cooling power) (Blazejczyk et al., 2012).

In response to the wide variation in outdoor thermal indices and their limitations, the European COST Action 730 (Cooperation in Science and Technical Development) brought together an interdisciplinary team of researchers from 19 European countries plus experts from Australia, Canada, Israel, and New Zealand to develop the Universal Thermal Climate Index (UTCI) (McGregor, 2012; Jendritzky et al., 2012; Havenith et al., 2011). The

UTCI is universal in its utility and application, considering the range of heat exchange, whole body calculations as well as localized measurements, and is valid in all climates and seasons (McGregor, 2012). For detailed descriptions of the UTCI see Jendritzky et al. 2012, also visit <http://www.utci.org>. However, Lam et al. (2016) point out that most outdoor thermal comfort studies have been conducted under non-extreme conditions and very few during heatwaves. In addition, Vanos et al. (2017) note that as comprehensive as the UTCI and other indices may be, they were tested and created for adults - assuming “an average man” as their human subject. Existing indices therefore overlook important factors necessary to properly assess children’s heat stress and comfort, especially under heatwave conditions.

1.6 STUDENT THERMAL COMFORT IN OUTDOOR PLAY SPACES

Children’s outdoor play spaces (OPS) – whether in childcare play spaces, urban schools, or parks – can be considered urban micro-climates. Given the effectiveness of the UTCI in representing the temporal variability of microclimatic thermal conditions, this may be a useful assessment tool for OPS, once parameters are modified to apply to children.

We found only a single study that evaluated thermal comfort of children during activity in school playgrounds. This study assessed the performance of an outdoor human heat balance model (COMFA energy budget model) on children playing outdoors, using both physiological parameters (heart rate monitoring) and subjective reporting of thermal comfort (actual thermal sensation (ATS) (Vanos et al., 2017). The study was able to identify thermal comfort and heat stress responses of children. The science-based approach of the study could be extended to a range of thermal environments and larger

⁷ The WBGT is the most widely used index worldwide. It emerged from the “corrected effective temperature” (CET) index, which accounts for the effects of air temperature, humidity, and radiation on thermal comfort. The WBGT index has been widely adopted by many American health, safety, and military bodies, international organisations, and as ISO 7243. The equipment required to measure this index can be impractical to use, limiting its applicability across a broad range of environments and situations (Epstein and Moran, 2006) and it has been criticized as overly simplistic and ‘clunky’ (see Jendritzky et al., 2012)

student participation to generate a better understanding how outdoor play and well-being of children is impacted by heat.

Outdoor play spaces contain a number of surfaces that children come into physical contact with, including playground equipment, ground surfaces, and rest areas. It is thus necessary to study surface temperatures of objects and floor materials in these environments. Vanos et al. (2016) studied playgrounds in Arizona and found many of the surfaces too hot to be used by children (Fig. 5).

Many outdoor play spaces in schoolyards across Sydney and beyond contain artificial materials such as soft fall and Astroturf, which are favoured for their durability and low maintenance requirements. A study conducted in early learning centres in Western Sydney through the summer of 2017-18 measured surface temperatures of various materials in OPS (Fig. 6). Artificial materials (soft fall and Astroturf) reached mean temperatures of up to 89 °C when in full sun and well over 40°C in shade, clearly posing a significant risk to children's safety. Natural materials (grass, sand, and wood) had far cooler surface temperatures, with the lowest temperatures recorded for shaded natural and semi-natural materials (Blick, 2018; Table 4).

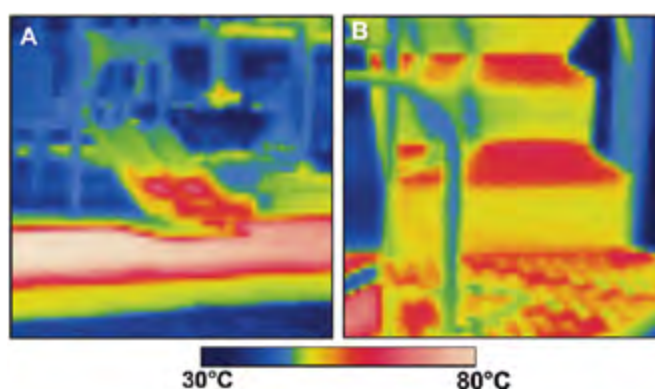


Figure 5: Surface temperature images of children's playgrounds in Arizona photographed with Infrared Thermography (IRT). (A) Slide and black/green rubber ground surface in sun (71°C on slide, 82°C on rubber), and under shade sail (blue/green); (B) playground steps in sun, black powder-coated metal (58°C). Source: Vanos et al., 2017.



Figure 6: Outdoor play spaces in three Western Sydney childcare centres. The images show a variety of synthetic (Astroturf and soft fall, a-c) and natural materials (grass, sand, b, d), as well as shade provided by trees and built structures (a-d). Source: Blick (2018).

Table 4: Mean temperatures (°C) of surface materials used in outdoor play spaces. Measurements of ambient air temperatures taken between 12pm and 2pm are indicated in parentheses to the right of the name of each centre. Parentheses next to average temperatures show 1 SD. Source: Blick (2018).

Surface category	Surface material	Centre A (33°)		Centre B (37°)		Centre C (35°)	
		Sunlit	Shaded	Sunlit	Shaded	Sunlit	Shaded
Natural	Grass	36.3 (3.1)	-	46.6 (10.8)	33.6 (1.6)	45.4 (3.3)	28.5 (0.9)
	Sand	41.7 (3.6)	25.3 (3.1)	-	31.8 (0.6)	-	-
Semi-natural	Wood	53.6 (2.7)	40.4 (0.9)	57.2 (1.6)	-	64.9 (1.5)	-
	Woodchips	68.2 (2.0)	-	64.7 (4.0)	32.7 (1.1)	74.4 (4.6)	-
	Brick, rock, cement	49.4 (2.4)	23.3 (1.3)	44.7 (2.2)	-	53.2 (4.5)	32.1 (1.6)
Artificial	Astroturf	56.4 (2.5)	47.3 (1.9)	89.6 (3.6)	43.1 (3.0)	60.2 (3.2)	-
	Softfall	72.2 (1.2)	33.3 (1.0)	74.8 (0.8)	35.0 (1.2)	82.8 (1.9)	40.0 (3.0)

Outdoor play spaces – as well as urban parks and playgrounds – are important spaces for urban sustainability, social connection, physical activity, and general community well-being (Boldemann et al., 2006; Vanos et al., 2016). Well-designed play spaces provide comfortable and safe areas for children to engage in activities for improved health and well-being (Vanos, 2015) and also contribute to microscale cooling, providing heat refuges in high seasonal temperatures. Conversely, improperly

designed, outdoor play spaces can contribute to micro urban heat island effects (see, for example, Moogk-Soulis, 2010), and become intolerably hot and unsafe for children. Given the dangerously high surface temperatures found in children's OPS, and anticipated climate warming scenarios, children may be increasingly denied access to outdoor play, spending more time indoors, where sedentary activities dominate.



1.7 EFFECTS OF HEAT STRESS ON STUDENT OUTDOOR LEARNING AND WELL-BEING

The cognitive, psychological, social and behavioural, and physiological benefits to children of outdoor activities are well-established in literature and practice (e.g. Buell et al., 1968; Wells, 2000; Clements, 2004; Kuo and Taylor, 2004; Burdette and Whittaker, 2005; Dymont and Bell, 2008; Louv, 2008; Dreissnack, 2009; Aarts et al., 2010; Dowdell et al., 2011). Wells (2000) highlighted that proximity to and engagement with nature enhances children's cognitive abilities, particularly executive function. Exposure to nature also increases children's attention spans, focus, creative thought processes, problem-solving skills, self-discipline and self-regulation (Wells, 2000; Burdette and Whitaker, 2005). Kuo and Taylor (2004) and Louv (2008) report marked decreases in children's symptoms of attention-deficit/hyperactivity disorder, where the "greener" the natural setting, the greater the reduction in symptoms. Direct exposure to nature is essential to children's overall physical and emotional health, combating obesity, countering mental health problems, including depression, and improving social skills (Louv, 2008; Dreissnack, 2009). Malone's (2008) review of learning outside the classroom drew on research from around the world, showing that explorative play and experiential learning activities in a variety of outdoor "green" environments result in higher test scores, improved motor skill development and physical fitness, encourage confidence and self-esteem, and foster leadership qualities, social competence, and a sense of environmental responsibility.

Despite the clear cognitive, social, and health benefits to children, studies in the US show an alarming reduction in both direct contact with nature and unstructured outdoor play since the mid 1990s (Burdette and Whitaker, 2005). Children's busy and highly structured schedules, and increasing "screen time" leave them little opportunity to "go outside and play" (Clements, 2004). Schools concerned about

managing "risk" due to potential litigation threats can further limit outdoor activities. By adding predicted hotter temperatures and increased frequency of very hot conditions means that curricular and personal learning activities of children may be increasingly confined to the classroom. Such a development will limit the opportunities for young people to develop the skills they need to be safe and the resilience to manage complex environments (Malone, 2008)

In summary, "green" outdoor environments provide significant opportunities and benefits to children's development – both through formally structured activities and informal play. Further, trends in environmental education are blurring historically-established boundaries between learning indoors and playing outdoors, taking children into school kitchen gardens, and to local bush areas and waterways for environmental education (NSW DoE, 2018c). However, student outdoor thermal comfort and heat stress is poorly understood in Australian contexts.

The study of outdoor play spaces in three early learning centres across Western Sydney (Blick, 2018) and research in California school outdoor spaces (Vanos et al., 2017), combined with a growing understanding of micro-urban heat island effects suggests that school OPS – as well as children's playgrounds and urban parks – are in urgent need of retrofitting to facilitate cooling benefits and provide safe, comfortable spaces for children's activities. Children's immediate safety is the most obvious concern; in high summer temperatures and extreme heat events, parents are instructing teachers to keep their children inside. These factors may indicate a worrying trend towards more time spent indoors, negatively impacting children's physical activity levels and time spent in proximity to nature or engaging in environmental education.

2 SUSTAINABILITY AND ENVIRONMENTAL EDUCATION

2. SUSTAINABILITY EDUCATION IN AUSTRALIAN SCHOOLS

Education for Sustainability (EfS) is an internationally-recognised framework that includes sustainable development practices and approaches, environmental education and nature education (AAEE NSW, 2018b), the natural and built environments, social, economic and governance considerations, as well as individual responsibility and resilience. EfS is a mandatory requirement under the National Quality Standards for early childhood teachers.⁸ It also refers to the process of integrating sustainability education into the Australian school curriculum. Sustainability is an Australian Curriculum cross-curriculum priority that is built on three key concepts: understanding the planet as a set of complex and interdependent life support systems; connecting diverse worldviews on global sustainability issues to individual and community actions; and building the capacities for thinking, acting, and reflecting to create more equitable, respectful, and sustainable futures (ACARA, 2016).

Incorporating sustainability principles into school curricula is a matter for individual states and territories. Sustainability and other cross-curriculum priorities are designed to be incorporated into existing curricula, addressed through specific learning areas, and aim to stimulate conversations between teachers, students, and the wider community (ACARA, 2016). In many cases, the impetus for sustainability projects is based on individual teacher initiatives. For example, the *Getting Started with Sustainability in Schools* guide, provided by the Australian Education for Sustainability Alliance (AESA) aims at empowering teachers to develop sustainability education through the EfS framework.

Sustainability initiatives across schools in Australia focus on four key themes (Education for Sustainability, 2012; ACT Government, 2015):

- a) Operations:** examples include reducing energy consumption and waste through resource recovery / diversion programs (recycling and composting), reducing food waste and water consumption.
- b) Grounds:** examples include improving grounds and developing curriculum by installing school gardens, chickens, and composting programs.
- c) Curriculum and Events:** examples include biodiversity modules, outdoor education, renewable energy, interactive nature walks, waste and biodiversity audits.
- d) Community Engagement:** examples include Student Action Groups, community clean up and stewardship projects, active transportation campaigns.

2.2 SUSTAINABILITY AND ENVIRONMENTAL EDUCATION IN NSW

Australian Association for Environmental Education (AAEE), NSW Chapter

AAEE NSW is a State Chapter of the Australian Association for Environmental Education, the national peak professional association for environmental educators in Australia since 1976. The AAEE NSW offers support to environmental and sustainability educators across the state through advocacy for best practice programs, research, capacity building, policy recommendations. It helps building collaborative networks and learning from the traditional custodians of Country. They offer grants, awards, scholarships, and a biennial state conference (AAEE NSW, 2018a), and regular newsletters including current research. Their March 2018 newsletter featured a Climate Council report authored by Will Steffen and

Martin Rice: [2017: Another record-breaking year for heat and extreme weather](#).

For the past 20 years, the AAEE NSW has been involved in Learning for Sustainability Plans, NSW school curriculum policy development, and continues to provide submissions and recommendations on sustainability issues and directions for a sustainable future. The AAEE's most recent Strategic Plan (2018 – 2021) affirms its support for EfS in three key areas: 1) advocating and supporting education and engagement for sustainable living, environmental protection and enhancement; 2) professional development for members and others in the sector; and 3) building local networks to facilitate collaboration and skill sharing (AAEE, 2018b). In December 2017, AAEE NSW was awarded funding from the NSW Environmental Trust (Environmental Education grants program) to deliver the *Best practice sustainability education and engagement for NSW* project. The Take Me Outside component (modelled on Canada's highly successful program of the same name) aims to engage 100 school and/or community groups in activities to improve the natural places they have adopted (AAEE NSW, 2018c).

Sustainable Schools NSW

Sustainable Schools NSW is a curriculum focused resource hub for environmental education, managed by the AAEE NSW. It is a state network for educators, and provides teaching resources, project ideas, links to funding opportunities, and strategies for student engagement with nature. Teachers are encouraged to draw on a suite of resources to explore sustainability themes and identify areas of improvement – first in their classrooms, and then by extending it to the school and the community. This scaling-up approach relies on the ability of teachers to propose a solid "business case" to the school principal,

⁸ see <http://www.acecqa.gov.au/physical-environment>, particularly standard 3.3 'Education for Sustainability'.

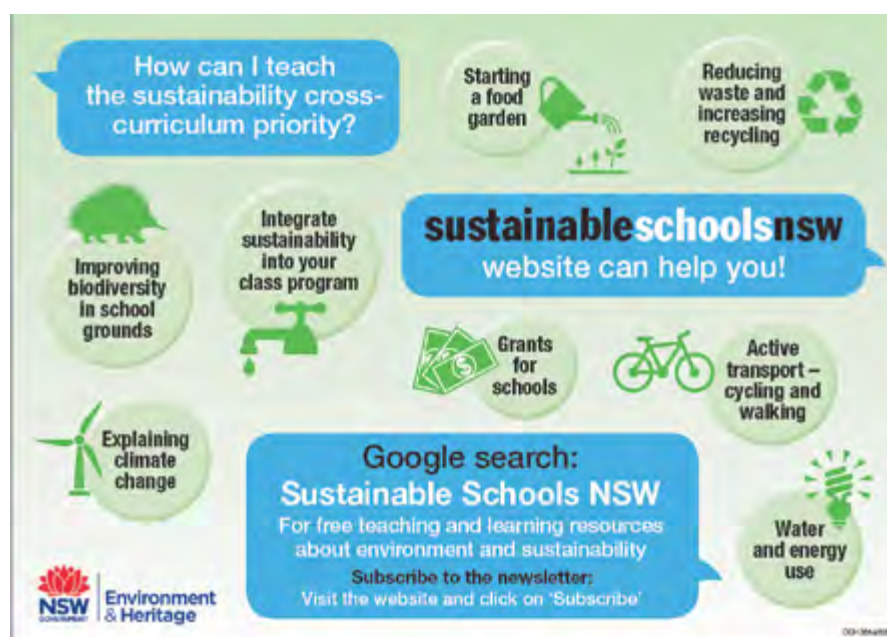
after mapping "stakeholders" in the school community and extensive engagement with "influencer groups" (Getting Started with Sustainability in Schools, 2016).

NSW Department of Education (DoE) Resources

The NSW Department of Education's Environmental Education Policy offers guidelines for schools to manage their resources in an ecologically sustainable manner, as a starting point for addressing global environmental issues (NSW DoE, 2018c). As noted, sustainability is a cross-curriculum priority and is intended to be integrated through all key learning areas. The DoE website provides links to teaching and learning resources, listing sustainability topics, and links to support teachers in developing learning activities for assessment and action. The site also provides links to current research about benefits of outdoor and environmental education.⁹ In addition, the DoE has 25 Environmental and Zoo education centres across the state.

The NSW DoE's Sustainability Action Process webpage provides a framework for teachers and students to investigate real world issues and needs by encouraging active student participation. The Action Process outlines five steps: Make the Case; Explore; Plan; Take Action; and Reflect, and offers links to learning resources on topics including energy use and efficiency, biodiversity, and thermal comfort for different age ranges (NSW Department of Education, 2018d). Notably, also the NSW Office of Environment and Heritage is actively involved in sustainability education at schools (Fig. 7) and has recently released a comprehensive report on its activities (NSW OEH, 2017).

Figure 7: Sustainable Schools NSW Flyer. The document showcases different themes and opportunities for sustainability education. Source: <https://www.sustainableschoolsnsw.org.au>



Guides and resources like those provided by the NSW DoE, AESA, AAEE NSW, and Education for Sustainability allow a high degree of flexibility in how environmental education is designed, planned, and delivered. This approach encourages ground-up innovation and context-appropriate projects and activities, and has resulted in thousands of sustainability-related activities, initiatives, and projects in schools across the country. Many of these initiatives invite reflection on and learning about aspects of the school environment and encourage action to improve their environmental and economic sustainability. However, by placing responsibility for driving sustainability initiatives on teachers, this approach may also limit the scope of interventions, as teachers do not have the knowledge or capacity to significantly alter the built environment or develop improved school policies.

NSW DoE's Sustainability Action Process webpage defines thermal comfort (via a link to a Wikipedia page) according to Fanger's heat balance model of the human body, which is aligned with existing indoor thermal comfort design policies and standards (NSW Department of Education, 2018d). However, as noted earlier, these standards (and therefore the curriculum learning guides) are based on sedentary adults working in office environments or refer to thermal comfort in homes. There is a clear need to identify and address gaps in knowledge, and integrate research findings at national, state, and municipal levels, and within school district jurisdictions, that are flexible enough to address specific actions and needs to increase sustainable operations of individual schools.

⁹ See, for example: *Every experience matters - an evidence-based research report on the role of learning outside the classroom for children's whole development from birth to eighteen years* by Dr Karen Malone; *Health benefits of contact with nature* by Planet Ark; *Stephanie Alexander kitchen garden national program evaluation - final report* by the University of Wollongong reports on the impacts of the food education program. All retrieved from <https://education.nsw.gov.au/teaching-and-learning/curriculum/learning-across-the-curriculum/sustainability/research>. Accessed August 19, 2018.

PART 2.

INFRASTRUCTURE

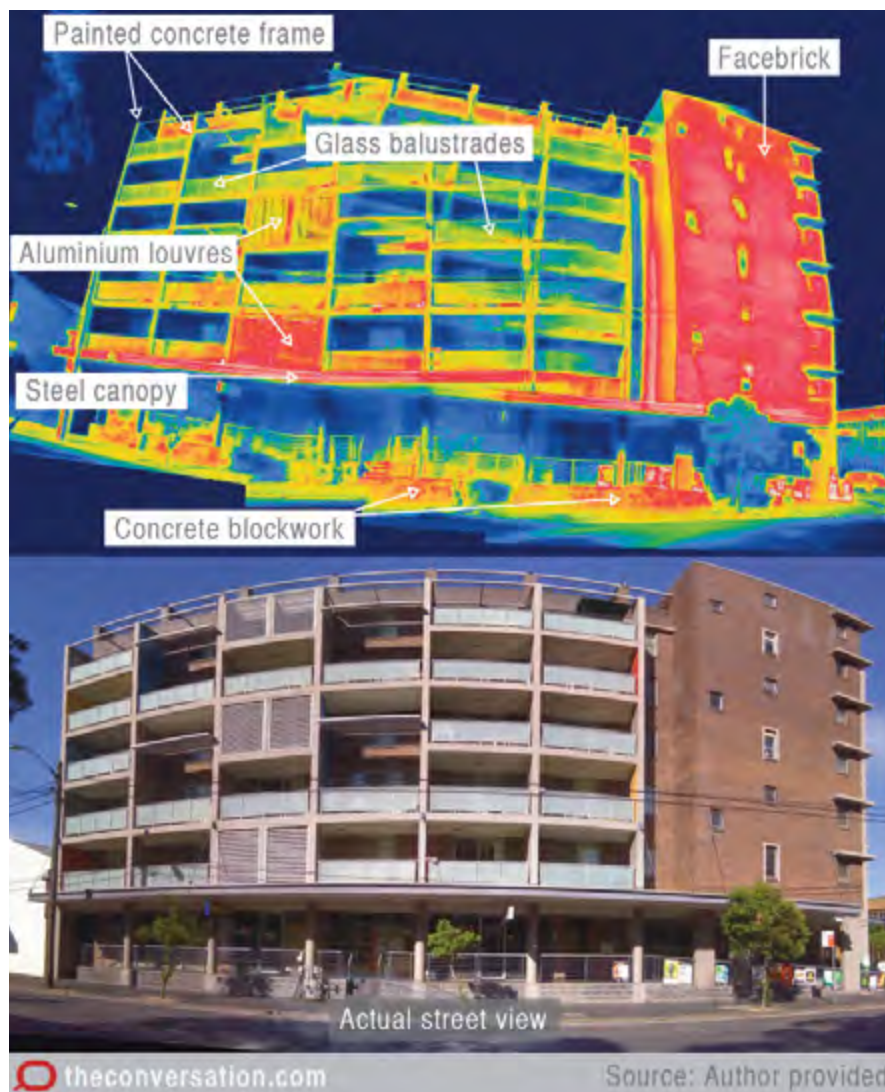


Figure 8: Thermal image showing surface temperatures of different building materials. Red = hottest > blue = coolest. Source: <https://theconversation.com/building-cool-cities-for-a-hot-future-57489>.

3 PLANNING AND CONSTRUCTION OF SCHOOLS IN NEW SOUTH WALES: LEGISLATION AND POLICY

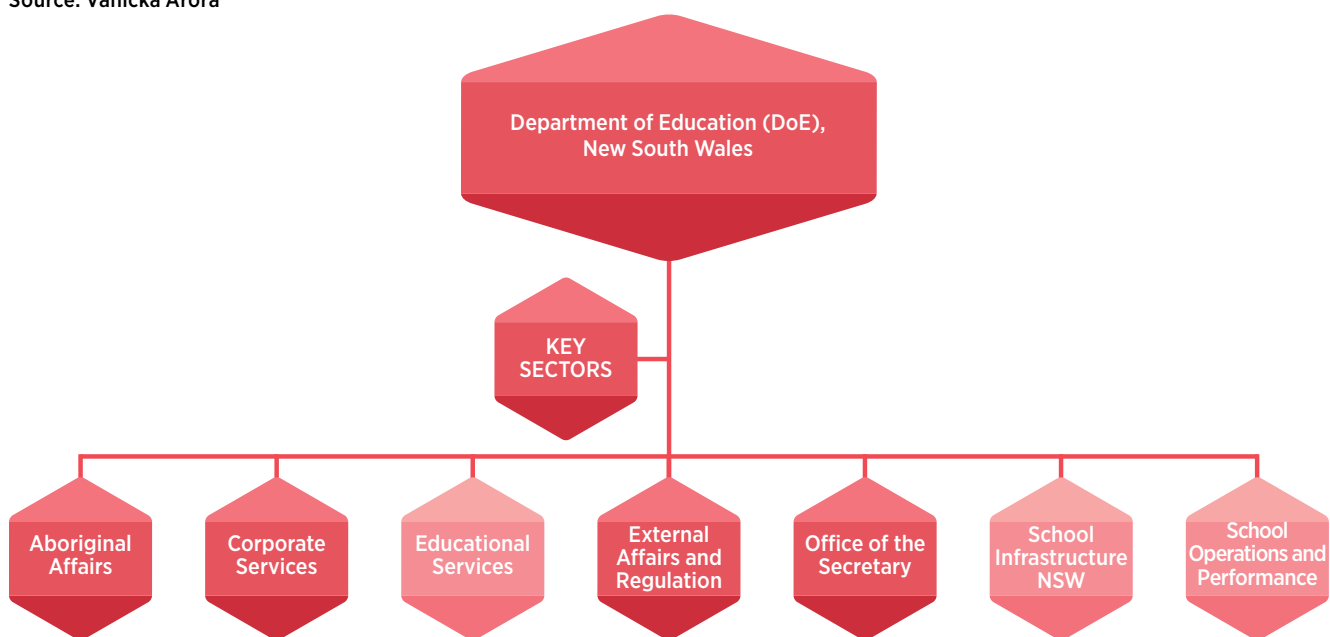
The designing and planning of physical infrastructure, built environment and open spaces within schools has a significant impact on ensuring thermal comfort and on reducing dependence on mechanical means of cooling. Various factors contribute to creating a thermally conducive interior (and exterior) environment within each school. This chapter explains the roles of different organisations, policies and standards that can influence thermal environments in and around schools in NSW.

The construction, relocation and upgrading of public schools in Australia is organised at different levels of Government (Fig. 9). In NSW these actions are commissioned and overseen by the School Infrastructure unit of the State Government, which operates under the NSW Department of Education (NSW DoE; Fig. 10). Private schools are also expected to comply with standards set out by the NSW DoE. Other aspects related to the operation, performance of schools and services provided by them are

also overseen the NSW DoE. Planning consent for schools is required at local council and state levels. *The National Construction Code (NCC) 2016*, is the minimum performance-based building code that all new buildings – including schools – must comply with.



Figure 9: Framework policy and legislation for schools in NSW.
Source: Vanicka Arora

Figure 10: Sectors or Units within the Department of Education.**Source: Vanicka Arora**

Other agencies and stakeholders include Urban Growth NSW, Landcom, and the Hunter Development Corporation (together previously known as the Land Commission of New South Wales) are corporations owned by the state government and are involved in complex urban development projects on government land. They are allocated school redevelopment work or assist when schools are integrated in the larger urban design developments. They also interact with schools through workshops and site visit programs.¹⁰

3.1 NSW DEPARTMENT OF EDUCATION¹¹

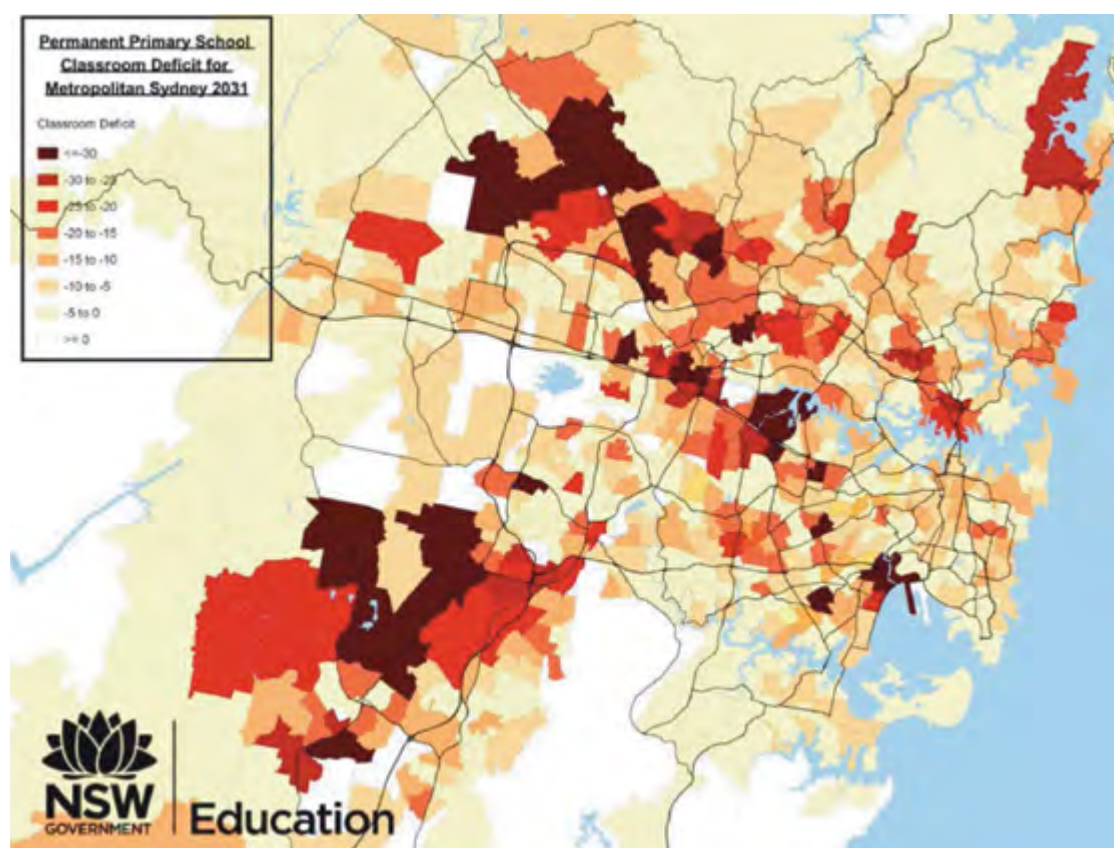
The NSW DoE operates under the Education Act of 1990 (New South Wales Consolidated Acts). The current NSW DoE Strategic Plan (2018-2022) anticipates a significant increase in new and upgraded classrooms. This requirement for school infrastructure as the consequence of a rapidly growing population and the resulting need to provide adequate education facilities for children. It is estimated that an additional 2000 new classrooms will need to be built across the state of NSW to accommodate an additional 164,000

students over the next 15. The majority (80%) of expected increases in school enrolment numbers will take place in the Greater Sydney Region. At present, large classroom deficits have been identified in this region that clearly overlap with centres of rapid urban development in the north-west and south of the Sydney Basin (Fig. 11).

¹⁰ For further details, please see <http://www.urbangrowth.nsw.gov.au/>. For an overview of NSW DoE see <https://education.nsw.gov.au/>. For specific details as well as updates on school infrastructure including ongoing projects see <https://www.schoolinfrastructure.nsw.gov.au/>.

¹¹ For an overview of NSW DoE see <https://education.nsw.gov.au/>. For specific details as well as updates on school infrastructure including ongoing projects see <https://www.schoolinfrastructure.nsw.gov.au/>

Figure 11: Forecast permanent primary classroom deficit at 2031. Source: NSW DoE 2016, cited in New South Wales Auditor-General's Report. Source: <https://www.audit.nsw.gov.au/publications/latest-reports/planning-for-school-infrastructure>



The NSW Government's 2018/19 Budget includes an allocation of over \$6 billion over four years to deliver more than 170 new and upgraded schools. This includes an additional \$747 million spending announced for the maintenance and funding for over 2200 existing schools. In the middle of 2018, 18 new schools were in the 'Design Stage', while 7 were in the 'Planning Stage' and 9 were in the process of tendering and construction (14 schools have recently been completed). In addition, 24 upgrades were being planned, 72 upgrades had been designed, and 38 were in progress (46 schools have recently been upgraded).

The School Infrastructure Division announced an investment of \$500 million in July 2018 into a 'sustainable air conditioning programme for schools across the state that were facing mean maximum temperatures in January of 30°C and above, over the next four years (Details in Section 5 of this document). For more information on the Cooler Classrooms Program visit: <https://www.schoolinfrastructure.nsw.gov.au/news/2018/07/cooler-classrooms-program.html>

3.2 THE EDUCATION FACILITIES STANDARDS AND GUIDELINES (EFSG)¹²

The EFSG is a set of supporting guidelines, standards and specifications issued by NSW DoE. These guidelines do not apply to schools that have been constructed prior to the creation of the guidelines. Levels of compliance vary within the guidelines and both the design and specification guides exceed some of the minimum standards set out by the National Construction Code Australia and Australian Standards.

The EFSG is meant to support school administrations, designers and contractors with information, design templates and specifications for individual aspects of school infrastructure, which include design and layout of the buildings and interiors, building materials and technologies for construction, finishes for both exterior and interior spaces, all building services, doors, windows and other openings, fittings, site planning and so on. There is some emphasis on developing environmentally sustainable systems in schools, provided through Education Principle 4 of the department.

This EFSG initiative was commissioned in 2013 with the objective of being updated on a regular basis using real-time experience and continued refinement of 'best practice'. With reference to cooling, the EFSG has two dedicated design guidelines, *DG55 Cooling Policy*¹³ and *DG06 Cooling/Heating Policy*¹⁴ and two guidelines, *DG57 Ventilation*¹⁵ and *DG90 Landscape Design*¹⁶, that indirectly relate to cooling. These are briefly reviewed.

The NSW DoE Educational Facilities will:

Education Principle 1: First and foremost, focus on the needs of learners and learning.

Education Principle 2: Build community and identity and create a culture of welcome, inclusion and belonging that reflects and respects diversity within the school's community.

Education Principle 3: Be aesthetically pleasing.

Education Principle 4: Provide contemporary, sustainable learning environments that:

- Promote learning for students and teachers through collaboration, social interaction and active investigation.
- Encourage learner self-management and self-direction.
- Support a full range of teaching strategies from direct explicit instruction to facilitation of inquiry and authentic project and problem-based learning.
- Facilitate learning and connection anywhere, anytime by providing seamless access to ICT and integration of learning resources throughout the learning spaces.
- Be integrated into, and maximise the use of the natural environment.
- Enable aspects of the buildings, building design and outdoor spaces to be learning tools in themselves—for example, learning from the ecologically sustainable features of the design and associated energy management systems.
- Are age and stage appropriate?

Education Principle 5: Embed the potential for re-configurability, both in the present for multi-purpose use and over time for changing needs.

DG55 Cooling Policy

The air-cooling policy indicates a mandatory compliance level and also sets out air cooling requirements in all new school buildings that are located between the 30 °C and 33 °C mean maximum January isotherms (Fig. 12). In existing schools, the hottest permanent classrooms will be addressed on a priority basis. This policy addresses air cooling in general, which includes evaporative cooling, heat reclaim systems, and reverse air conditioning. It does not specifically address air conditioning, yet it states that air-conditioned classrooms should ideally be 24 °C in summer and 21 °C in winter. There is emphasis on passive cooling strategies within the policy, with exemptions for special areas such as computer rooms, performance spaces and so on (Fig. 13).

The more recently announced Cooler Classrooms Program is an addition to DG55 and suggests growing pressure from parent communities (Rickard, 2011; Singhal, 2018) to focus on air conditioning in existing classrooms. It must be noted that ceiling-mounted fans for cooling are mandatory in NSW classrooms. Specific design guides are available in DG55 that explain how fans should be installed.

Figure 12: Identification of zones in NSW based on mean maximum January isotherms.

Source: efsg.det.nsw.edu.au



Figure 13: Resources available for reference on the EFSG website related to DG55 Cooling Policy. Source: efsg.det.nsw.edu.au

Overview

Whole of Life

Ecologically Sustainable Development

Design

Fabric

Openings

Finishes

Services

DG51 Hydraulics Generally

DG52 Drainage (& Trade Waste)

DG53 Water

DG54 Gas

DG55 Cooling Policy

DG56 Heating

DG57 Ventilation

DG61 Electrical Services

DG62 Power

DG63 Lighting

DG64 Communications

DG65 Special Electrical Systems

DG66 Photovoltaic Solar Power Generator

Fittings

Site

Colour Schemes

DG55 Cooling Policy

Ecologically Sustainable Development - 14/08/2018 | 12:12

Whole of document update of DG02 Ecological Sustainable Development to align with NSW Government Resource Efficiency Policy and departmental priorities, and removal of repetitive wording which is already present in other sections of EFSG.

Ecologically Sustainable Development - 14/08/2018 | 12:12

Corrected spelling mistake in title of section 4

Ecologically Sustainable Development - 14/08/2018 | 12:05

Whole of document update of DG02 Ecological Sustainable Development to align with NSW Government Resource Efficiency Policy and departmental priorities, and removal of repetitive wording which is already present in other sections of EFSG.

My favourites

Ungrouped

EDIT FAVOURITES

Related Resources

Australian Standards

National Construction Code (NCC)

ID	TITLE	COMPLIANCE LEVEL ①	
EXPAND ALL			
55.01	AIR-COOLING POLICY	<div><div></div><div></div><div></div></div>	MANDATORY
55.02	SCOPE	<div><div></div><div></div><div></div></div>	MANDATORY
55.03	LEGIONNAIRES' DISEASE HAZARDS	<div><div></div><div></div><div></div></div>	MANDATORY
55.04	DOCUMENTATION	<div><div></div><div></div><div></div></div>	MANDATORY
55.05	DESIGN APPROACH	<div><div></div><div></div><div></div></div>	MANDATORY
55.06	CEILING/WALL FANS	<div><div></div><div></div><div></div></div>	MANDATORY
55.07	EVAPORATIVE COOLING SYSTEM	<div><div></div><div></div><div></div></div>	MANDATORY
55.08	AIR CONDITIONING SYSTEMS	<div><div></div><div></div><div></div></div>	MANDATORY
55.09	CONTROLS	<div><div></div><div></div><div></div></div>	MANDATORY
55.10		<div><div></div><div></div><div></div></div>	

<https://efsg.det.nsw.edu.au/design/services/dg55coolingpolicy>

DG06 Cooling/Heating Policy

The DG06 guideline addresses infrastructure design with a focus on reducing energy consumption and greenhouse gas emissions. Recommendations include broad strategies for orientation, shading, glazing and insulation. Each of these passive design strategies will also be discussed in more detail in the next section. Active air-cooling systems are not encouraged by this policy except in the areas which are covered under the DoE's Air Cooling guidelines (discussed above).

DG57 Ventilation

The ventilation policy reiterates compliance to the National Construction Code (NCC) as well as Australian Standards AS1668 Parts 1 and 2 which deal with mechanical ventilation, ventilation rates, etc. and suggest passive sustainable design strategies should be prioritised wherever possible.

DG90 Landscape Design

The Landscape Design Policy addresses climate control mechanisms such as shading of building facades, wind break planting, external shading devices and describes the social and learning benefits of sensitively designed landscape areas within school premises. With regards to shading, it recommends a combination of outdoor structures (e.g. awnings) and trees for shading as strategies.

3.3 NSW PLANNING AND ENVIRONMENT DEPARTMENT¹⁷

The NSW Planning and Environment Department (NSW PED) owns the State Environmental Planning Policy (SEPP). The design quality principles in the SEPP aim to ensure that the design of school infrastructure responds appropriately to the character of the area, landscape setting and surrounding built form to ensure that schools and school buildings are an integral part of the community. *The Better Placed Design Guide for Schools* issued by the office of the NSW Government Architect (2018a)¹⁸ includes recommendations to 'respond to the natural environment' and 'respond to sun, wind and aspect'. The design guide also endorses to minimise the dependence on mechanical systems and increase the use of passive systems to reduce the overall ecological footprint of schools. It also describes the frameworks through which these guidelines may be implemented, including aspects of 'participatory pedagogy', 'collaborative brief' development and 'post occupancy evaluations'.

The SEPP for Educational Facilities was reviewed in 2017. The NSW Government Architect's Office supported this review with a Design Guide and Best Practice Manual.¹⁹ The school design policy principles, which include codes on context, built form and landscape and principles on sustainability, efficiency and durability offers the possibility to dovetail research into policy and guidelines set out by the NSW PED. However, there is no clear focus or emphasis on passive cooling within

the guidelines. However, these principles are implied in a range of contexts within the overall mandate of the Government Architect's Office. In the absence of specific recommendations, such as building materials, technologies palette, or best practice examples of schools that achieve the goals set out by the Guide, it is difficult to gauge how individual architects may interpret this document and put it in practice effectively. Also, this document does not link with the existing EFSG, which has far more detailed standards for school design, so its value in terms of design guidance towards cooler school environments is limited.

3.4 NATIONAL CONSTRUCTION CODE OF AUSTRALIA²⁰

The Australian Building Codes Board (ABCB) is a Council of the Australian Government (COAG) standards writing body that is responsible for the development of the National Construction Code (NCC), comprised of the Building Codes Australia (BCA) and the Plumbing Codes Australia (PCA). The NCC is a performance-based code containing all performance requirements for the construction of buildings, which includes 'deemed to satisfy' solutions that meet performance requirements of different classes of buildings.

Public buildings are classified as Class 9 Buildings, which include schools. It excludes residential sections and other sections of school buildings that may be identified as different classes. Section E of the PCA addresses concerns of Heating, Ventilation and

Air Conditioning that are related with drainage and plumbing, while Section J of the BCA Volume 1 (For Building Types 2-9) addresses Energy Efficiency of Buildings.

All public buildings, including schools, need to comply with the minimum performance requirements specified within the NCC. Energy efficiency and Performance Based Codes are two specific focus areas outlined by the ABCB. The Energy Efficiency Project looks specifically at commercial and residential projects. The Business Plan developed by the ABCB for 2017/18, notes that specific research and policy initiatives will be drafted that focus on extreme weather events and natural hazards, along with policies that specifically address cooling in extreme temperatures (ABCB, 2018b).

Specification JV of this particular section provides details of criteria when calculating the annual energy consumption of services applicable for a Class 9b building, which includes theatres, cinemas and schools (see Fig. 14 as example for a Class 5 building). Thermal comfort is a by-product, not a mandate of the deemed to satisfy provisions. This means that even though the overall reduction of energy requirements is one of the agendas, it is not contingent on providing a thermal comfort standard internally.

¹⁷ <https://www.planning.nsw.gov.au/>

¹⁸ For details on the Better Placed Guidelines see <http://www.governmentarchitect.nsw.gov.au/guidance/design-guide-for-schools>.

For best practice examples published see <http://www.governmentarchitect.nsw.gov.au/resources/case-studies/2017/08/australia-street-infants-school>. <http://www.governmentarchitect.nsw.gov.au/guidance/design-guide-for-schools>. For best practice examples published see .

¹⁹ <http://www.governmentarchitect.nsw.gov.au/resources/case-studies/2017/08/australia-street-infants-school>.

²⁰ The amendments to the National Construction Code can be reviewed at <http://www.abcb.gov.au/ncc-online/NCC/2016-A1?vol=56a3b1a8-d528-471b-be8a-5527c2d7db47#56a3b1a8-d528-471b-be8a-5527c2d7db47>


Figure 14: A sample 'performance solution scenario' shared by the ACBC for reference on the performance design processes undertaken by building practitioners.
Source: <https://www.abcb.gov.au>.

DEVELOPMENT OF PERFORMANCE SOLUTIONS



ENERGY EFFICIENCY VERIFICATION METHOD

PBDS 1-003-C



The Performance Requirements of the National Construction Code (NCC) can be met using either a Performance Solution or a Deemed-to-Satisfy (DTS) Solution or a combination of both solutions. The following demonstrates the performance based design process that should be used in conjunction with the [Development of Performance Solutions Guidance document](#).

Scenario:

The energy efficiency of a Class 5 building design, proposed to be built in Melbourne, is being assessed. As the initial design has a level of thermal performance above what is prescribed in the DTS Provisions, it is proposed to take advantage of the higher efficiency by using more cost effective glazing that differs from the DTS Provisions. As the design differs from what is prescribed in the DTS Provisions, a Performance Solution will be used.



PREPARE A PERFORMANCE-BASED DESIGN BRIEF

What are the design objectives?

- To reduce costs to the client by using more cost effective glazing, whilst meeting the relevant Performance Requirements of the NCC.

Who should be consulted?

- Building designer, client, builder, environmentally sustainable design (ESD) consultant and the regulatory approval authority.
- This group formed the stakeholder group for this project.

What is the basis of the Performance Solution?

- Verification Method JV3 provides an alternative method to the DTS Provisions to meet the energy efficiency Performance Requirements.
- The acceptance criteria is design with a heating and cooling load less than the 'reference building' modelled using JV3.

What evidence is proposed?

- A written report explaining the approach used, the modifications made to the design, the heating and cooling energy use, as determined by the energy rating software simulations for both the 'reference building' and the proposed design.


Which DTS Provisions are applicable?

- The DTS Provisions of NCC Volume One Parts J1 to J7, specifically J2 Glazing.

Which Performance Requirement is applicable?

JP1 in NCC Volume One Section J - Energy Efficiency.

Note: for brevity, the applicable Performance Requirements have been limited. This solution may also impact other Performance Requirements and must be considered in accordance with A0.7.



The information in this document is intended to be used as guidance material only, and is in no way a substitute for the NCC and related State and Territory legislation. The information in this publication is provided on the basis that all persons accessing the information undertake responsibility for assessing the relevance and accuracy of the information to their particular circumstances.

© 2018 Commonwealth of Australia and States and Territories of Australia

4 STANDARDS AND CERTIFICATIONS FOR SUSTAINABLE BUILDING PLANNING AND DESIGN

SECTION HIGHLIGHTS

- Standards for the design of built environment focus primarily on energy consumption and how to achieve increasing efficiency of power consumption by reducing loads on mechanical systems as well as reducing greenhouse gas emissions.
- Schools are not currently required to comply with standards on energy consumption that apply to homes or commercial buildings.
- For schools, the details on Energy Efficiency are described in Section J of the Building Code of Australia Class 2 to Class 9 Buildings, 2016 (Volume 1), which have mandatory compliance across Australia.
- The EFSG guidelines *DG06*, *DG56*, *DG90* and *DG57*, which address cooling of the interior environment, planning and landscaping of schools and ventilation requirements offer varying degrees of compliance. These requirements are in addition to the existing codes mandated by the ABCB.
- With respect to the outdoor environment, the Australian Standard²¹ AS4685 relates to playground equipment and surfacing, which primarily address safety concerns related to injury due to falling, etc. Local council programmes and state programmes addressing greening of urban areas at a city or state level have been discussed elsewhere in this document.
- Certifications schemes such as the Green Star Certification, The British Building

Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED) rating address sustainability concerns and are voluntary schemes.

- Most of the prevailing design standards used in Australia correlate with climatic zones and temperature ranges, **but do not address rising temperatures.**

4.1 GREEN STAR CERTIFICATION²²

The Green Building Council of Australia is a member-based organisation. It organises the Green Star Certification, and is an important advocate for sustainable building practices. The Green Star Certification is a rating system that assesses multiple stages of the building, starting at the design stage, through to the construction and operation stages. All building typologies found in Australia have been covered in this rating system. Due to costs for the assessment, and the system itself being voluntary, its scope and utility for schools is limited. In Australia, 25 institutions have been certified and include private schools and universities. However, not a single school in NSW belongs to this small group.

4.2 THE NATIONWIDE HOUSE ENERGY RATING SCHEME (NatHERS)

NatHERS²³, provided through the Department of the Environment and Energy (2018), is a rating system that uses a scale from 0-10, based on the cooling and heating requirements of a potential residential building. It is a mandatory rating scheme issued under the NCC, but currently applies only to Class 1 and Class 2 building types, which include houses and individual units in apartment blocks. Software tools accredited under NatHERS are referenced in the NCC as part of one option for demonstrating compliance with the relevant energy efficiency and performance requirements. No equivalent system currently exists for schools or other education institutions.

BASIX²⁴ supersedes the NatHERS system within NSW and addresses reduction in water consumption and green-house gas emissions (see Fig. 15 for an example). It is issued and operated by the NSW Department of Planning and Environment. This standard applies to residential buildings only, though it includes upgrades as well as new buildings. Currently this rating does not extend to schools.

²¹ The Australian Standard AS4685 can be purchased here <https://infostore.saiglobal.com/en-au/standards/as-4685-set-2014-1724668/>

²² Details on the GBCA can be accessed here <https://new.gbca.org.au/>

²³ <http://www.nathers.gov.au/governance/national-construction-code-and-state-and-territory-regulations>

²⁴ <https://www.planningportal.nsw.gov.au/planning-tools/basix>

Figure 15: Sample BASIX Certificate with different indicators evaluated.
Source: <https://www.basix.nsw.gov.au>

BASIX Certificate

Building Sustainability Index www.basix.nsw.gov.au

Single Dwelling

Certificate number: 717171S

This certificate confirms that the proposed development will meet the NSW government's requirements for sustainability, if it is built in accordance with the commitments set out below. Terms used in this certificate, or in the commitments, have the meaning given by the document entitled "BASIX Definitions" dated 18/09/2014 published by the Department. This document is available at www.basix.nsw.gov.au

Secretary
 Date of issue: Monday, 05 July 2017
 To be valid, this certificate must be lodged within 3 months of the date of issue.



Project summary		
Project name	BASIX 50 house	
Street address	25 Bangalee Street Stanmore 2048	
Local Government Area	Inner West Council	
Plan type and plan number	deposited 123123	
Lot no.	Z	
Section no.	-	
Project type	separate dwelling house	
No. of bedrooms	4	
Project score		
Water	✓ 45	Target 40
Thermal Comfort	✓ Pass	Target Pass
Energy	✓ 53	Target 50

Certificate Prepared by	
Name / Company Name:	ScottPlan
ABN (if applicable):	N/A

4.3 NATIONAL AUSTRALIAN BUILT ENVIRONMENT RATING SYSTEM (NABERS)

NABERS²⁵ is a rating system managed by the NSW Office of Environment and Heritage as a nationally recognised rating system for buildings. The operation of NABERS is overseen by a steering committee with representatives from each state and territory. It provides environmental rating tools for energy, water, waste and indoor environments. This rating system can be used to support applications for funding under the Energy Savings Scheme, operated by the NSW Government or other State Government funding schemes. NABERS can be used to rate commercial offices, shopping centres, hotels and homes. It is a tool to measure the actual operational performance of existing buildings and tenancies and relies on a certified auditor to carry out the inspection and evaluation of the building.

4.4 BREEAM AND LEED CERTIFICATIONS²⁶

The British Building Research Establishment Environmental Assessment Method (BREEAM) was launched in 1990. The United States *Leadership in Energy and Environmental Design* (LEED) rating scheme was launched in 1998 by the Green Building Council. Both schemes are widely recognised and used internationally to rate buildings against environmental sustainability indicators by certified auditors. LEED is the most popular and widely used green building rating system. International versions have been released for certifying projects around the world. The 2016 BREEAM for new construction has been updated to address environmental, social, and economic impacts and prioritises the Indoor Environmental Quality category over most other systems (Awadh, 2017). With respect to thermal comfort, LEED certified buildings need to either meet or exceed the *ASHRAE Standard 55:2010* or *ISO 7730:2005* or *CEN Standard EN15251:2007* when applied to at least 50% of individual occupant space and provide group thermal comfort controls for all shared multi-occupant space.

4.5 STANDARD EN15251

EN15251 is the standard to assess 'Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings'. It addresses indoor air quality, thermal environment, lighting and acoustics and is issued by the European Standards Council²⁷. It specifies methods for long-term evaluation of indoor environments as well as criteria for necessary measurements. It is primarily applicable to non-industrial buildings where the criteria for environments are controlled. Like ASHRAE standards, it recognises differences between mechanically and naturally ventilated buildings (Nicol and Wilson, 2011). Furthermore, like ASHRAE, this standard provides parameters (but no design solutions) that should be achieved for indoor comfort.

²⁶ Other similar systems include GSAS or Estidama

²⁷ A comprehensive set of European Standards is available at <https://www.en-standard.eu/>



PART 3. COOLING SCHOOLS



Figure 16: Artists rendition of design for new high-rise Ultimo Public School from Wattle Street (top) and proposed rooftop play areas (bottom) Photo: Design Inc in association with Lacoste and Stevenson and BMC2. Source: <https://www.smh.com.au>

5 TRENDS FOR SCHOOLS IN NSW

SECTION HIGHLIGHTS

- Recently, new trends to improve efficiency in construction times, operation costs, energy efficiency as well as space efficiency have emerged in NSW, driven by state government policy. Some of these emerging trends have direct implications on how thermal comfort will be achieved or prioritised with respect to local council requirements.
- Modular classrooms are fast emerging as a favoured solution for both retrofitting existing schools with new classrooms, but also in the design of all new school campuses.
- Elements of passive cooling including hi-efficiency glazing materials, insulation both vertically and horizontally and mixed mode cooling systems that incorporate evaporative cooling and conventional air-conditioning systems are being explored (ARENA, 2018).
- 'Smart technologies' are emerging, including close monitoring of the classrooms using real time energy metering, measurements of CO2 concentrations, data capture and communications to actively manage energy demands and control indoor environment quality.
- High rise schools are now constructed to accommodate new schools in where density of urban fabric and cost for real estate is high.
- Outdoor shading structures for learning, play and other outdoor activities are becoming increasingly popular as trees are required to adhere to stringent standards of safety (NSW-DoE, 2015).

5.1 MODULAR CLASSROOMS FOR SCHOOLS

To address the growing demand for schools and classrooms across the state, new design approaches including that of modular classrooms is explored by the NSW DoE. These classrooms will be based on principles of flexibility and prefabrication to reduce construction times and cost but serve the same purposes as the existing permanent classrooms (Robertson, 2017). Several contracting firms have been exploring ways to include energy efficiency measures such as solar powered generation, high-insulation walls and double glazing. One such contracting firm is Hivve²⁸, which is the branch of a larger contracting agency dealing with prefabricated buildings. Eastern Portable Buildings (Hiive), has made a foray into 'modular classrooms' as a quick, smart and effective way to meet the infrastructure needs of the NSW DoE. In collaboration with the Australian Renewable Energy Agency, two pilot classrooms have been trialled at St. Christopher's Catholic Primary School in the south west suburbs of Sydney and Dapto High School. In these trials, Hivve classrooms are entirely powered by solar energy and their energy usage, thermal comfort, indoor air quality and other parameters will be monitored for one year (ARENA, 2018).

²⁸ Other firms operating within NSW include Ausco Modular Learning Spaces (http://www.ausco.com.au/education-sector?gclid=CjwKCAjwzenbBRB3EiwAl tS-u9mYvnW-BcXjsVlfdet-r6FjzoAReRojNmZuLuwp7C036p1G1Egz9BoC1_MQAvD_BwE), Modular Building Systems (<http://mbs.com.au/>)



Figure 17: Modular classroom sample with solar powered roofs, thermal insulation in glazing and universal access. Source: <https://hivve.com.au/news/>

5.2 HIGH-RISE SCHOOLS IN NSW

“As urban densification and loss of residential land becomes increasingly prevalent in major cities worldwide, moving ‘upwards’ into highrise architecture becomes the only feasible option for urban planners (Swinburn, 2017). Similar trends are underway for educational infrastructure, where existing schools in inner-city suburbs are relinquishing valuable green space to commercial developers (sensu, Truong et al., 2018).” Construction of new schools is often restricted by available space and high purchase costs of land. As Truong et al. further explain: “Given this impasse, high-rise or vertical schools are making their debut in Australia (The Urban Developer, 2018) and will become common- place in the 21st Century (Ernst and Young, 2018).” Future educational research will need to consider implications for children’s outdoor learning and nature experiences, active play opportunities, as well as physical activity.



Figure 18: View of high-rise Arthur Philip High School in Parramatta. Source: <https://www.dailytelegraph.com.au>

The NSW DoE has begun to engage with hi-rise schools in dense urban areas to accommodate the projected growing need for school classrooms and commissioned the Design Worldwide partnership and Sutera Architects to develop *Concept Design Guidelines for Multi-level Schools* in New South Wales in 2015 (The Urban Developer, 2018).

After St. George's Anglican High School in Perth opened in 2015, construction of the Arthur Philip High School commenced in Parramatta CBD. However, compliance debates regarding possible flood hazards have delayed finalisation of the project (Bosworth, 2017). Arthur Phillip High School will accommodate up to 2,000 students along with a new multi-storey 1,000 student facility for Parramatta Public School on the existing school sites. The first of its kind for the NSW Government, the project presents a unique opportunity to test new strategies for the construction of schools in the heart of a metropolitan centre. The new school will also showcase the delivery of multi-storey education facilities in response to Sydney's increasing residential density. The

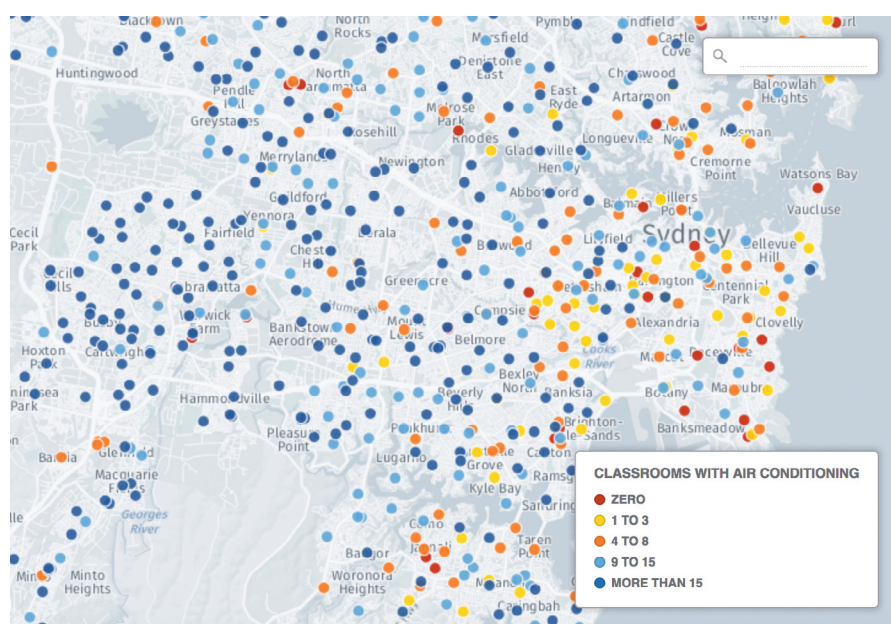
NSW DoE also plans construction of a hi-rise school in Surry Hills in inner Sydney. There are debates regarding how hi-rise schools can provide necessary outdoor space. Local councils, such as Parramatta City Council are putting forward concerns regarding future infrastructure development, disaster risks and densification leading to vehicular congestion (Bosworth, 2017). On the other hand the NSW DoE sees the need for increased classrooms in dense urban areas as driving force for vertical schools (Martin, 2017).

5.3 AIR CONDITIONING IN NSW SCHOOLS

The NSW DoE is trying to limit the use of air conditioning in new schools where mean maximum January temperatures fall below the threshold of 33 °C, at which schools automatically qualify for air conditioning (Singhal, 2018). When below the threshold temperature, NSW DoE is investing in "sustainable and cost-effective approaches to improving thermal comfort ... via passive measures such as insulation, sunscreens,

ventilation and appropriately designed landscaping" (NSW DoE, 2018a), and 'smart systems' that offer heating, cooling, humidity control and outside fresh air (NSW Department of Education, 2018b). However, recent media articles (e.g. Singhal, 2018; Bunch, 2018; Vender, 2018) report that NSW parents are concerned that passive ventilation strategies will be inadequate when new schools reach capacity.

Figure 19: Number of air-conditioned classrooms in NSW Schools. Source: Baker and Gladstone, Sydney Morning Herald, July 12, 2018 (<https://www.smh.com.au>).



Currently, approximately 150 schools in NSW – around 10,000 classrooms – have no form of air conditioning or evaporative cooling. In Western Sydney, only 97 of the 452 schools in that region are fully air conditioned, according to data from NSW DoE (Baker and Gladstone, 2018). Public pressure has resulted in the NSW government allocating \$500 million for new air conditioning units to be installed starting July 1st, 2018. It is anticipated that the Cooler Classrooms Program will bring air conditioning to around 1000 schools over the next five years (NSW DoE, 2018a, b; Singhal, 2018). The Labour Government added the additional funding to the \$300 million it had already earmarked for school air conditioning, bringing the total pledge to \$800 million. All schools experiencing a long-term mean January maximum of 30°C and above will receive air conditioning in their permanent classrooms and libraries (Baker and Gladstone, 2018).

The NSW Cooler Classrooms Program recognises the need for adequate ventilation, along with the adaptive capacity of people to adjust their sense thermal comfort depending on the surrounding environment. It will consider a range of factors that influence how a classroom feels for students including humidity, the local microclimate, classroom and school design, as well as the impact of hot days on students with specific needs (Vender, 2018). However, some see air conditioning as an unaffordable and unsustainable strategy to mitigate the problem of rising temperatures, as well as providing low quality air to school children (Singhal, 2018). The NSW DoE has suggested that additional electricity required for air conditioning will be partly offset by generating solar power, although it is unclear to what degree.

5.4 COVERED OUTDOOR LEARNING AREAS (COLAS)

The trend of using covered outdoor spaces as an extension of the indoor classroom is well established within NSW, with the EFSG guidelines outlining several standard options (3 X 5 m and 7 X 6.6 m without seating, 5 X 9 m with seating). The Australia Street Infants School in Sydney was the recipient of several design awards for a COLA designed in collaboration with the principal of the school and the architects (Fig. 20). Shading of outdoor learning spaces is aiming to increase resilience of school against hot climate and to provide a cooler outdoor learning environment (NSW Government Architect, 2018b).



Figure 20: COLA at a school in Sydney, Australia. Source: Brett Boardman, 2009.

6 PASSIVE DESIGN STRATEGIES FOR LANDSCAPING IN SCHOOLS

6.1 PLANTING TREES FOR SHADE

Trees have many known benefits, including reduction of air temperature, glare and UV radiation (Coder, 1996; Norton et al., 2015). Trees encourage outdoor pedagogical strategies, reduce the ecological footprint of a school and provide local fauna with refuge, habitat and resources (Roy et al., 2012). The Tree Management Guide for NSW describes the multiple benefits of trees, including their contribution to the “positive perspective and vitality of open spaces for active and passive recreation” (NSW DoE, 2015). Guiding principles for selection and placement of different tree classes (e.g. evergreen vs deciduous, low statue vs tall statue) are provided in EFSG Guidelines (Fig. 21).

Another consideration in the cooling benefits of trees is the need for adequate water for evapotranspiration, where water stored in the soil is transported through the tree and evaporates through the leaves. However, in recent years, trees have come under increased scrutiny due to risks of injury from falling branches, resulting in their preventive removal (NSW DoE, 2015). The EFSG Guideline DG92 specifies continuous assessment of existing trees of school grounds and provides a list of native and exotic species not suitable for planting in school premises.

6.2 SITE PLANNING: GEOMETRY AND LAYOUTS

Density and volumetric massing of built structures with respect to the available open area, alignment with respect to prevailing sun-paths and wind directions all contribute to passive cooling. Density of urban built form has a positive relationship with heat island effects (e.g. Norton et al., 2015). Alignment with sun-paths and prevailing wind directions are established design methodologies for passive cooling designs. However, this strategy is difficult to implement in practice with respect to existing schools or even with respect to neighbourhood design at the scale of school masterplans. The EFSG Guidelines *DG02 Ecologically Sustainable Development* have recently introduced Green Building Design and Green Star Rating adherence policies, though currently their adherence levels are not confirmed. *DG02* also identifies the need for an environmental management plan as well as specific guidelines on energy management that include site planning and layouts as a passive cooling design strategy.

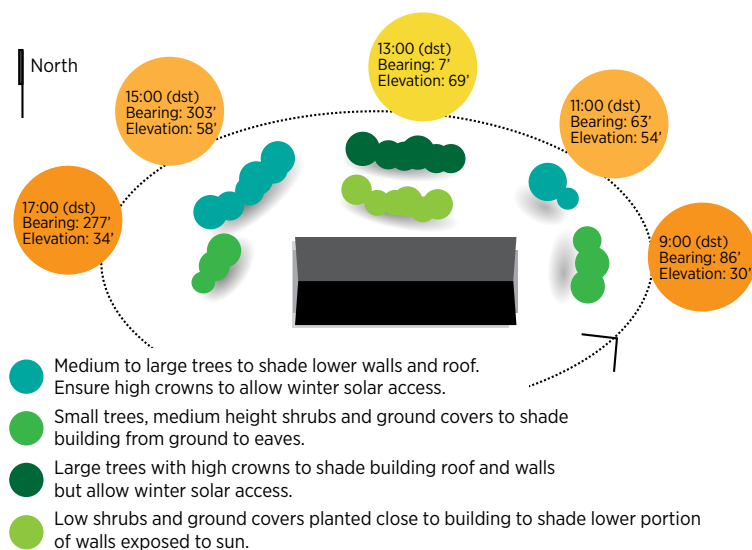
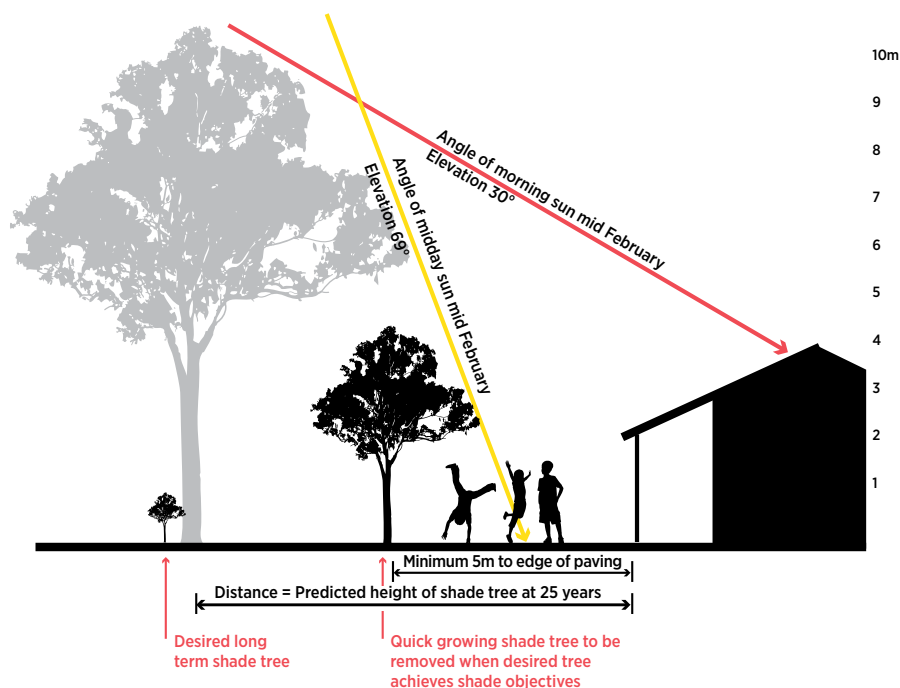


Figure 21: Strategies on location of planting with respect to the built fabric as prescribed the EFSG Guidelines PS504.01

Source: <https://efsg.det.nsw.edu.au>

Guidelines on location of planting to optimise thermal comfort in mid February



Guidance on the location of planting to maximise shade and thermal comfort in mid February

6.3 OUTDOOR SHADING

Outdoor shading in schools is provided through temporary or permanent structures, sheds, pergolas and trellises. The reduction of ambient air temperature has been clearly established due to shading devices, especially for long periods of time (Gill et al., 2007). The man-made structures are generally easy to design and install and encourage outdoor learning, play and engagement with the environment. Artificial shade structures are increasingly replacing trees and vegetation, resulting in a reduction of green space. More details on COLAs are described in Section 5.

6.4 OUTDOOR PAVING, SURFACES AND GREENING

Outdoor surfaces contribute significantly to outdoor ambient temperatures. A wide range of interventions can be used to reduce surface temperatures. These interventions include selection of highly reflective, 'cool materials' or application of paints on existing surfaces to increase their reflectivity of solar radiation and thus reduce ambient temperatures (Santamouris et al., 2011). A number of reflective coatings, 'cool coatings' and lighter coloured surfaces have been examined for their performance with respect to ambient temperatures in exterior spaces. Reflective surfaces work by reducing convection loads and reducing ambient temperature and are easy to maintain. Where feasible, greening or adding grass and low-density vegetation can further help to lower outdoor temperatures. The most effective way to reduce urban heat is to expand the urban tree canopy (Spronken-Smith and Oke, 1999). Spatial layout and vegetation structure are important factors in determining their cooling potential (Lehmann et al., 2014). However, green infrastructure can be difficult to maintain, especially in extended periods of low rainfall and drought.

The EFSG Guideline *DG40* on materials and finishes prescribes porous materials for outdoor paving, especially near trees, but advises against loose gravel due to concerns of safety. It offers no restriction on colour of paving finishes, though it does prescribe the use of brushed finishes, broom finishes and advises against the use of asphalt, concrete and exposed wash aggregates.

7 PASSIVE DESIGN STRATEGIES FOR SCHOOL BUILDINGS

7.1 INSULATION AND GREEN FACADES

Green facades refer to growing vegetation vertically on the surfaces of walls. Green facades are particularly beneficial on walls with high solar exposure and where space at ground-level is limited (Wong and Chen, 2010), or where aerial obstructions limit tree growth (Cameron et al., 2014; Alexandri and Jones, 2008). However, irrigation and maintenance can be a persistent and costly problem.

The Australian Standard *AS4859* outlines the general criteria and technical provisions for thermal insulation of buildings, referred to by *Section J on Energy Efficiency* by the NCC (ABCB, 2018b) and both are mandatory for all public buildings, including schools. Insulation provision has been prescribed for facades as well as for ceilings and floors, with additional provisions for reflective insulation for outdoor walls. Details on required R values for insulation provisions in different parts of the building as well as for buildings in different climate zones are also provided. Requirements for insulation in school buildings are also provided in EFSG. Neither the NCC nor the EFSG Guidelines currently have any specific guidelines on greening of facades.

7.2 CEILING INSULATION, COOL AND GREEN ROOFS

The benefits from the use of cool roofing materials arise from their lower surface temperature and carry-on effects on air conditioning and general thermal comfort inside buildings. Haberl and Cho (2004) reported energy savings through application of cool materials (mainly white roofing systems) on residential and commercial buildings varied between 2-44% with an average of 20%. measured summertime daily air-conditioning savings and peak demand reductions of 10-30%, and Santamouris and colleagues reported energy savings of up to 40% (Santamouris et al., 2011).

Heat transfer through a bare roof was greater than that through a greened roof and roof with soil only. Thermal benefits of green roofs were greatest when both vegetation and soil cover was present (Wong et al., 2003). To be effective, green roofs need regular irrigation and ideally involve dense vegetation cover (Santamouris, 2014). The EFSG Guideline *DG27* on roofing prescribes insulation for reducing heat transfer, sound transfer and bulk insulation. It specifically refers to *Section J* of the NCC (ABCB, 2018), which describes insulation and building fabric.

7.3 WINDOWS, DOORS, VENTILATORS AND GLAZING

A recent study in South East Queensland (Kuri, 2016), which examined the impact of retrofitting six classroom buildings from 2012 to 2014, concluded that the range of adaptive actions undertaken by teachers to reduce feelings of thermal discomfort was a critical aspect of research. The team of researchers was unable to conclusively quantify cooling effects achieved by a range of interventions, which included installation of stack ventilation, cool roofs, shade sails and schoolyard greening based on the *ASHRAE 55 Adaptive Comfort Standard*. The EFSG guidelines *DG31*, *DG32*, *DG37* and *DG39* describe design considerations for windows, doors, openable ventilators and glazing which include aspects of thermal performance, reflectance and absorptance with respect to size, location, proportions of glazed surfaces and other aspects. *Section J1* and *J3* of the NCC address openings and glazing with respect to energy efficiency of buildings.

8 INNOVATIVE COOLING SOLUTIONS

SECTION HIGHLIGHTS

- Greening urban environments remains a priority action to reduce UHI effects
- Selection of plant species and planting design can have a significant effect on maximum cooling benefits.
- Adequate water is required to achieve high cooling effects.
- Combination of green infrastructure and the use of cool materials can provide synergistic effects on thermal comfort and result in significant energy savings.
- City councils, universities, and industry are partnering in research and implementation of cooling strategies in Western Sydney.
- Primary and secondary school environments are receiving attention, but this is limited to indoor environments. Thermal properties of school outdoor play spaces have not been studied, indicating an urgent need for a research agenda.

Increasingly, urban areas are building heat-smart infrastructure by using climate-responsive design principles in outdoor environments (Brown et al., 2015). An increasing amount of research describes the cooling effects of green and blue infrastructure in urban environments, and provides strategies for mitigating heat at micro-scales (e.g. Brown et al., 2015; Gunawardena et al., 2017; Matthews et al., 2015; Santamouris et al., 2011; Santamouris, 2014; Zölch et al., 2016). While planting trees (green infrastructure) is often

the preferred means to provide cooling in urban landscapes, their effectiveness in cooling depend on a range of factors. Importantly, cooling by trees has an 'active' and a 'passive' component. Active cooling is achieved through transpiration of water from leaf surfaces and the resulting transfer of latent heat. To make this process effective, soil water must be available in sufficient quantities, which is often difficult to provide in areas where impervious surfaces dominate. Passive cooling is realised by shading of surfaces and the resulting reduction of radiant heat. The effectiveness of shading depends on factors like density and size of tree canopies. Clearly, canopy density varies among species and trees may need several decades to grow a canopy that can deliver any meaningful shade.

A recent study, [Cooling Western Sydney](#), evaluated the impact of urban heat mitigation technologies (green infrastructure, water and cool materials) on human thermal sensation in Western Sydney (Sydney Water, 2017). The study found that the most effective strategy to mitigate urban heat used a combination of water-based technologies such as fountains, together with reflective cool materials technologies such as cool roofs and pavements (Fig. 22). It is well-known that increasing albedo (i.e. capacity of a surface to reflect solar radiation) markedly reduces local peak ambient temperature by preventing radiation

from being absorbed. This can be achieved through the use of materials with high diffuse solar reflectivity and high emissivity values, while ensuring glare is minimised through material colour selection (e.g. Haberl and Cho 2004; Santamouris et al., 2011; Santamouris, 2014). Modeling results of this study show that the combined use of water-based technologies and cool materials can potentially reduce the number of *Cooling Degree Days* by 29-43%. Cooling Degree Days are used by the Australian Bureau of Meteorology to reflect the number of days where cooling measures are needed to maintain a basic temperature comfort level of 24 °C.²⁹

²⁹ Cooling Degree Days represent the number of degrees of cooling needed per day to maintain the BASE temperature comfort level of 24°C. If the average daily temperature is above the BASE comfort level, cooling is required. For example, an average daily temperature of 27°C would require the equivalent of 3 Cooling Degree Days to maintain a BASE comfort level of 24°C for that day (Australian Government Bureau of Meteorology).

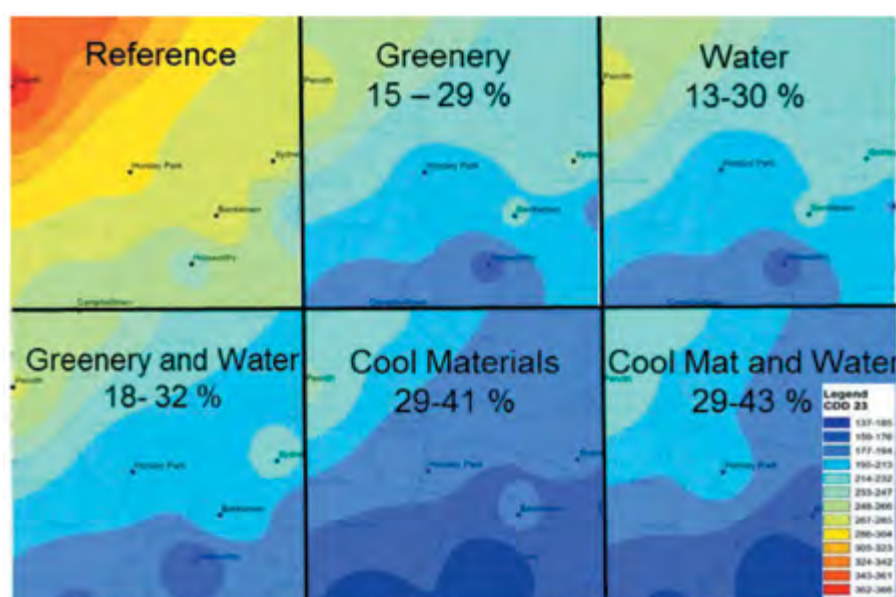


Figure 22: Spatial distribution maps of the Greater Sydney Area. The maps depict the reduction in 'Cooling Degree Days' when urban areas use climate-responsive design principles, compared to a reference scenario. Source: Sydney Water, 2017.

Spatial distribution maps showing the reduction in Cooling Degree Days when comparing the reference case to the various mitigation scenarios. The combination of cool materials and water presents the greatest reduction of 29-43%.

Modelling results from this study further indicate that large scale application of cool materials and water could lower average air temperature by 1.5 °C, and when applied in combination with green infrastructure, achieve air temperature reductions of up to 2.5 °C with positive follow-on effects on public health, lower energy consumption and reduced emission of CO₂.

Innovative cooling solutions applied to school environments – both in outdoor play spaces and to school grounds on a large scale could make a significant contribution to reducing UHI effects, both directly (through design solutions) and indirectly (through raising awareness, education, and demonstrating solutions). However, research on the application of climate-responsive design to schools is currently lacking, as is knowledge transfer from other sectors applying cooling innovations.

8.1 COOLING PROJECTS IN WESTERN SYDNEY

This section highlights examples of recently completed and ongoing cooling projects as well as council strategies in Western Sydney. More information around heat and its impacts on Western Sydney is provided on the Western Sydney Regional Organisation of Councils website (<https://wsroc.com.au/projects/project-turn-down-the-heat>).

Cool Streets (Blacktown City Council)

The Cool Streets initiative was developed through a partnership with Blacktown City Council, Gallagher Studio and CRED Consulting. It was designed to empower communities to cool their neighbourhoods through interactive participatory decision-making. A pilot project, undertaken in late 2015 and early 2016 on Boonderoo Avenue in Blacktown empowered residents to take the lead in deciding on the layout and type of trees on their street, with a specific focus on improving environmental

outcomes, increasing climate resilience of neighbourhoods and lowering electricity consumption.

Cooling the City Strategy (Penrith City Council)

The Cooling the City Strategy was adopted in 2015 and is designed to make Penrith a better place to live by addressing the UHI effect. The Strategy aims, amongst other plans, to plant more than 100,000 trees in the LGA over three years and to undertake an inventory of over 12,000 urban trees to identify which species are most vulnerable to urban heat. The Strategy recognises adequate water is required for trees to deliver their cooling benefits. Operational staff of the council are trained in water sensitive urban design and green engineering approaches. The council also partnered with the Institute for Sustainable Futures (UTS) and U.lab in 2015-16 to run a [design competition for climate adapted people shelters at bus stops](#). The feasibility of installing the winning design in Penrith is currently being determined.

Cool Parramatta (City of Parramatta Council)

Cool Parramatta is a city council-hosted website which offers information on UHI in Parramatta. Interactive heat maps, infographics and other means highlighting the risks and dangers of heat to citizens and city infrastructure, and identify places to go during hot summer days to keep cool. One of the infographics lists things that Parramatta can do to mitigate the UHI through delivering better infrastructure (e.g. shade structures, reflective and light-coloured surfaces, water features, greening city streets with trees). The council does not have a heat-specific strategy like Penrith. However, a [scoping paper](#) was provided by Gallagher Studio in 2013 that addresses Parramatta's UHI. This study interpreted thermal maps to identify priority areas for intervention and develop UHI mitigation projects with the council.

Where should all the trees go? An analysis of urban canopy cover in Australia (2020 Vision)

The 2020 Vision is an Australian network of 200 organisational partners, 1000 individual supporters and 29 strategic experts across industry, business, NGOs, government, academia and individuals working towards making urban areas 20% greener by 2020, and providing tools and resources to reach this shared goal. The report provides information on canopy levels, overlays urban heat and socio-economic data, and provides an overall vulnerability indicator. The website provides links to both state and national reports. The state report for NSW identifies losses and gains of tree cover in different municipalities, highlighting areas that are the most vulnerable to UHI effects. Among these, Inner West and Western Sydney suburbs rate as some of the most vulnerable areas and most in need of greening.

Cooling the Commons (Western Sydney University, Institute for Culture and Society)

This pilot research report was prepared by members of the Mapping Urban Resilience in Riverland Sydney (MURRS) research group at WSU in 2016. It documents social and collective responses to environmental stress, including UHI effects, identifying public spaces in the city that offered cooling respite from summer heat. By highlighting ways that individuals and communities are trying to keep cool, the study aims to inform and support urban design and public policy cooling strategies.

FURTHER INFORMATION

Guide to urban cooling strategies (Centre for Low Carbon Living)

This document provides practical guidance for built environment professionals and regulatory agencies seeking to optimise development projects to moderate urban microclimates and mitigate urban heat island effects in major urban centres across a range of climates in Australia, including Parramatta and Western Sydney (Fig. 23).

Beat the heat (NSW Health)

This website provides the community with information on how hot weather influences health, how to prepare for and stay healthy in the heat, how to recognise and treat heat-related illness, and how you to care for people who are at risk of heat-related illness.

Adapt NSW (NSW Office of Environment and Heritage)

This resource on urban heat in Sydney provides up-to-date information on the projected impacts of land use change on urban heat in the near future (2036), including maps, data, and technical reports.

Building cool cities for a hot future (The Conversation)

This article, written by researchers from UNSW explains how the interaction between urban form, building materials and solar radiation create microclimates across the city. Building heights and materials, width and orientation of streets, presence of absence of vegetation, and exhaust from vehicle use are some of the contributors discussed.

Thermal properties of playgrounds (The Conversation)

In this article, researchers from Western Sydney Uni report on thermal properties of playground equipment and surface temperatures. Findings from Blick (2018) are used to raise the question if designers should take on social and health responsibility when construct play spaces for children.



Figure 23: Urban design strategies for cooler cities. Source: RP2024 Guide to Urban Cooling Strategies 2017 (Low Carbon Living CRC, 2017). Retrieved from <http://www.lowcarbonlivingcrc.com.au>

9 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Average summer temperatures across Western Sydney are rising. Extreme heat events – days where air temperatures measured in shade are greater than 40 °C – are expected to occur more frequently and last longer. For this reason, numerous councils, government agencies and other organisations are developing strategies and actions geared towards mitigating urban heat. Evidence-based climate-responsive design principles are already being used to cool urban open spaces, and could be applied to school infrastructure upgrades and new builds. There is a current window of opportunity to do so in NSW – with the investment of \$6 billion in new school infrastructure and upgrades over the next four years, and an urgent need to address the impacts of rising temperatures on children's safety, health, and learning. This scoping report has outlined a range of grey and white literature relevant to student thermal comfort, and the thermal properties of school environments and curriculum design. We conclude by offering four areas for future research.

SCHOOL AND CHILD-SPECIFIC THERMAL COMFORT STUDIES

Many different thermal comfort indices exist, yet these are largely unsuitable for studying student thermal comfort and school environments. School building design standards are based on thermal comfort models that do not reflect the real-life dynamism of indoor and outdoor environments, nor the adaptive agency of users. Thermal comfort studies performed inside schools to date do not account for thermal microvariations in classrooms or their effects on children (proximity to solar radiation entering through windows; drafts, etc). No information is available for teachers how to restore thermal comfort in classrooms – which may or may not reflect children's needs and preferences as children prefer

cooler temperatures compared to adults. In addition, very few thermal comfort studies have been carried out in Australian schools. Of these, none investigate the outdoor thermal school environment and the impact of rising temperatures on student thermal comfort, safety, health, learning outcomes and activity patterns. Finally, very few studies of thermal comfort of children exist. Less than 10% of all published articles on thermoregulation involve children, and of these, few have considered the specific characteristics and needs of students. These observations highlight the urgent need for innovative research that helps define thermal comfort of school children and their teachers. It is necessary to develop standardised assessment criteria and methods to characterise thermal comfort in outdoor and indoor school environments, acknowledging that schools in Australia are built across different climate zones and will experience novel climate conditions as result of ongoing and rapid environmental change.

IMPACTS OF RISING TEMPERATURES ON CHILDREN'S ACTIVITY, HEALTH, AND LEARNING

Green environments provide significant environmental, economic, social, psychological and physiological benefits to individuals and communities. Trees offer shade, fresher air, habitat and food for insects, and animals, and provide beneficial learning and recreational environments for children and adults alike. However, trees are disappearing from school grounds at an alarming rate. The Sustainable Schools initiative of the Australian Association for Environmental Education is developing an increasing number of curricular activities based on outdoor education. The question arises if, and where, outdoor education can safely be delivered if temperatures are increasingly hot and schoolyards are increasingly empty? Meanwhile, the NSW government is investing

\$800 million in school air conditioning from July 2018 onwards. Will rising temperatures lead to children spending more sedentary time inside air-conditioned environments, and if so, what implications might this have for environmental education, and children's academic performance, thermal adaptability, and overall well-being? To answer these important questions, collaborative and interdisciplinary research must be implemented to study these effects and develop strategies that counter eventual negative effects that arise from a reduction in outdoor activities.

ADDRESSING TRENDS IN SCHOOL ENVIRONMENTS AND CURRICULA; DEVELOPMENT OF BEST COOLING PRACTICES

Despite existing research on UHI effects and a host of emerging projects that focus on mitigating heat stress and facilitating thermal comfort, no 'best-practice' standards and guidelines for development of explicitly heat-resilient school infrastructure and curricular activities (outdoor and indoor) currently exist. Outdoor play spaces and schoolyards in Western Sydney can become unsafe thermal environments for students in summer heat. Schools in NSW are cutting down existing trees and thus reduce natural shading as response to risk concerns and liability issues. Currently, the NSW DoE is not providing additional shade by erecting shade sail structures due to insurance considerations. It is well known that increasing albedo markedly reduces local peak ambient temperature by preventing radiation from being absorbed. Yet school outdoor play spaces in Western Sydney seemingly favour darker coloured synthetic materials with a very low albedo and low infrared spectrum reflectivity which leads to absorption and radiation of heat. Are these trends due to the unavailability of alternative materials, a lack of knowledge, a lack of design



standards, insurance liability, and maintenance considerations, some combination of these, or other issues? What could be the best thermal design of the growing number of COLA infrastructure? Research is needed to better understand these factors so that effective interventions can be developed to ensure the materials and design approaches used in schoolyards are not increasing thermal loading of children. Given the space that schools occupy in the urban landscape, it is necessary to identify and implement climate-responsive design strategies to mitigate UHI effects in their communities. It is also necessary to develop practical approaches that help reverse negative trends like the removal of established trees and use of dark-coloured, non-permeable surface materials.

INTER-AGENCY COLLABORATION AND CO-ORDINATION

This report has identified gaps in communication, collaboration and coordination (CCC) between a range of sectors and organizations. Areas of improvement include: CCC between those that design and those that deliver curriculum-based approaches to sustainability education; CCC among organizations involved in development of policies and design standards; CCC between decision makers for tree removal and installation of air conditioning systems. The trend in removing trees from schoolyards and installing air conditioning may only increase local heat through lack of shade and venting of additional hot air. However, innovative design solutions for cooling are becoming increasingly available. Thus,

perhaps the most pressing requirement – and possibly the most challenging – is the need to improve CCC across government, industry, academic, practitioner, and community sectors. Coordination is needed across these areas to facilitate knowledge sharing, address barriers to changing established policy and practice where required, and collaboratively design and test innovative cooling strategies based on emerging research. This work is urgently needed to ensure heat-smart school environments and keep children safe, healthy, and cool as they learn, play, and socialise.

REFERENCES

- Aarts, M., Wendel-Vos, W., van Oers, H., van de Goor, I., Schuit, A. 2010. Environmental Determinants of Outdoor Play in Children. *American Journal of Preventive Medicine* 39: 212-219.
- AAEE NSW. 2018a. Australian Association for Environmental Education, NSW Chapter. About us. <https://www.aaeensw.org.au/about-us/what-aaee-nsw>
- AAEE NSW. 2018b. Australian Association for Environmental Education, NSW Chapter. Strategic Plan 2018-2021. Retrieved from <https://www.aaeensw.org.au/about-us/strategic-plan>. Accessed August 12, 2018.
- AAEE NSW. 2018c. Australian Association for Environmental Education, NSW Chapter. Contractor Position Available – Take Me Outside Project. June 1st, 2018. Retrieved from: <https://www.aaeensw.org.au/articles/contractor-position-available-take-me-outside-project>. Accessed July 5, 2018.
- ABCB (Australian Building Codes Board). 2018a. Indoor Air Quality Handbook. Retrieved from <http://www.abcb.gov.au/Resources/Publications/Education-Training/Indoor-air-quality>. Accessed August 3, 2018.
- ABCB (Australian Building Codes Board). 2018b. National Construction Code. Retrieved from Australian Building Codes Board: <http://www.abcb.gov.au/ncc-online/NCC/2016-A1?vol=56a3b1a8-d528-471b-be8a-5527c2d7db47#56a3b1a8-d528-471b-be8a-5527c2d7db47>. Accessed August 5, 2018.
- ACARA (Australian Curriculum, Assessment, and Reporting Authority). 2016. Cross-curriculum priorities. Retrieved from <http://www.acara.edu.au/curriculum/cross-curriculum-priorities>. Accessed August 10, 2018.
- ACT Government. 2015. Act Smart: Helping you make the change to a more sustainable future. Retrieved from <https://www.actsmart.act.gov.au/>. Accessed July 5, 2018.
- Alexandri, E., Jones, P. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment* 43: 480-493.
- ASHRAE. 1992. Thermal Environmental conditions for human occupancy. ANSI/ASHRAE standards, Atlanta
- ASHRAE Standard 62.1. 2004. Ventilation for Acceptable Indoor Air Quality. Atlanta GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- ASHRAE. 2013. ANSI/ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
- ARENA (Australian Renewable Energy Agency). 2018. Classrooms powered by renewable energy to be trialled in NSW schools. Retrieved from <https://arena.gov.au/news/classrooms-powered-renewable-energy-trialled-nsw-schools/>. Accessed August 19, 2018.
- Auliciems, A. 1981. Towards a psycho-physiological model of thermal perception. *International Journal of Biometeorology* 25: 109-122.
- Australian Water Association. 2018. Sydney Water and UNSW collaborate to cool Western Sydney. Posted 18th January, 2018. Retrieved from http://www.awa.asn.au/AWA_MBRR/Publications/Latest_News/Sydney_Water_and_UNSW_collaborate_to_cool_Western_Sydney.aspx Accessed July 20th, 2018. Accessed August 5, 2018.
- Awadh, O. 2017. Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis. *Journal of Building Engineering* 11: 25-29.
- Baker, J., Gladstone, N. 2018. Where Summer is Stifling: The NSW Schools with and without air-con. Sydney Morning Herald, July 12, 2018. Retrieved from <https://www.smh.com.au/politics/nsw/where-summer-is-stifling-the-nsw-schools-with-and-without-air-con-20180711-p4zqsx.html>. Accessed August 8, 2018.
- Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., Tinz, B. 2012. Comparison of UTCI to selected thermal indices. *International Journal of Biometeorology* 56: 515-535.
- Blick, M. 2018. How cool is my kindy? Thermal assessment of outdoor space in childcare facilities across Western Sydney. Final Report, Western Sydney University, 27p.
- Boardman, B. 2009. COLA at Australia St. Infant's School. Photograph retrieved from https://www.archdaily.com/59670/australia-st-infants-school-cola-scale-architecture/scale_australiastprimaryschool_cola_1915 Accessed August 1, 2018.
- Boldemann, C., Blennow, M., Dal, H., Martensson, F., Raustorp, A., Yuen, K. et al. 2006. Impact of preschool environment upon children's physical activity and sun exposure. *Preventive Medicine* 42: 301-308.
- Bosworth, T. 2017. Skyscraper school late and over budget by \$50 million. *The Daily Telegraph*. Retrieved from <https://www.dailytelegraph.com.au/newslocal/paramatta/skyscraper-school-late-and-over-budget-by-50-million/news-story/707bb1c30bfa964d7a3543a257a0cebe>. Accessed August 19, 2018.
- Brown, R. D., Vanos, J., Kenny, N., Lenzholzer, S. 2015. Designing urban parks that ameliorate the effects of climate change. *Landscape and Urban Planning* 138: 118-131.
- Buell J., Stoddard P., Harris FR., Baer DM. 1968. Collateral social development accompanying reinforcement of outdoor play in a preschool child. *Journal of Applied Behaviour Analysis* 1: 167-173.
- Bunch, A. 2018. NSW Schools Promised \$500m for air-con. June 15 2018. Retrieved from <https://www.news.com.au/national/breaking-news/nsw-schools-promised-500m-for-aircon/news-story/310b558d8a6397472d3dfcf43919fa45>. Accessed July 5, 2018
- Burdette, H. L., Whitaker, R. L. 2005. Resurrecting free play in young children: Looking beyond fitness and fatness to attention, affiliation and affect. Chicago: American Medical Association.
- Cameron, R. W. F., Taylor, J. E., Emmett, M. R. 2014. What's 'cool' in the world of green façades? How plant choice influences the cooling properties of green walls. *Building and Environment* 73: 198-207.
- CEN. 2007. DIN EN15251 – Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. European Committee for Standardization.
- Chen, L., Ng, E. 2012. Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities* 29: 118-125.
- Clements, R. 2004. An investigation of the status of outdoor play. *Contemporary Issues in Early Childhood* 5: 68-80.
- Coder, K. 1996. Identified benefits of community trees and forests. Ottawa Forests and Green Space Advisory Committee.
- de Dear, R., Brager, G., Cooper, D. 1997. Developing an adaptive model of thermal comfort and preference. In: Final Report ASHRAE RP-884.
- de Dear, R. J., Brager, G. S. 1998. Developing an adaptive model of thermal comfort and preference. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States).
- de Dear, R. 2011. Revisiting an old hypothesis of human thermal perception: alliesthesia. *Building Research & Information* 39: 108-117.
- de Dear, R., Kim, J., Candido, C., Deuble, M. 2015. Adaptive thermal comfort in Australian school classrooms. *Building Research & Information* 43: 383-398.
- de Freitas, C. R., Grigorieva, E. A. 2015. A comprehensive catalogue and classification of human thermal climate indices. *International Journal of Biometeorology* 59: 109-120.
- Department of the Environment and Energy. 2018. Nationwide House Energy Rating Scheme - National Construction Code and State and Territory Regulations. Retrieved from: <http://www.nathers.gov.au/governance/national-construction-code-and-state-and-territory-regulations>. Accessed August 19, 2018.

- Dowdell K., Gray T., Malone K. 2011. Nature and its influence on children's outdoor play. *Australian Journal of Outdoor Education* 15: 24-35.
- Driessnack, M. 2009. Children and Nature-Deficit Disorder. *Journal for Specialists in Paediatric Nursing* 14: 73-75.
- Dyment J., Bell A. 2008. Grounds for movement: Green school grounds as sites for promoting physical activity. *Health Education Research* 23: 952-962.
- Earthman, G. I. 2004. Prioritization of 31 criteria for school building adequacy. Baltimore, MD: American Civil Liberties Union Foundation of Maryland, United States.
- Education for Sustainability. 2012. The Australian Sustainable Schools Initiative (AuSSI). Retrieved From <http://www.education4sustainability.org/2012/08/21/the-australian-sustainable-schools-initiative-aussi/>
- Epstein, Y., Moran, D. S. 2006. Thermal comfort and the heat stress indices. *Industrial Health* 44: 388-398.
- Ernst and Young. 2018. Revolutionising education from the ground up: how will vertical schools change the nature of education. EY and Hayball, Australia, 8p.
- Fisk, W. J. 2017. The ventilation problem in schools: literature review. *Indoor Air* 27: 1039-1051.
- Getting Started with Sustainability in Schools. 2015-6. In the School: How do I start a Sustainability Project in my School? Retrieved from <https://sustainabilityinschools.edu.au/school>. Accessed July 18, 2018.
- Gill, S. E., Handley, J. F., Hennos, A. R., Pauleit, S. 2007. Adapting cities for climate change: the role of the green infrastructure. *Built Environment* 33: 115-133.
- Goodman, J., Hurwitz, M., Park, J., Smith, J. 2018. Heat and Learning. *HKS Working Paper* No. RWP18-014. <http://dx.doi.org/10.2139/ssrn.3180724>
- Gunawardena, K. R., Wells, M. J., Kershaw, T. 2017. Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment* 584: 1040-1055.
- Haberl, J. S.; Cho, S. 2004. Literature review of uncertainty of analysis methods (Cool Roofs), Report to the Texas Commission on Environmental Quality. Energy Systems Laboratory (<http://esl.tamu.edu>), Texas A&M University. Available electronically from <http://hdl.handle.net/1969.1/2071>.
- Havenith, G., Fiala, D., Blazejczyk, K., Richards, M., Bröde, P., Holmér, I., Rintamäki, H., Benshabat, Y., Jendritzky, G. 2011. The UTCI clothing model. *International Journal of Biometeorology* 56: 461-470.
- Haverinen-Shaughnessy, U., Moschandreas, D., Shaughnessy, R. 2011. Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air* 21: 121-131.
- Haverinen-Shaughnessy, U., Shaughnessy, R. J. 2015. Effects of classroom ventilation rate and temperature on students' test scores. *PLOS one* 10, e0136165.
- Higgins, S., Hall, E., Wall, K., Woolner, P., McCaughey, C. 2005. The impact of school environments: a literature review. Design Council, London, United Kingdom.
- Höppe, P. 2002. Different aspects of assessing indoor and outdoor thermal comfort. *Energy and buildings*, 34: 661-665.
- ISO. 2005. ISO 7730 Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
- Jegasothy, E., McGuire, R., Nairn, J., Fawcett, R., Scalley, B. 2017. Extreme climatic conditions and health service utilisation across rural and metropolitan New South Wales. *International Journal of Biometeorology* 61: 1359.
- Jendritzky, G., de Dear, R., Havenith, G. 2012. UTCI – why another thermal index? *International Journal of Biometeorology* 56: 421-428.
- Keep, G. D. 2002. Buildings that Teach. *Educational Facility Planner* 37: 18-22.
- Kim, J., de Dear, R. 2018. Thermal comfort expectations and adaptive behavioural characteristics of primary and secondary school students. *Building and Environment* 127: 13-22.
- Kingma, B., Schellen, L., Frijns, A. J. H., van Marken Lichtenbelt, A. 2012. Thermal sensation: a mathematical model based on neurophysiology. *Indoor Air* 22: 253-262.
- Kuiri, L. 2016. The physical and social aspects of retrofitting passive cooling strategies to timber school buildings and their surrounds in South East Queensland. Fifty years later: Revisiting the role of architectural science in design and practice: 50th International Conference of the Architectural Science Association. The Architectural Science Association and The University of Adelaide.
- Kuo, F. E., Taylor, A. F. 2004. A potential natural treatment for attention-deficit/hyperactivity disorder: Evidence from a national study. *American Journal of Public Health* 94: 1580-1586.
- Lam, C. K. C., Gallant, A. J., Tapper, N. J. 2016. Perceptions of thermal comfort in heatwave and non-heatwave conditions in Melbourne, Australia. *Urban Climate* 23: 204-218.
- Lehmann, I., Mathey, J., Röbler, S., Bräuer, A., Goldberg, V. 2014. Urban vegetation structure types as a methodological approach for identifying ecosystem services – Application to the analysis of micro-climatic effects. *Ecological Indicators* 42: 58-72.
- Levinson, R., Akbari, H., Konopacki, S., Bretz, S. 2005. Inclusion of cool roofs in non-residential Title 24 prescriptive requirements. *Energy Policy* 33: 151-170.
- Louv, R. 2008. Last child in the woods: Saving our children from nature deficit disorder. Chapel Hill, NC: Algonquin Books.
- Malone, K. 2008. Every Experience Matters: An evidence-based research report on the role of learning outside the classroom for children's whole development from birth to eighteen years. *Report commissioned by Farming and Countryside Education for UK Department Children, School and Families, Wollongong, Australia*. Retrieved from https://www.researchgate.net/publication/265231721_every_experience_matters_An_evidence_based_research_report_on_the_role_of_learning_outside_the_classroom_for_childrens_whole_development_from_birth_to_eighteen_years. Accessed August 19, 2018.
- Martin, R. 2017. High-rise schools may seem strange but expect to see more in Australia. *ABC News*. Retrieved from <http://www.abc.net.au/news/2017-04-27/high-rise-schools-and-their-place-in-australia/8477060>. Accessed August 19, 2018.
- Matthews, T., Lo, A. Y., Byrne, J. A. 2015. Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. *Landscape and Urban Planning* 138:155-163.
- McGregor, G. R. 2012. Special issue: Universal thermal comfort index (UTCI). *International Journal of Biometeorology* 56: 419-419.
- McNamara, D. R., Waugh, D. G. 1993. Classroom Organisation: a discussion of grouping strategies in the light of the 'Three Wise Men's' report. *School Organization* 13: 41-50.
- Mendell, M., Eliseeva, E., Davies, M., Spears, M., Lobscheid, A., Fisk, W., Apte, M. G. 2013. Association of classroom ventilation with reduced illness absence: a Prospective Study in California Elementary Schools. *Indoor Air* 23: 515-528.
- Moogk-Soulis, C. (2010). Schoolyard and public space heat islands: a study in Windsor-Essex, Sarina-Lambton and Chatham-Kent, Ontario. Prepared for: Riverside Optimist Club, Windsor; and the Public Health Units of Windsor-Essex, Sarnia-Lambton, and Chatham-Kent. October 5-6, 2010, Windsor, Sarnia, Chatham, 17p. (<http://www.moogk-soulis.com/wp-content/uploads/2011/05/CMS-Tri-Counties-Heat-Island-Final-Report-w-Figures.pdf>) Accessed August 25, 2018.
- Nicol, J. F., Humphreys, M. A. 1973. Thermal comfort as part of a self-regulating system. *Building Research and Practice* May/June, 174-179.
- Nicol, J. F., Humphreys M. A. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings* 34: 563-572.
- Nicol, J. F., Wilson, M. 2011. A critique of European Standard EN 15251: strengths, weaknesses and lessons for future standards. *Building Research and Information* 39: 183-193.
- Nikolopoulou, M., Steemers, K. 2003. Thermal comfort and physiological adaptation as a guide for designing urban spaces. *Energy and Buildings* 35: 95-101.
- Nikolopoulou, M. 2011. Outdoor thermal comfort. *Frontiers in Bioscience* 3: 1552-1568.
- Nikolopoulou, M., Kotopoulos, A., Lykoudis, S. 2018. From indoors to outdoors and in-transition; thermal comfort across different operation contexts. In: 10th Windsor Conference: Rethinking Comfort, 12-15 April 2018, Windsor.
- Nitschke, M., Tucker, G., Bi, P. 2007. Morbidity and mortality during heatwaves in metropolitan Adelaide. *Medical Journal of Australia* 187: 662.
- Nitschke, M., Tucker, G. R., Hansen, A. L., Williams, S., Zhang, Y., Bi, P. 2011. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environmental Health* 10: 42.
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., Williams, S. G. 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning* 134: 127-138.
- NSW Department of Education. 2015. Tree Management Guidelines- A Guide to assist with the management of trees in NSW schools.

- NSW Department of Education. 2016. Sustainability Action Process: Thermal Comfort. Years 7-10. Making the case for change. Retrieved from <https://schoolsequella.det.nsw.edu.au/file/7545a09f-c0b1-4a4f-84cb-0daca842443b/1/Thermal-comfort-sec.zip/index.htm>. Accessed August 10, 2018
- NSW Department of Education. 2018a. More new classrooms, preschool places and teachers in \$17.3 billion education budget. Media Release June 20, 2018. Retrieved from [https://education.nsw.gov.au/news/media-releases/more-new-classrooms,-preschool-places-and-teachers-in-\\$17.3-billion-education-budget](https://education.nsw.gov.au/news/media-releases/more-new-classrooms,-preschool-places-and-teachers-in-$17.3-billion-education-budget). Accessed July 8th, 2018.
- NSW Department of Education. 2018b. NSW Budget: Half a billion dollars to air-condition more classrooms. Media Release June 14, 2018. Retrieved from <https://education.nsw.gov.au/news/media-releases/nsw-budget-half-a-billion-dollars-to-air-condition-more-classrooms>. Accessed July 8, 2018.
- NSW Department of Education. 2018c. Environmental Education Policy for Schools. Retrieved from <https://education.nsw.gov.au/policy-library/policies/environmental-education-policy-for-schools>. Accessed August 3, 2018
- NSW Department of Education. 2018d. Sustainability Action Process. Retrieved from <https://education.nsw.gov.au/teaching-and-learning/curriculum/learning-across-the-curriculum/sustainability/sustainability-action-process>. Accessed August 3, 2018.
- NSW Department of Environment and Heritage. 2015. Climate Change Impact Snapshot. November 2015, NSW Government, Sydney.
- NSW Government Architect. 2018a. *Better Placed Design Guide for Schools*. Retrieved from <http://www.governmentarchitect.nsw.gov.au/guidance/design-guide-for-schools> Accessed August 18, 2018.
- NSW Government Architect. 2018b. *Australia Street Infants School*. Retrieved from <http://www.governmentarchitect.nsw.gov.au/resources/case-studies/2017/08/australia-street-infants-school>. Accessed August 18, 2018.
- NSW OEH (Office of Environment and Heritage). 2017. Project summaries: 2017 Environmental Education. (Dec 22, 2017. Retrieved from: <http://www.environment.nsw.gov.au/grants/environmental-education-projects-2017.htm> Accessed July 10, 2018.
- Nye, B., Hedges, L. V., Konstantopoulos, S. 2000. The effects of small classes on academic achievement: the results of the Tennessee class size experiment. *American Educational Research Journal* 37: 123-151.
- Parsons, K. 2003. Human thermal environments: The effects of hot, moderate and cold temperatures on human health, comfort and performance. Taylor & Francis. London.
- Potter, J., de Dear, R. 2000. Field study to calibrate an outdoor thermal comfort index. In *Biometeorology and urban climatology at the turn of the millennium. Selected papers from the Conference ICB-ICUC*, Vol. 99: 315-320.
- Rickard, L. 2011. Government backflips on school air-con, but too late for sweating students. Retrieved from <https://www.watoday.com.au/national/western-australia/government-backflips-on-school-air-con-but-too-late-for-sweating-students-20110302-1be34.html>. Accessed July 5th, 2018.
- Rivkin, S. G., Hanushek, E. A., Kain, J. F. 2005. Teachers, schools, and academic achievement. *Econometrica* 73: 417-458.
- Robertson, J. 2017. New prefab buildings to change the concept of the temporary classrooms in NSW. *Sydney Morning Herald*, 22 November, 2017. Retrieved from <https://www.smh.com.au/national/nsw/new-prefab-buildings-to-change-the-concept-of-the-temporary-classrooms-in-nsw-20171122-gzqvau.html>. Accessed August 19, 2019.
- Roy, S., Byrne, J., Pickering, C. 2012. A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening* 11: 351-363.
- Rupp, R. F., Vásquez, N. G., Lamberts, R. 2015. A review of human thermal comfort in the built environment. *Energy and Buildings* 105: 178-205.
- Sanders, W. L., Rivers, J. C. 1996. Cumulative and residual effects of teachers on future student academic achievement. Research Progress Report, University of Tennessee Value-added Research and Assessment Center, Knoxville, TN, United States.
- Santamouris, M., Synnefa, A., Karlessi, T. 2011. Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy* 85: 3085-3102.
- Santamouris, M. 2014. Cooling the cities—a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy* 103: 682-703.
- Singhal, P. 2018. 'Short-sighted': Sydney's new schools to be built without air conditioning. *Sydney Morning Herald*, Feb 5th, 2018. Retrieved from <https://www.smh.com.au/education/shortsighted-sydneys-new-schools-to-be-built-without-air-conditioning-20180205-h0tsaw.html>. Accessed August 8, 2018.
- Sirin, S.R. 2005. Socioeconomic status and academic achievement: a meta-analytic review of research. *Review of Educational Research* 75: 417-453.
- Spronken-Smith, R., Oke, T. 1999. Scale modelling of nocturnal cooling in urban parks. *Boundary-Layer Meteorology* 93: 287-312.
- Steffen, W., Rice, M., Alexander, D. (2017). 2017: Another Record-Breaking Year for Heat and Extreme Weather. Climate Council of Australia. Retrieved from <https://www.climatecouncil.org.au/resources/2017-heat-report/>. Accessed August 18, 2018.
- Sundell, J., Levin, H., Nazaroff, W. W., Cain, W. S., Fisk, W. J., Grimsrud, D. T., ... & Samet, J. M. 2011. Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air* 21: 191-204.
- Swinburn, A. 2017. Vertical School Design: Strategizing the spatial configuration of a multi-storey typology to facilitate education in dense city environments: NSW Architects Registration Board.
- Sydney Water. 2017. Cooling Western Sydney: A strategic study on the role of water in mitigating urban heat in Western Sydney. Retrieved from <http://www.sydneywater.com.au/SW/about-us/our-publications/reports-and-publications/index.htm>. Accessed August 8, 2018.
- The Urban Developer. 2018. 7 vertical schools proving Australia's education system is on the way up. The Urban Developer. Retrieved from <https://theurbandeveloper.com/articles/7-vertical-schools-proving-australias-education-system-is-on-the-way-up>. Accessed August 8, 2018.
- Truong, S., Singh, M., Reid, C., Gray, T., Ward, K. (accepted, 2018). Vertical schooling and learning transformations in curriculum research: Points and counterpoints in outdoor education and sustainability. *Curriculum Perspectives*.
- Vanos, J. K. 2015. Children's health and vulnerability in outdoor microclimates: A comprehensive review. *Environment International* 76: 1-15.
- Vanos, J. K., Middel, A., McKercher, G. R., Kuras, E. R., Ruddell, B. L. 2016. Hot playgrounds and children's health: a multiscale analysis of surface temperatures in Arizona, USA. *Landscape and Urban Planning* 146: 29-42.
- Vanos, J. K., Herdt, A. J., Lochbaum, M. R. 2017. Effects of physical activity and shade on the heat balance and thermal perceptions of children in a playground microclimate. *Building and Environment* 126: 119-131.
- Vender, M. 2018. NSW to invest half a billion in school air conditioning. HVAC&R News, June 15, 2018. Retrieved from <http://www.hvacrnews.com.au/education/nsw-to-invest-half-a-billion-in-school-air-conditioning/>. Accessed August 8, 2018
- Wells, N. M. 2000. At home with nature: Effects of "greenness" on children's cognitive function. *Environment and Behaviour* 32: 775-795.
- WSROC. 2018. Turn down the heat – Strategy and action plan. Draft. Western Sydney Regional Organisation of Councils, 39p.
- Wong, N. H., Chen, Y., Ong, C. L., Sia, A. 2003. Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment* 38: 261-270.
- Xu, Z., Etzel, R. A., Su, H., Huang, C., Guo, Y., Tong, S. 2012. Impact of ambient temperature on children's health: a systematic review. *Environmental Research* 117: 120-131.
- Zölch, T., Maderspacher, J., Wamsler, C., Pauleit, S. 2016. Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale. *Urban Forestry & Urban Greening* 20: 305-316.
- Zomorodian, Z. S., Tahsildoost, M., Hafezi, M. 2016. Thermal comfort in educational buildings: A review article. *Renewable and Sustainable Energy Reviews* 59: 895-906.

CONTACT US

Western Sydney University,
Locked Bag 1797, Penrith, NSW 2751



[WESTERNSYDNEY.EDU.AU](https://www.westernsydney.edu.au)