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Retrofitting Passive Cooling Strategies to a Brisbane School: A Case Study of the Physical and Social Aspects.

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Abstract

In subtropical southeast Queensland, a common approach to improving thermal comfort in existing school classrooms is to use air-conditioners. However, increasing reliance on air-conditioners in schools adds to energy costs and increases carbon emissions. Greater understanding of low energy approaches to improving thermal comfort is needed to address this problem. The purpose of this research was to firstly, evaluate the impact of four passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds in a Brisbane school. The retrofitted interventions were: 1) stack ventilation, 2) cool roof, 3) shade sails over courtyards, and 4) schoolyard greening. Secondly, the research explored the adaptive behaviour of teachers during times of perceived over-heating in classrooms. The research used a case study methodology that combined quantitative (temperature) and qualitative (perceptions of teachers) data gathering within an overarching systems framework. Classroom temperatures were collected before and after interventions from 2012 to 2015. Teachers participated in an online questionnaire and semi-structured interviews in 2015.

Results indicate that the duration of high classroom temperatures decreased following each intervention. However, the reduction in classroom temperature was not enough to be within an acceptable comfort range for summer months, particularly during hot and humid weather. Common adaptive behaviours exhibited by teachers included the use of windows and ceiling fans to increase air movement, and scheduling more intense teaching in the cooler, morning session. The research identified times in the school year when classrooms with passive, retrofitted interventions were within an acceptable comfort range. However, a significant finding was that air-conditioning some classrooms and not others was seen to be an equity issue. The research makes an important contribution to the information available to schools on low energy approaches to improving thermal comfort. These approaches include reducing heat load in existing classrooms by retrofitting passive cooling strategies, increasing awareness amongst school communities of the environmental impact of mechanical cooling and heating, and increasing awareness amongst teachers of the potential for adaptive behaviours to decrease the use of mechanical cooling and heating.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly authored works that I have included in my thesis.

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Adaptive comfort, passive cooling, retrofitted classrooms, adaptive actions.

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List of Abbreviations

ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
IPCC	Intergovernmental Panel of Climate Change
T_{mm}	Monthly mean temperature
T_{rm}	Running mean temperature

Chapter 1 Introduction

The link between thermal comfort and energy use in buildings has increased over the last twenty years due to the need for communities to reduce their greenhouse gas emissions, and to reduce the impacts of climate change (de Dear et al. 2013). Within the field of thermal comfort research, the adaptive comfort approach suggests that occupants of naturally ventilated buildings can be comfortable in a higher range of temperatures, if they have ways of adjusting their environment to suit them (Nicol, Humphreys and Roaf 2012). Increasing adaptive behaviours in existing buildings is seen as a pathway to low-energy occupation. New sustainable buildings can be designed using passive design principles to provide comfort for occupants, reducing the use of cooling and heating devices. Yet, even if all new buildings were zero carbon buildings (they produce energy on site to balance out the energy used for construction, materials and to run the appliances in the building over its expected life), they would “make a very small dent in the emissions of the building stock as a whole” (Swan and Brown 2013). Herein lies the ‘wicked problem’, of how to maintain thermal comfort in existing buildings and lessen building emissions to reduce impact on climate change (Roaf, Nicol and de Dear 2013). Swan and Brown (2013) suggest improving existing building stock by retrofitting and framing the problem as socio-technical in nature, rather than by just making technical changes to the fabric of the building.

Overheating in summer is a problem in existing classroom buildings in South East Queensland. Older timber classroom buildings were originally constructed with little or no insulation to resist heat from solar radiation. Clusters of individual buildings are surrounded by asphalt surfaces, another source of heat to classrooms. A common solution to achieving thermal comfort in overheated houses, offices or schools in Australia, as in other developed countries, is to install air-conditioning (Roaf et al. 2010). However, it is possible that schools in South East Queensland could improve the thermal comfort in their existing classroom buildings using methods involving low energy such as stack ventilation, cool roof, shade sails over courtyards, and schoolyard greening.

In 2011 a school community decided that, instead of installing air-conditioning, they wanted to fund alternative, passive cooling strategies to reduce heat in their classrooms, and to prevent burdening the school with increasing electricity costs. The Parents and Citizen's Association asked school parents for advice. A response came from a parent who is an architect experienced in designing workplace and childcare buildings for the subtropics. A research project emerged looking for effective, passive, cooling strategies for the school, within a worldview that retrofits to existing buildings should be designed with a climate responsive approach to reduce reliance on electrical devices for cooling and heating. Consultation with the Parents and Citizens' Association and the School Principal followed. The cooling strategies had to incorporate particular criteria; be of low capital cost, have little or no running costs, be suitable for retrofitting to timber buildings, able to be equitably applied across classroom buildings, and would cause minimal disruption to normal operations of the school. Of interest also was the idea that cooling strategies, using these criteria, have the potential to be applicable to other, similar schools.

In order to understand the issues surrounding thermal comfort and passive cooling strategies, an extensive review of the literature was undertaken in *Chapter 2 – Literature Review*, linking relevant fields of research; the adaptive comfort approach, thermal comfort studies of school children in tropical and subtropical climates, studies of thermal comfort behaviours of teachers and school children, passive cooling strategies that have been implemented to schools, urban heat island mitigation measures applicable to schools, and energy saving behaviours in Australian society. An outcome of the literature review was the clear need for further exploration around thermal comfort and passive cooling strategies in existing older school buildings in subtropical climates, such as in south east Queensland.

A study was devised where the application of passive cooling strategies to an older school in Brisbane was linked with information from teachers regarding their effectiveness. This study has been designed to explore the following research questions:

1 How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

2 What is perceived to be an acceptable comfort zone for classroom occupants?

3 What adaptive actions do teachers currently practise to reduce discomfort from overheating in their classrooms?

The structural logic of the thesis follows the traditional structure of introduction, literature review, methodology, results, discussion and conclusion. This *Introduction* has provided a background to the case study research. *Chapter 2 - Literature Review* informed the research questions for the study. *Chapter 3 Method – The Case Study* begins with a description of the case study school and the passive cooling strategies that were implemented to the school. Then, with the physical context established, the research design of a case study with mixed methods approach to analysing quantitative and qualitative data is explained. This is followed by explaining quantitative and qualitative methods used in the study. The results of the study are in *Chapter 4 Results - Temperature Analysis* and *Chapter 5 Results – Perceptions Analysis*. *Chapter 6 Discussion* begins with a convergence of the findings of the temperature and perception results over the year 2014. The chapter continues discussing findings in response to the three research questions, referring back to literature reviewed for the study. The Discussion chapter includes implications of the research, primarily the transferability of these findings of this case study to other schools and a fourth research question that has emerged from the study. The thesis finishes with *Chapter 7 Conclusion* and includes proposed future research directions.

Chapter 2 Literature Review

2.1 Introduction

The previous chapter introduced the case study of a Brisbane school and background to the research project. The purpose of this chapter is to position the study within the relevant field of research and determine the research questions.

In order to understand the issues surrounding adaptive thermal comfort and implementing passive cooling strategies in a school, an extensive review of the literature was undertaken linking relevant fields of research. This chapter presents each field in a section and the order of these can be referred to in the content pages of this thesis. At the end of this chapter is a summary of the key findings of the literature review and their relationship to the research questions of the case study.

An outline of how the relevant fields of research are linked together is discussed here. To better understand how thermal comfort is currently defined in in the literature, particularly for naturally ventilated classrooms, the adaptive comfort model, thermal comfort studies in sub-tropical and tropical classrooms, and thermal comfort behaviours of teachers and school children were reviewed. Focussing into the topic of interventions to existing schools that aim to reduce overheating in classrooms, other case study schools where interventions have been proposed or have been implemented, were reviewed. Broadening the review further, urban heat island mitigation measures relevant to aspects of the case study school environment were reviewed. These were in particular the reduction of asphalt covered ground surfaces, application of heat reflective cool roof and increasing vegetation in urban environments. As this case study aimed to investigate the impact of interventions in the physical and social context of the school, developing a framework of how to research social complex problems and developing an appropriate research design, required reviewing relevant studies that linked social and technical aspects of the environment in the same study. Methods of collecting and combining quantitative data from the built environment and qualitative data from occupants of the same environment were also reviewed. To better understand the broader social context of the school, themes of sustainability and climate change as reasons for low carbon behaviours in Australian society and the Australian school context were reviewed.

2.2 Understanding Thermal Comfort in Naturally Ventilated Classrooms

In the late twentieth century in Australia, as in the USA and European countries with similar living standards, a common solution to achieving thermal comfort has been to install air-conditioners in buildings (Roaf et al. 2010). Due to the need to reduce greenhouse gas emissions to reduce the impacts of climate change, however, the link between energy use in buildings and thermal comfort has become an increasing area of research over the last twenty years (de Dear et al. 2013). In their review of this field, De Dear et al. suggest that changes in the way thermal comfort is delivered to building occupants is being driven by climate change and the urgency of decarbonizing the built environment. They have extensively reviewed the changes that have occurred in the field. One of these changes is that thermal comfort has shifted from Fanger's steady state chamber experiments testing the physiological reactions of the human body in a chamber of changing interior conditions (Fanger 1970), to field studies of mostly adult populations in office environments (de Dear and Brager 1998).

Thermal comfort research has been dominated by understanding the environmental and personal factors that contribute to the heat balance equation of the human body (de Dear et al 2013). The Predicted Mean Vote (PMV) method used to determine thermal comfort is based on understanding how the body regulates itself to external environmental factors of humidity, ambient temperature, radiant temperature and wind, and personal factors of layers of clothing and metabolic rate. Participants of a thermal comfort study using the PMV method, cast thermal sensation votes on a seven point scale of 'Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm, and Hot' (ASHRAE 2013). However this relationship of body to the immediate interior environment in the PMV method is regarded as the same for any location and a static model of thermal comfort (Brager and de Dear 1998). An important development in understanding factors to thermal comfort has been the hypothesis that the interactions occupants have with their buildings influences their level of thermal comfort. This is known as the Adaptive Comfort Model, which identifies a dynamic relationship between interior temperatures that the majority of the population regard as acceptable, to the exterior temperature of the location, for naturally ventilated buildings (Nicol and Humphreys 2002, 2009, 2010; de Dear and Brager 1998, 2002; Nicol, Humphreys & Roaf 2012).

2.2.1 Adaptive Comfort Model

The Adaptive Comfort Model suggests that occupants can be comfortable in a higher range of temperatures in naturally ventilated buildings if they have ways of adjusting their environment to suit them. Nicol, Humphreys and Roaf (2012) suggest that people react in ways that tend to restore their comfort if they experience a change that produces discomfort. Ways of achieving comfort are by opening windows to increase cross-ventilation, using window shutters, blinds or curtains to control solar gain on glazing and glare, and turning on ceiling fans to increase air movement with a range of speeds (Nicol, Humphreys and Roaf 2012). The Adaptive Comfort Model is based on the relationship between an indoor comfort temperature band and the running mean of the number of previous days' outdoor temperature. The indoor temperature band range varies seasonally. In summer, warmer indoor temperatures are acceptable to occupants compared with cooler indoor temperatures in winter. Nicol, Humphreys and Roaf suggest that this understanding can be used to design comfortable buildings and also to encourage more research around comfort in other regions 'to see the complexities of the comfort system they themselves inhabit' (2012, p23). Describing this model further, de Dear and Brager (1998) describe three adaptive processes. They are physiological (acclimatization), behavioural (using operable windows, fans etc.) and psychological (habituation or expectation of prevailing climatic conditions).

The Adaptive Comfort Model has been developed and included into two standards used by engineers of indoor environments. In Europe, Standard EN1521 is more widely used based on the work of Nicol and Humphreys (2002, 2009, 2010). The development of Standard EN15251 used data from the European Union project Smart Controls and Thermal Comfort (SCATs). It concentrated on naturally ventilated office buildings in free running mode. The other standard is the Adaptive Model developed by Brager and de Dear (2001) for the American Society of Heating, Refrigerating and Air-conditioning Engineers, included as a section in ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy.

Thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment" (ASHRAE 2013, p19). The purpose of ASHRAE Standard 55 (2013) is to identify combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions, which are acceptable to a majority of the occupants within a space. The Standard states that environmental factors includes air temperature, radiant temperature, air speed and humidity and personal factors include metabolic rate and clothing insulation. ASHRAE Standard 55 was originally developed for engineers to use to determine indoor conditions when designing heating ventilation air-conditioning equipment, usually for office type buildings occupied by adults. Due to increasing research into the Adaptive Comfort Model, the 2002 issue of ASHRAE Standard 55 included a section that provided an optional method for determining acceptable thermal conditions in naturally conditioned spaces. Brager and de Dear developed the Adaptive Comfort Model based on an analysis of 21,000 sets of raw data, compiled from thermal comfort field studies in 160 buildings located on four continents in varied climatic zones. Brisbane was one of six Australian cities included in the RP-884 database. The buildings were separated into heating ventilation air-conditioned (HVAC) and naturally ventilated buildings. The naturally ventilated buildings were defined as having no mechanical air-conditioning and ventilation occurred when occupants used windows or operated ceiling fans. Occupants of buildings were asked to provide their Thermal Sensation Vote (TSV) using a seven-point scale of 'Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm and Hot'. At the same time, indoor operative temperatures (a combination of air temperature, radiant temperature and humidity), metabolic levels and outdoor temperatures were monitored. The middle ranges of the TSV (Slightly Cool, Neutral and Slightly Warm) were regarded as acceptable. Plotting the middle three TSV Votes with the indoor operative temperature and the outside monthly mean air temperature of the location resulted in a scatter plot graph forming distinct bands for 80% and 90% of the population. Figure 2.1 shows the bands of acceptable indoor air temperatures for 80% (7°C wide) and 90% (5°C wide) of the population.

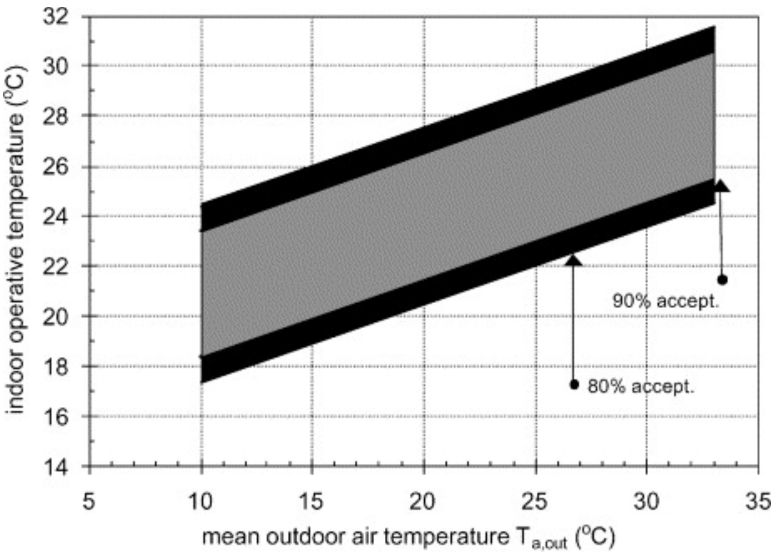


Figure 2.1 Acceptable Indoor Temperature Ranges for Naturally Conditioned Spaces (Brager and de Dear 2001)

Both standards, ASHRAE 55 and EN15251, have similar graphs but there are differences in their development and use. The ASHRAE chart applies only to naturally ventilated buildings while the EN15251 chart applies to any building in a free-running mode, when heating ventilation air conditioning is turned off and windows are open to outdoor temperature. Office buildings with mechanical ventilation and openable windows were included in the EN1521 data if operating in free running mode, but this building type was excluded from the ASHRAE Standard (Nicol and Humphreys 2010). Also, the monthly mean was first used in ASHRAE 55 (Brager and de Dear 2001). A more accurate mean was found to be the exponentially weighted running mean (Nicol and Humphreys 2002; Nicol, Humphreys and Roaf 2012; Ferrari and Zanotto 2011). This method was included in later versions of ASHRAE Standard 55, allowing researchers to choose between using a running mean for seven days or 30 days previous to the day in question of the thermal comfort study (ASHRAE 2010; 2013). This research project refers to the Adaptive Comfort Model defined in latest version of ASHRAE 55 (2013), as it has been used for thermal comfort studies in Australian schools (de Dear et al. 2015), sub-tropical countries (Kwok & Chun 2003;

Puteh et al. 2012; Hwang et al. 2009; Yang and Zhang 2007) and tropical countries (Wong & Khoo 2003).

ASHRAE 55 states that the Adaptive Comfort Model can be applied to naturally conditioned spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows and that meet all of the following criteria:

a) There is no mechanical cooling system (e.g. refrigerated air-conditioning, radiant cooling or desiccant cooling) installed. No heating system is in operation.
b) Occupants have metabolic rates ranging from 1.0 to 1.3 *met* (near sedentary level)
c) Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5 to 1.0 *clo* (lightweight clothing).
d) The prevailing mean outdoor temperature is greater than 10°C and less than 33.5°C.

Another suggested use for the Adaptive Comfort Model is to determine building performance over a longitudinal study (ASHRAE 55, 2013). As yet, no longitudinal study comparing time periods using the Adaptive Comfort Model have been found in the literature.

In applying the Adaptive Comfort Model to any location, the external temperature is the key environmental input and humidity levels of the environment are not included. A concern is that as the Adaptive Comfort Model refers only to temperature, it is not an adequate determining factor when assessing discomfort in warm humid climates, such as Brisbane, Australia. In the 2004 version of ASHRAE 55 the effective outdoor temperature was replaced with dry-bulb temperature, simplifying the standard. ASHRAE authors noted that 'the following effects are already accounted for and therefore it is not required that they be separately evaluated: local thermal discomfort (draft), clothing insulation, metabolic rate, humidity and air speed' (ASHRAE 2013, p.13). The reason for this was that the development of the Adaptive Comfort Model involved field studies in differing climate zones including the hot humid tropics. However this meant that effects of humidity on comfort were not to be captured by applying ASHRAE's Adaptive Comfort Model (de Dear et al. 2013).

In a study by Nicol (2004) the adaptive comfort model was applied to thermal comfort studies in hot humid locations, including Brisbane. Nicol found that the effect of humidity on the acceptable temperature range of comfort was narrowed; the upper threshold is reduced down in temperature by one degree (2004). High humidity levels (>75%) are uncomfortable for occupants as the high level of moisture content in the air limits the transfer of perspiration from skin. Increasing air movement across the skin increases the process of perspiration and is an approach to providing comfort (Allard and Santamouris 1998). The ASHRAE 55 recognises the effect of increasing air speed on comfort, and for spaces with indoor temperatures over 25°C states that the upper limit can be increased according to the speed: average air speed 0.6m/s increases the upper limit by 1.2°C, 0.9 m/s increases by 1.8°C and 1.2m/s increases by 2.2°C (ASHRAE 2013, p13). However, to include this increased upper temperature level in a study would require an audit of all fans in a location to check their air speeds and pattern of use by occupants.

2.2.2 A Thermal Comfort Study of Australian School Children

In recent work by thermal comfort researcher, de Dear, a survey of the thermal comfort of school children in Australian schools was undertaken with the aim of defining the preferred, neutral and acceptable temperature ranges for Australian school children (de Dear et al. 2015). The survey was conducted across nine, primary and secondary schools, in a variety of classrooms with and without mechanical cooling systems. Three schools were naturally ventilated, three had evaporative cooling, and three had air-conditioning systems. The aim of the study was to inform a thermal comfort (air conditioning) policy being developed for a portfolio of schools across one state in Australia, New South Wales. Although some classrooms were equipped with air conditioning, using operable windows and ceiling fans was regarded as the primary method of space cooling. Unfortunately, air conditioning use was not monitored in the survey results. It would be informative to link the children's responses with either naturally ventilated or air-conditioned classrooms.

There were two main aspects to the study. The first aspect was to conduct thermal comfort studies investigating the perceptions and preferences of students in the classrooms and, at the same time, indoor temperatures were collected, as described in AHSRAE 55. Questionnaires were collected from 2850 school children aged 10 to 18. The study found an indoor operative temperature of 22.5°C was the neutral and preferred temperature of the children. The acceptable temperature range for primary and high school students was 18.5°C to about 26.5°C in summer. Interestingly, this range is cooler than the range from the Adaptive Comfort Model, which suggests 80% of adult populations prefer temperatures of 21 - 28°C.

A second aspect of the research was to apply an overheating metric protocol to the nine schools to find the number of hours they exceeded the upper 80% threshold of the Adaptive Comfort Model during school hours. The study followed an operational protocol shown in Table 2.1 (de Dear and Candido 2012).

Table 2.1 Operational Protocol for Applying the Overheating Metric

	Operational Protocol for Overheating Metric
Step 0	Identification of local threshold
Step 1	Monitoring indoor thermal conditions across the property portfolio
Step 2	Monitoring outdoor weather conditions across the property portfolio for heat-wave criteria
Step 3	Tallying the number of occupied hours in an operation year
Step 4	Calculating the running, exponentially weighted mean outdoor temperature
Step 5	Calculate daily adaptive acceptable temperature threshold
Step 6	Tally all temperature exceedance hours in the monitoring period
Step 7	Decision regarding remediation of comfort conditions

Source: de Dear and Candido 2012

Their findings showed the number of hours that indoor temperatures exceeded the upper 80% threshold of acceptability was relatively low; 1.9% of total occupied hours. Although the focus was on overheating, it was found that the number of hours below the lower 80% threshold was greater; 7.1% of total occupied hours. This study suggested that the classrooms had more of a problem being under-heated than overheated.

The results of the study found that the schools sorted into two distinct groups of thermal sensitivity; low thermal sensitivity (highly adaptable to outdoor temperature variations), and high thermal sensitivity (low adaptability to outdoor temperature variations). The highly adaptable schools were located in climates with higher temperature diversity than the schools with low adaptability. Their observations of the low adaptability group of schools 'comprised more naturally ventilated schools than air-conditioned schools dispelling the suspicion that Australian school children are becoming addicted to air-conditioning' (de Dear 2015 et al., p.315) An earlier discussion of the study suggested this might be the situation (de Dear et al. 2014).

Interestingly, recommendations in a conference paper from the study differed from the later published version (de Dear et al. 2014, 2015). In the conference paper, de Dear et al. were wary of the finding of 22.5°C being taken as a benchmark for comfort in schools, as it could result in an overzealous roll out of air conditioning units in schools. They raised the major policy question of whether the New South Wales State Government 'should design, build and operate its school building stock in a way that reflects, or even anticipates these comfort pressures to air condition every classroom and buffer their occupants entirely from the natural rhythms of daily weather, season and climate?' They used the strong counter argument that some disadvantages of air conditioning split system units are that they recirculate air, reducing indoor air quality, which may negatively impact student health and performance (de Dear cite Mendell & Heath 2005). Their recommendations were to limit the installation and use of air conditioning in this portfolio of schools to classrooms where there is demonstrable overheating occurring, and once installed they should be operated as the comfort strategy of last resort, not the default. They further suggested a policy be put in place to operate air conditioning only when upper temperature thresholds are exceeded, removing individual teachers from deciding when to turn on the air conditioning (de Dear et al. 2014). The most noteworthy changes in recommendations from the conference paper (2014) to the published paper (2015) were a) to use a threshold of upper temperature to inform a policy of when air conditioners are in operation, b) that the decision to install air-conditioning in a school should be made on a case-by-case basis by referring to the frequency of adaptive thermal comfort criteria being exceeded, and c) to take into account the thermal performance of each building within its specific climatic context (de Dear et al. 2015).

There are further limitations in using a threshold method of counting the frequency the temperature is over an upper limit (too hot) or under a lower limit (too cold). This method of counting frequency only indicates when the temperature is over a threshold; it could be over by half a degree or by three. A different method is needed to measure the extent of the high temperatures in classrooms, in order to validate the perceived problem of overheating in classrooms.

2.2.3 The Adaptive Comfort Model and Outdoor Temperature

There are two main methods of inputting outdoor temperature into the Adaptive Comfort Model; the monthly mean temperature (T_{mm}) or the running mean temperature (T_{rm}) (Ferrari and Zanotto 2011). Monthly mean temperature (T_{mm}) is based on a historical series of air temperatures in a specific location, representing the typical climate of the location. Monthly data is readily available from nearby weather stations and is calculated as a simple mean. The first version of ASHRAE 55 Standard used the monthly linear mean. It was replaced in later versions with an exponentially weighted running mean for 7-days previous or 30-days previous, to the day in question (ASHRAE 2010, ASHRAE 2013).

Nicol and Humphreys (2002) suggested the use of running mean temperature (T_{rm}) as it allows a higher reliability in the relationship between indoor and outdoor temperature. In thermal comfort studies the occupants' evaluation of indoor environmental conditions is directly compared with temperature, humidity and other environmental factors, for that particular day. Running mean temperature is an average of the mean daily temperatures of a certain number of previous days before the day in question (present day $_{od}$) with an exponential weighting applied to the previous days. The most weighting is given to the immediately previous day and decreases in weight further away from the day in question.

$$T_{rm} = (1-\alpha)\,(T_{od-1} + \alpha\, T_{od-2} + \alpha^2\, T_{od-3} + \alpha^3\, T_{od-4} + \ldots)$$

where T_{od-1} is the yesterday's daily mean temperature, T_{od-2} is the day before that, and so it goes on for seven days previous

where α is a constant value, ranging between 0 and 1 representing the time for a person to respond to a change in weather conditions through their clothing response

For the value of α, Nicol and Humphreys suggest a α=0.8, based on the European SCATs database. ASHRAE 55 recommends that a slow-response running mean with α=0.9 be used in climates where day-to-day temperature changes are minor, as in the humid tropics (ASHRAE 2013). In the overheating metric for Australian schools, de Dear and Candido used α=0.6 (2012).

In a study applying the Adaptive Comfort Standard to two cities in Brazil, both linear and exponential methods were used to calculate mean temperatures and the results compared as shown in Figure 2.2 (De Vecchi et al*.* 2015). De Vecchi et al. found that when the climate of the location had a smaller day-to-day temperature range, then the methods produced similar results. But when significant day-to-day temperature variations are present then results varied, leading to different comfort thresholds and consequently different sums of discomfort hours. The city with the steadier temperature range was tropical Belem, close to the equator within the Amazon rainforest. The city with the wider, day-to-day range was Florianopolis, located at a latitude of 28°S with a humid, subtropical climate, similar to Brisbane's latitude of 27.5°S and in the same Köppen climate classification Cfa, shown in Figure 2.3 (Peel et al 2007). When De Vecchi et al. compared the discomfort hours between monthly mean results and exponentially weighted results, the difference was within 1%; the monthly mean method produced 27% of discomfort hours, the exponentially weighted results 28% (using α=0.6) and 26.6%. (α=0.8). Within 1% is a relatively small difference between results if the purpose of a study is to indicate how much time a location's temperature is generally outside the acceptability zone. Although, when the results are graphed, the outdoor temperature rise and fall can be seen to affect the threshold lines the most in the exponentially weighted results images a) and b) in Figure 2.2.

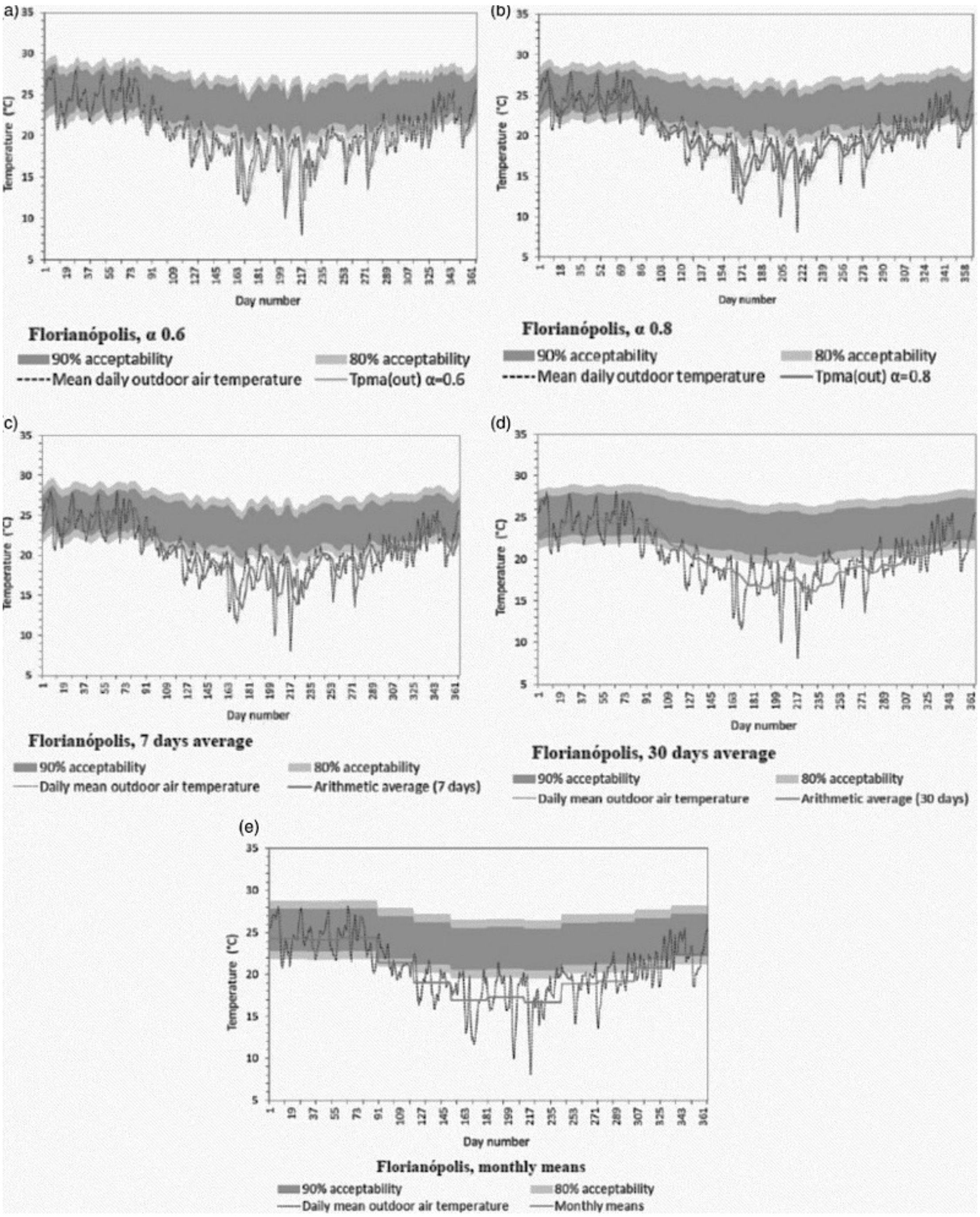


Figure 2.2 Comparison of Adaptive Comfort Model as a Result of Differing Mean Methods (De Vecchi et al 2015)

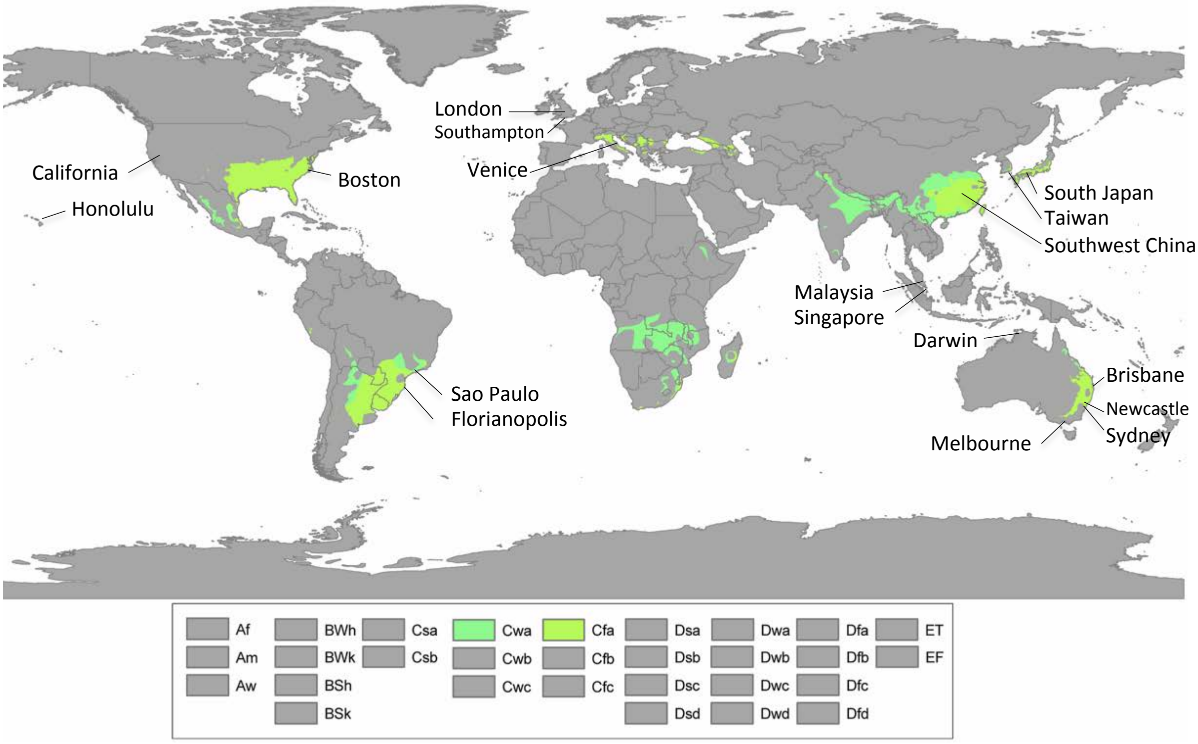


Figure 2.3 Köppen World Map showing subtropical areas Cwa and Cfa (Peel et al. 2007) and locations of studies reviewed in this chapter

2.3 Thermal Comfort Studies in Sub-Tropical and Tropical Classrooms

Countries such as Singapore, southern Japan, Malaysia, Taiwan, and southwest China traditionally have naturally ventilated classrooms and over the past decade the question has arisen of whether to air-condition classrooms, as has been the practice in Western countries. As living standards have improved in these countries, air-conditioning has generally become more affordable. To assess the thermal comfort of children in naturally ventilated classrooms, the ASHRAE Standard 55 has been used in thermal comfort surveys in Singapore (Wong and Khoo 2003), Japan (Kwok & Chun 2003), Malaysia (Puteh et al. 2012), Taiwan (Hwang et al. 2009) and sub-tropical China (Yang and Zhang 2008).

In these studies, a large proportion of the students reported “neutral” in naturally ventilated classrooms at temperatures greater than the comfort zone of the Adaptive Comfort Model. However, given a choice, a large proportion of occupants preferred to be cooler. In Singapore for example, the occupants found the acceptable range of indoor temperatures to be from 27.1 to 29.3°C. The “neutral” temperature was 28.8°C (Wong and Khoo 2003). In Japan, 72% of the occupants of the naturally ventilated classrooms expressed satisfaction with the indoor climate conditions at 26.9°C. When the occupants were asked what they would prefer, more than half responded that they would prefer to be cooler (Kwok & Chun 2003). In Taiwan it was found that 87% of respondents indicated that they were satisfied with the level of thermal comfort in their classrooms, even though only 35% of the physical measurements fell with the ASHRAE comfort range for 80% acceptability (Hwang et al. 2009). Although the majority of the students perceived the thermal conditions to be neutral, they desired them to be cooler. These studies suggest that neutral temperature is not the same as the preferred comfort temperature.

2.4 Teachers' and Children's Thermal Comfort Behaviours

Within the field of research of teachers and children's thermal comfort behaviours in classrooms, of particular interest to this study were behaviours studied in overheated classrooms in schools with comparable environmental conditions to the case study school. The studies reviewed from the United Kingdom were from schools with asphalt areas surrounding classrooms. The studies reviewed from Brazil and Venice Italy, are from locations in the same climate classification as Brisbane (*cfa).*

2.4.1 Thermal Comfort Studies of School Children in the United Kingdom

A definition of overheated classrooms from the United Kingdom is internal operative temperatures greater than 28°C for more than 1% of annual occupied hours (Firth & Cook 2010). During a school year, when classrooms are occupied for 200 days, six hours a day, 1% is 120 hours (Firth & Cook 2010). In a study in four schools in Southampton, United Kingdom, classrooms were assessed for their overheating risk as it is predicted that summer temperatures are going to increase in the future due to climate change (Teli et al. 2011). A survey of the teachers in the four schools found that 80% of teachers found classrooms too warm in July. The teachers were asked what measures they undertook when overheating occurred. Window opening was top of the list. However, it was found that their buildings had poor cross ventilation and windows that only partially opened. This study is also interesting because outside surfaces surrounding school buildings were mainly tarmac (asphalt), similar to schools in South East Queensland.

Another study assessed the thermal comfort of children in classrooms, as comfort models are largely based on adult subjects in offices (Teli et al. 2012). A thermal comfort survey questionnaire was developed for primary school children aged 7 to 11, based on the ASHRAE Thermal environment point-in-time survey form (ASHRAE 2013). The survey showed that children responded with warmer sensation votes than adults and preferred a cooler indoor thermal environment. They suggested possible explanations for the children feeling warm. Children have a higher metabolic rate per kilogram body weight, they have limited adaptive opportunities in classrooms, such as opening windows themselves, children do not always adapt their clothing, such as removing their jumper, and children spend a lot of time outdoors playing, unlike adult occupants in offices who are more sedentary and stay inside for most of the day. Teli et al. suggested more research be done to verify their observations and obtain a better understanding around factors that influence children's thermal comfort.

A more recent study in the United Kingdom investigated whether children across two schools have different thermal preferences to adults (Teli et al. 2015). The two schools were in different building types and were surveyed over two years. One school was a 1970's lightweight steel frame building with prefabricated concrete wall panels, surveyed April to July 2011. The other school was a brick Victorian building constructed in 1884, surveyed a year later, April to July 2012. The thermal capacity per m^2 of the walls differed between the schools; the lightweight walls were 55 kJ/m^2K and the solid masonry walls were $169kJ/m^2K$. Thermal responses differed due to weather variables between the two years. Summer 2012 had a sudden shift from rather cool temperatures to a warm period, suggesting there was less time to thermally adapt, and possibly less tolerance to higher temperatures. This was reflected in lower comfort temperatures in the Victorian school survey. The variance between the thermal capacities of the buildings was regarded as an important parameter in thermal comfort. In the lightweight school the correlation of comfort temperature with the outdoor running mean temperature was stronger, as it was more affected by the outdoor climate, compared with the Victorian brick school. The higher thermal mass walls of the Victorian school created a more stable indoor thermal environment, isolating the occupants from the outdoor temperature variations. It was found that the children preferred approximately two degrees lower comfort temperature than the Adaptive Comfort Standard, which is based on adults in offices. As they found comfort temperature is sensitive to weather anomalies they suggest referring to a wider temperature band, rather than a regression line, as a more appropriate way of representing the relationship between indoor comfort and outdoor temperature (Teli et al. 2015).

2.4.2 Thermal Comfort Studies of School Children in Brazil and Italy

Two thermal comfort studies that investigated adaptive actions of school children in Brazil, found children tended not to adjust their environment to suit their comfort. This was attributed to either having restricted spontaneous movement in the classroom due to discipline codes (Bernardi and Kowaltoski 2006), or teachers' preferences taking precedence over children's preferences (De Guili, Da Pos and De Carli 2012).

Bernardi and Kowaltoski conducted a case study investigating user perception and behaviour in classrooms in two schools in Sao Paulo, Brazil (Bernardi and Kowaltoski 2006). The study examined user awareness and the attitudes of students in adjusting classroom conditions for their comfort. This study followed an earlier study measuring comfort conditions in 15 of 150 public schools of Campinas, Brazil (Kowaltowski et al. 2001). The earlier study identified students' reactions to changes in the classroom space (changing furniture location and window arrangement, while the children were out of the classroom) and knowledge of environmental comfort concepts. Fifteen schools were chosen randomly and questionnaires given to students, teachers, staff and directors, assessing values such as satisfaction, preferences, desires and dislikes. From this data a broad evaluation of the comfort conditions was made, prior to the second study, which involved observations of user awareness and interactive behaviours with the environment. The second study observed student's behaviour in two schools over four days. Physical measurements within classrooms were also taken of wet and dry bulb air temperature, air speed and lighting levels (Bernardi and Kowaltoski 2006).

Bernardi and Kowaltoski found that children in a classroom do not have the same freedom as an adult to move about the room, to open a window to adjust their comfort. This study enforces the notion that the teacher has control of adjusting the physical classroom environment to improve comfort for themselves and the children. They also suggested that the classroom could be a place for teaching concepts of environmental comfort to children. Teachers could lead by example through their behaviour, actively changing the classroom to suit comfort levels in the classroom. Kowaltowski (citing Gifford 1976), suggested that the concept of environmental numbness, described as a type of paralysis in the individual where the user rarely exercises any attitude in relation to unpleasant situations, could be a reason for the children's lack of making adjustments in the classroom. However, according to Bernardi and Kowlatoski (2006), as children have restricted movement in the classroom, environmental numbness is not a reasonable explanation.

A study designed to find a relationship between the building and well being of school children was undertaken in seven schools near Venice (De Guili, Da Pos and De Carli 2012). School children's perceptions of their indoor environment were studied in 28 non air-conditioned classrooms, involving 614 children aged 9 to 11. Physical spot measurements of temperature, humidity, illuminance and CO_2 concentration levels in the classroom were taken. At the same time students completed a questionnaire evaluating the indoor environmental conditions with their level of satisfaction, their reactive behaviour towards discomfort, and their level of interaction with the environment, such as opening a window. Non-parametric statistical tests mapped significant differences between schools, and between girls and boys in the same school, to provide levels of comparison for the study. Children's reactions towards discomfort were evaluated to understand if children behaved as passive users, which the researchers believed frequently occurs with adults. They found the main issue children had with indoor environment was uncomfortably high temperatures in summer. In addition, some schools had poor air quality and noise issues. Response options on the questionnaire were 'active user', 'passive user' or 'did nothing'. A response such as asking the teacher to do something was identified as a ‘passive user’ response. The majority of the responses described the children as ‘passive users’ or ‘did nothing’. De Guili et al. concluded that the children were passive because they could not interact with the environment as the teacher decided on the level of lighting, set the shades and opened windows. They further suggested that classroom controls could be automated to provide good environmental quality, instead of leaving it to teachers’ preferences.

Further modification to the questionnaire was considered. Some proposed questions asked the children not what they do, but what the teacher does in reaction to discomfort, for example ‘Does the teacher open the windows during the break?’ A more direct research approach is to design a questionnaire for teachers.

2.5 Retrofitting Interventions to Overheated Classrooms

At the time of undertaking this literature review, there were no studies in subtropical climates that reported retrofitting existing school buildings with interventions to alleviate overheating. The most relevant was a report prepared for Hawaiian schools studying aspects of thermal comfort (Goore 2015). The climate of Hawaii is mostly tropical. At sea level, temperatures in summer range from 29-32°C and in winter 26-28°C. The Department of Education in Hawaii was under social pressure to air condition all classrooms but to do so was not considered economically feasible or environmentally desirable (Aguilar 2008, Hawaii DOE 2015). Adopting a more realistic approach, the Department developed a heat abatement program for overheated classrooms in the existing stock of school buildings (Hawaii DOE 2015). Air conditioning was included in the heat abatement program, but passive cooling strategies were preferred as they are lower in cost compared to the ongoing electricity costs of air conditioners (Goore 2015).

A pilot school near Honolulu was identified as having building factors that impact on classroom temperature. Classrooms in the older buildings of Campbell Elementary were monitored and found to have higher maximum temperatures than outdoors. The study of the physical environment of the school revealed building factors that impacted on classroom temperature.

- Windows with louvers allowed less airflow than windows with larger openings.
- Buildings had no overhangs to shade windows from the sun.
- Rooms three floors above the ground were consistently 3-5°F warmer than lower levels. This was attributed to roof colour and insulation level.
- A black roofed building was consistently 3-5°F warmer than a grey roofed building throughout the school year.
- A room adjacent to asphalt paving was 6°F warmer than a room adjacent to grass.
- In addition, an air-conditioned portable building was compared to a non air-conditioned portable building. It had a narrower indoor temperature range throughout the school year, August 2013 to April 2014.

In this Hawaiian school Goore found that 'solar gain is the single most important contributor to interior temperature' (2015, p 7). Three types of interventions to classroom buildings were recommended: 1) reduce solar gain, 2) increase natural ventilation and, 3) use mechanical conditioning. To reduce solar gain they used lighter roof colours, added roof insulation, replanned paved areas, shaded asphalt surfaces adjacent to rooms, and provided natural shading by trees. To increase natural ventilation they addressed fenestration configuration, used unpartitioned rooms, and practiced night flushing. Mechanical conditioning considered first ceiling fans, then photovoltaic powered air conditioning units, and optimizing air conditioning usage. Goore suggested the recommended interventions should be tested in the field to validate their effectiveness (2015).

Nearer to Brisbane, a multi-case study in Newcastle, New South Wales, Australia, evaluated the thermal comfort of occupants in naturally ventilated, mixed mode and air-conditioned buildings on a university campus (Dixon 2005). The study investigated low energy ventilation strategies as a way to reduce energy consumption in non-residential buildings. Results showed that 'attaining satisfactory thermal comfort at all times in non-air conditioned environments is difficult or impossible in this climate' yet Dixon (2005) suggested that 'optimum comfort in such environments lies with the ability to fine-tune the building/climate relationship' and 'lies in thoroughly understanding the limitations of passive design concepts'. Using passive design concepts of ventilation is challenging in hot and high humidity conditions.

An existing school building type in New South Wales, the demountable classroom, was studied for continued use (Slee and Hyde 2014, 2015a, 2015b). These buildings are also used in Queensland schools. Demountable classrooms account for 12% of all New South Wales government classrooms. Poor thermal performance and internal environmental quality are reasons why occupants perceive demountable classrooms as sub-standard and even obsolete (Slee and Hyde 2015b). They investigated ways to improving the thermal performance of these buildings. They found temperatures inside demountable buildings were warmer than outside in summer months and that the largest thermal heat gain was from solar radiation (Slee and Hyde 2015b). To reduce solar gain, they suggested using ventilated facades and ventilated roof cavities. To moderate heat inside, the use of phase change materials, instead of retrofitting thermal mass, was suggested (Slee and Hyde 2015a). Considerations such as whether these interventions can be implemented to existing buildings, who would fund them, at what cost, and how long it would take to implement, are yet to be considered.

In Queensland, a study on a courtyard building at the Sunshine Coast University discussed causes of overheating of classrooms compared to the outside temperature (Rajapaksha and Hyde 2012). Overheating occurred when there were no breezes in the courtyard. Increasing airflow through the building was suggested to reduce overheating, however, how this improvement might be done was not discussed (Rajapaksha and Hyde 2012).

In Europe there have been retrofits to education buildings to reduce overheating in summer. The cooler European climate generally requires buildings to have heating in winter, but as buildings are designed to keep heat in during winter this can cause overheating problems in summer (Tritantis 2005). A collection of twenty-five case studies of buildings used for education in nine countries in Europe (including

Germany, Norway, Denmark, Greece, United Kingdom) as well as the United States, has provided insights into a bioclimatic approach to retrofitting and understanding buildings as a space system, to improve classroom conditions. Most of the education buildings were two to five storeys high, constructed of brick or other high thermal mass walls, and had retrofitted interventions that increased ventilation by using stack devices, double skin facades, and transition spaces such as atria or courtyards with skylight roofs (Tritantis 2005).

In the United Kingdom, warmer summers have been on the increase and have been suggested by some researchers as an early indication of climate change. A response is for buildings to be more naturally ventilated to reduce energy consumption in buildings (Tuohy et al. 2010). Increasing cross ventilation contributes to the thermal comfort of occupants, as higher air velocities increase evaporation rate on the skin's surface and enhances the cooling sensation. Air speeds of 0.8 metres per second can make a space feel 2°C cooler to occupants (Allard 1998). Santamouris and others discuss passive cooling to new and existing buildings of all types (Santamouris and Asimakopoulos 1996; Santamouris 2007; Santamouris et al. 2007; Givoni 2011). They also discuss building ventilation (Santamouris and Wouters 2009, Allard and Santamouris 1998).

Santamouris was involved in the Teenergy Schools: High Energy Efficiency Schools in the Mediterranean Area Project, across schools in Italy, Greece, Spain, and Cyprus. The project aimed to improve energy efficiency in existing secondary schools, through implementing common strategies for the three Mediterranean climatic regions of coast, mountain and plain (Teenergy 2009). The project provided research support to school building designers about energy saving techniques, renewable energies, the integration of innovative materials, the improvement of heating systems and strategies for passive cooling. Twelve pilot school projects tackled issues of upgrading indoor conditions in terms of thermal comfort, air and lighting quality, and improving the energy behaviour of new school buildings and retrofitted schools. Passive cooling improvements, during summer, on two pilot schools included installing insulation, installing new windows with heat reflective glass, using sun-shading devices to reduce glare and solar gain, and implementing night cooling through sensor controlled openings (Teenergy 2009).

Designing climate responsive buildings in sub-tropical Australia to provide a level of comfort for the occupants is discussed by Hyde, Groenhout, Barram, Yeang 2013, Kennedy 2010, Prescott 2001, Hyde 2000, Australian Government 2010, and Think Brick 2014. Architectural science principles are discussed by Koenisberger et al. 1980, Kwok & Grondzik 2007, and Szokolay 2008 and the seminal bioclimatic design approach is explained by Olgyagy 1963. Givoni's 1992, 1998, 2011 research of passive cooling strategies for buildings and urban design in warm humid climates suggests that using daytime ventilation for comfort, such as cross ventilation and ceiling fans, is applicable in climatic regions where the outdoor maximum air temperature is in the range of 28°C – 32°C (1998). In Brisbane, the summer months of the year have day-time temperatures that occur mostly in this range (Bureau of Meteorology 2015). Givoni's advice refers to the general macroclimatic description of a region. However, buildings are sited in specific contexts and can be affected by the surrounding local physical environment resulting in them having their own microclimate (Erell et al. 2012). Oke (1987) describes a canyon effect occurring in cities where tall buildings block the paths of breezes and conditions closer to the ground are in their own layer or microclimate. Climate responsive design needs to consider both the general aspects of a region (macroclimate) with the local aspects of a site (microclimate).

2.6 Mitigation Measures for Urban Heat Island Effect

The Urban Heat Island Effect is a phenomenon where urban areas of cities are warmer compared to nearby rural areas, although they are in the same climate region. This is due to the presence of hard, paved materials such as asphalt and concrete (Givoni 1998; Santamouris 2012). Concrete and asphalt absorb solar radiation during the day and re radiate this as heat later in the day or night (Akbari and Rose 2001). A key indicator of the Urban Heat Island Effect occurring in a location is when the difference between the minimum and maximum temperatures is less compared to other nearby rural areas (Givoni 1998). Urban heat can have various negative impacts. It effects the energy consumption of buildings as people use air-conditioners to cool themselves, and it can exacerbate human thermal discomfort and health problems, especially among older and very young people. It can decrease the efficiency of air conditioners, reduce the cooling potential of natural ventilation during the day and of night flushing ventilation techniques, and it can increase pollution levels (Santamouris 2007b; Rosenfeld et al 1997).

There is extensive research on urban heat island mitigation strategies (Heat Island Group 2016, Gartland 2008; Santamouris 2013, Short et al. 2004, Block et al. 2013, Smith & Levermore 2008, Taha et al. 1988, Givoni 1998, Erell et al. 2012, Lopes et al. 2001). For more than a decade the US research team at Berkeley Laboratory have provided research for reducing urban heat in the US and other countries (Heat Island Group 2016). In Melbourne, Australia, there is a research effort focused on implementing urban heat island mitigation being undertaken by the Victorian Centre for Climate Change Adaption Research (Block et al. 2013).

Three urban heat island strategies have been explored further:

- Cool roof, a heat reflective paint for roofs.
- Shade sails, to shade hard, paved areas.
- Schoolyard greening, by increasing vegetation around buildings.

2.6.1 Cool Roof

A heat reflective paint applied to roofs to reduce solar radiation from transferring through the roof sheeting to the internal space underneath creates a cool roof (Synnefa, Santamouris and Livada 2006; Shen, Tan and Tzempelikos 2011). The paint is typically white with high albedo (Santamouris 2012). Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface. White paint has the highest albedo (95-99%) and asphalt, a low albedo (5-10%) (Taha et al. 1988; Cheng and Givoni 2005). A cool roof surface reflects and emits the majority and full spectrum of solar energy, ultraviolet light (5% solar energy), visible light (43%), and infrared energy (52%) which is felt as heat (Chin et al. in United States Environmental Protection Agency 2008). Many cool roofs are bright white and obtain their high solar reflectance primarily from the visible light portion of the solar spectrum. A Melbourne study of a high albedo roof showed significant internal heat load reductions of up to 5°C and externally, on the roof, they were up to 30°C cooler (Jensen, Hes and Aye 2013). In another Australian study, a cool roof combined with insulation was compared with a green roof planted with sedum, a dry land plant species. The cool roof provided the greatest reduction in the transfer of heat through the roof (Coutts et al. 2013). The roof planted with sedum performed better when it was regularly irrigated and mulched with white gravel, thus increasing the roof albedo.

2.6.2 Shade Sails

Shade sails are commonly used to shade outdoor areas in Queensland schools, to provide protection to children from ultraviolet radiation (Kennedy et al. 1997). Shade sails are made of either shade mesh or waterproof fabric and are tensioned between three or more points on an existing building or to self-standing rigid (often steel) posts. Shade sails of a hypar form with distinctive high and low points have a greater span capacity than shade sails with flatter pitches (Armijos 2008; Huntington 2004, 2013).

Shashua-Bar, Pearlmutter and Erell (2009) compared shade sails with tree cover, in two virtually identical courtyards. The trees and shade mesh were calculated to provide the same amount of shade in each courtyard. However, there was an increased temperature effect in the courtyard with the shade mesh. The shade mesh courtyard was found to have reduced airflow and the air temperature increased by 0.9K. However in this study, the form and colour of the shade mesh was not defined, either of which could have been attributing factors to the heat observed in the courtyard. A photograph of the shade mesh showed it to be a relatively flat form stretched across the courtyard top with little space for air to move up and out the sides of the courtyard. This form would trap warm air underneath it. The mesh was black so its low albedo would reflect very little solar energy off the mesh surface (Cheng and Givoni 2005). Shade sails provide the best shading in the middle of the day, when shade is on the ground, directly under the sail (Turnbull and Parisi 2005).

Shading of low angle morning and afternoon sun needs to be addressed by additional screening elements to the sides of a shade sail (Turnbull and Parisi 2005).

2.6.3 Green Infrastructure

Increasing vegetation as a measure to reduce urban heat is called green infrastructure (IPCC2014; Motazedian and Leardini 2012). Studies have shown the impact of vegetation in cooling the surfaces of building walls and surrounding ground surfaces (Thani, Mohamed and Idilfiltri 2012, Smith & Levermore 2008, Dimoudi and Nikolopoulou 2003, Rosenfeld, Akbari, Romm, Pomerantz 1997). Bowler et al. (2010) conducted a systematic review about the urban heat island mitigation measure of increasing vegetation for possible applications in Melbourne. This review identified studies from other countries that investigated the cooling effects of vegetation on urban areas, parks and gardens, trees and forests, ground vegetation and green roofs. The review found that green sites are cooler than non-green sites and suggested that urban greening using parks and trees may cool the local environment. This suggests that greening on a wider scale, from a street to suburb or city, could have an impact on reducing urban heat, but this is yet to be demonstrated (Bowler et al. 2010).

Proponents of the Biophilia Movement explain how increasing vegetation not only provides cooling benefits to urban environments, but has other advantages such as providing habitat for various species and bringing nature closer to children (Beatley 2011, Kellert et al. 2008, Almusaed 2011). Biophilia was first termed by E. O. Wilson and refers to 'the inherent human affinity to affiliate with natural systems and processes' (Kellert 2008, p 3). Author and journalist Louv argues children of this current generation need to spend more time in the natural environment to reduce the negative effects of what he calls 'nature deficit disorder' (Louv 2008). One way to bring nature closer to children is to increase vegetation in the safe environment of a schoolyard (Moore and Marcus in Kellert et al. 2008).

A schoolyard greening movement in Boston used case study schools to illustrate some advantages of schoolyard greening (BSFC 2000). Another advantage of schoolyard greening is the transformation of an under used schoolyard into a garden with positive benefits for the school occupants. Birkeland calls the development of urban land in this way, Positive Development (2008). A study of college students found views of vegetation from classroom windows improved academic outcomes (Benfield et al. 2015).

A study of fourteen schools around Melbourne, with five hundred children, investigated the effects of vegetation around school buildings and found that the higher the level of vegetation in the school, the more highly the children rate that environment as 'restorative' (Bagot 2015). Spending time during breaks in a green playground can have benefits on children's attention performance in the classroom. Bagot (2005) suggests allowing children's brains to have a rest from the concentration required in the classroom, by encouraging them to become engaged and fascinated in the playground. Fascination with nature in childhood can be influential in developing a sense of stewardship for the earth. A study of people who take action on behalf of the environment found they recalled formative childhood experiences in nature (Chawla 2009).

2.7 Researching Complex Social Problems

Mixed Methods Research is an approach increasingly used in the social and human sciences (Creswell 2014). Mixed Methods Research developed because the "complexity of research problems calls for answers beyond simple numbers in a quantitative sense or words in a qualitative sense; a combination that provides the most complete analysis" (Creswell and Plano Clark 2011, p 20). Another reason for using Mixed Methods Research is because one data source may be insufficient to meet the research aims (Creswell and Plano Clark 2011). According to some researchers, the best philosophical foundation for Mixed Methods Research is pragmatism (Tashakkori and Teddlie 2010, Creswell and Plano Clark 2011, Creswell 2014). A pragmatic stance means a researcher will use any methods available to gain knowledge for a research aim; both quantitative and qualitative methods can sit within the same research project (Tashakkori and Teddlie 2010).

2.7.1 Evaluating the Impacts of Interventions

A number of studies assess the impact of interventions by identifying one factor (heat) through quantitative measurement and qualitative methods. A way of evaluating the impact of an intervention is to measure its effect. However, some researchers suggest that examining only one aspect and its cause and effect can be problematic in the context of assessing sustainable buildings (Hes and Plessis 2015). The issue is that sustainability measures or actions need to have measurable effects to have value. Hes and Plessis refer to current green building certification to illustrate this point. Performance requirements or objectives for a new building are often listed in a performance rating system; Greenstar in Australia, LEED in USA or BREEAM in United Kingdom. Ticking off items on a list gains a level of certification for the building; the more items the higher the level of certification. However performance objectives are set in a generalized context for buildings meaning a building could be energy efficient in itself but the design does not consider its actual environmental or social context. An example given is ‘an efficient air-conditioning system in a building with windows that cannot be opened in an environment where 80% of the time the outside conditions are within comfort parameters’ (Hes and Plessis, p19). The weakness of referring only to building ratings for a building’s sustainability ‘is that sustainability is an aggregate of a number of independent factors, when it is actually an emergent property of the characteristics of and relationship between a large number of visible/knowable/explicit and invisible/unknowable/implicit factors’ (Hes and Plessis, p19). They emphasize the need to understand a building as a whole system and to look at relationships and dynamics between parts in the system.

To expand on this idea of system further, a building system need not be limited to performance of the building envelope, its climatic response and interaction with site ecology, but could include understanding the occupants and their active use of windows, and other controls, for adapting to climatic variations and understanding their expectations of comfort as informed by their social and cultural context.

2.7.2 Understanding a Complex Social Problem using Soft Systems Methodology

A framework for understanding a complex problem that involves subjective viewpoints of people is offered by Soft Systems Methodology (Checkland 1972; Checkland and Scholes 1990; Checkland 1999; Checkland & Poulter 2006). Introducing Soft Systems Methodology, Checkland and Scholes explain that it grew out of the failure of established methods of system engineering to understand messy, complex, problem situations. They explain that systems engineering works well where there is general agreement on the objective to be achieved (1990). An example given is the USA programme of landing a man on the moon and returning him safely to Earth (Kennedy 1951). However solving problems in organisations or systems of people are often messy and complex.

> 'Soft Systems Methodology was developed to cope with the more normal situation in which the people in a problem situation perceive and interpret the world in their own ways and make judgements about it using standards and values which may not be shared by others.' (Checkland and Scholes 1990, p. xiii)

Soft Systems Methodology is a cyclic learning process about an organisation of people (a system) that aims to create actions to improve a problematical situation (Checkland & Poulter 2006). Actions created from one learning cycle can be implemented back into the situation to provide another learning cycle. Soft Systems Methodology is used this way in action research (Sankaran, Tay and Orr 2009). Hand drawn diagrams are used in SSM Soft Systems Methodology for easier understanding of a system. The learning cycle that could occur from this project is described this way in Figure 2.4.

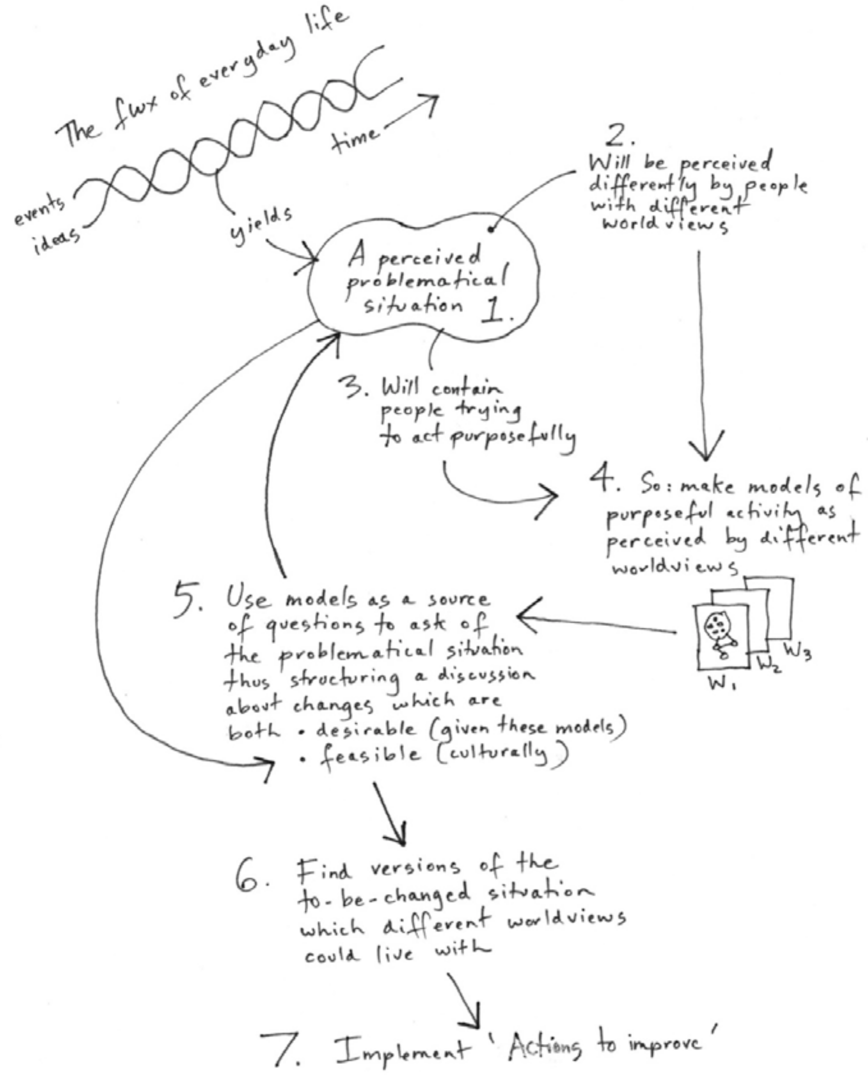


Figure 2.4 The Learning Cycle using Soft Systems Methodology Framework (adapted from Checkland & Poulter 2006)

The next section refers to other literature of building performance evaluations that refer to one or two key environmental factors and their social impact to building occupants.

2.7.3 Methods Used in Building Performance Evaluation Research

A seminal study of daylighting in California schools by the Heschong Mahone Group asked the research question "Does daylight and other aspects of the indoor environment in elementary school student classroom have an effect on student learning?" (Heschong Mahone Group 2003) The background context to this study was that school buildings in California up to 1963 used natural daylight for classrooms. However in recent decades, increasing reliance on electrical lighting changed school building design to reduce window area some schools even having windowless classrooms. The primary aim of the Heschong Mahone Group's study investigated links between the physical environment and student learning, focussing on daylighting. However another aim was to increase daylighting in classrooms to reduce the cost of using electrical lighting and redistributing these savings to teaching resources (Heschong Mahone Group 2003). Their study investigated 450 classrooms in Fresno, of 8000 grade 3 to 6 students, and gathered a high level of detail of physical attributes of the classrooms and perspectives of teachers in these classrooms.

Classroom data was collected in two phases. The first phase collected data about room sizes, building types, floor and wall coverings and how the rooms were furnished. In the second phase the researchers observed occupied classrooms noting operation of windows, lights, mechanical system, made subjective assessments of acoustic, thermal and lighting factors in the indoor environment and confirmed the accuracy of Phase 1 information. Quantitative measurements were taken to assess the environmental conditions in the occupied classrooms: of ambient light levels using a handheld illuminance meter; ambient air temperatures with a digital thermometer and radiant temperatures of various surfaces in the classroom using an infrared thermometer; and acoustic decibel levels using a handheld decibel level meter. When classrooms were unoccupied the researchers repeated these measurements and measured carbon dioxide levels in the air using a handheld CO_2 sensor.

Their study aimed to understand the teachers' perspective through interviews and a questionnaire. Teachers were interviewed about their experience of lighting, thermal, ventilation and acoustic conditions in classrooms. The teachers were enthusiastic and provided important insights into the operation of classrooms, giving opinions on positive and negative aspects of their classrooms, comfort complaints and impact of the environment on students. Insights from interviews assisted the interpretation of the findings from the questionnaire.

The questionnaire aimed at understanding teachers' opinions on comfort and how they interact with the various controls in the classrooms and was in a two pages format of multiple-choice questions. This anonymous questionnaire was distributed to all grade 3-6 teachers. Comfort questions were directed at thermal, ventilation, acoustic and lighting conditions and frequency of these conditions over a year. For example 'how often is the temperature in your classroom comfortable / too hot / too cold?' answered with a five point scale for level of frequency, '0 –Never occurs' to '5- Almost always, occurs about once a day or more, all year'. One question asked how the teacher interacted with the classroom by listing possible actions in a multiple-choice format. The combination of questionnaire and interviews provided HMG a greater depth of understanding of the impact of daylight on student learning.

Post occupancy evaluations are done on new sustainable buildings to ascertain their sustainability performance and whether the occupants are satisfied with their new building (Baird 2010; Lenoir, Baird and Garde 2012) and how existing school buildings perform as places of learning (Zhang and Barrett 2010). Post occupancy evaluations measure temperature to assess the thermal comfort factor, among others such as noise, glare, humidity, air quality, and amount of daylight (Deuble and de Dear 2014; Leaman and Bordass 2007). In a United Kingdom study of office workers in a new sustainable building Leaman and Bordass asked the question: *Are users more tolerant of 'green buildings'?* (2007). The study resulted in list for 'sources of dissatisfaction' or 'features that people like' in their indoor environment. At the top of the list for dissatisfaction were issues of thermal comfort and ventilation; the working environment was either 'too hot or too cold' and the air was 'too dry or stuffy and still'. For the features that people liked the top feature was 'workplaces near windows, with a view out' followed by 'line of sight and earshot contact with immediate colleagues' (Leaman and Bordass 2007).

In discussion Leaman and Bordass answer the question tentatively 'yes users are more tolerant'. However they advise that findings based on general summary type questions alone tend to describe green buildings more optimistically; to be able to make more rounded conclusions they recommend survey descriptions need to be followed up with more detailed accounts of context as can be discussed in interviews

In both of these studies by the Heschong Mahone Group and Leaman and Bordass, the questionnaire data gives a count of the responses among participants, chosen from the multiple choices presented in a survey. However following up with interviews was important to reveal other insights not obvious to the researcher. Semi-structured interviews allow a researcher to pursue a line of inquiry based on research aims and flexibility for the interview to be opened up to other contextual conditions the researcher may not be aware of (Yin 2014). Emergent themes can be discussed. Questions can also be rephrased by the interviewer for the interviewee, to explain the line of inquiry behind the written question. This is an advantage over questionnaires where questions have a chance to be misunderstood by participants. A social context can be obtained from interviewees, as Deuble found in a review of post occupancy evaluation interviews; interviewees talking about other aspects of the work environment both social and physical rather than concentrating on the performance of the building (Deuble & de Dear 2014). Questionnaires can be used for tally of frequency, a quantitative method in the social and human sciences (Creswell 2014).

2.8 Sustainability and Climate Change: Reasons for Low Carbon Behaviours

The commonly understood view of sustainability is that Earth's resources must meet present needs without compromising the ability of future generations to meet their own needs (IPCC 2014). The Earth's resources are finite and to provide an Australian type lifestyle to the world's population would need the resources of four earths (Henning 2015). In 2014 Australia ranked as the 12th highest country of CO_2 emissions per capita at 16 tonnes CO_2 per person; USA is higher at 10th with 17 tonnes CO_2 per person (GCP 2015). Although Australia has a smaller population (23.6 million) compared to countries with the largest emissions, (China with 1.4 billion people and the USA with 319 million), the Western lifestyles that Australia and the USA embrace are spreading into formerly third world regions such as India and China, both countries with large populations.

Electricity generation from fossil fuel combustion emits CO_2, a greenhouse gas, into the atmosphere, increasing the green house effect of global warming and consequent climate change (Keeling 1997). The Intergovernmental Panel of Climate Change (IPCC) is ‘certain that humans are the main cause of current global warming and the longer we wait to take action the more it will cost and the greater the technological, economic, social and institutional challenges we face’ (IPCC 2014 p.*v*). To tackle climate change the IPCC has listed responses in two categories: *adaptation* to a changing climate and *mitigation* to reduce the effects of climate change. Buildings can be adapted by installing building insulation, mechanical and passive cooling, and ecosystem-based options including green infrastructure (shade trees, green roofs etc). These adaptions aim to reduce heat in the built environment expected from increasing temperatures due to climate change. Mitigation in buildings includes energy saving options from device efficiency (heating/cooling) and behavioural and lifestyle change (appliance use, thermostat settings) (IPCC 2014). However, stating that behavioural and lifestyle change is needed is easier than it sounds.

Herein lies the wicked problem (Brown et al 2010), how to maintain thermal comfort in buildings and reduce building carbon emissions to minimise impact on climate change (Roaf, Nicol and de Dear 2013)?

Research directions for comfort in a lower carbon society were compiled in a special issue of Building Research & Information (Shove et al. 2008). There are movements of thought among the contributing authors away from purely physical or physiological paradigms toward those that emphasize meanings and social settings. Also, moving away from universalizing codes and standards (e.g. ASHRAE, Fanger 1970) toward more flexible and more explicitly adaptive strategies in engineering and design (e.g. Nicol and Roaf, 2005). Hitchings suggests steering away from quantitative analyses of the built environment and using comfort standards in more ‘contextually sensitive approaches’ (2009, p.93). He argues that approaching ‘groups of current users could identify the most sensitive ways of steering societies towards more sustainable thermal futures’ (Hitchings 2009, p.89). He also suggests investigating what users do between indoors and outdoor locations and how people adapt to times of heat. 'Instead of talking about what temperatures feel neutral in particular places when we have already accepted this to be dynamic, the ambition may now be to reveal which techniques people are willing to employ to get through particular periods more sustainably' (Hitchings 2009, p.93). Hitchings sees the potential of this line of research reducing the trend of occupants expecting steady indoor air conditions that have negative impacts on both use of energy and the wellbeing of occupants (2008).

Swan and Brown (2013) refer to the problem of retrofitting existing buildings as a socio-technical problem. They argue that if all new buildings performed as zero carbon buildings this would only make a small dent in the overall emissions from buildings, as there is so much existing building stock that people occupy (Swan and Brown 2013). They suggest sustainable retrofitting of people's homes and workplaces is needed and the approach needs to be more than a technical understanding of the physical nature of the building and needs to include issues about people, policy, regulation, building physics, market transformation, supply chains, process and monitoring (Swan and Brown 2013). They suggest framing the problem as a 'socio-technical system' to understand the interacting links between the physical building and social aspects, such as the way people live (Swan and Brown 2013).

One study to take a socio-technical approach is a post occupancy evaluation of energy efficiency retrofits to housing in the United Kingdom (Chiu et al. 2014). Chiu et al. were critical of current post occupancy evaluation surveys in that they assess building performance and what occupants think, but don't delve inside the 'black box' to understand how occupants interact with their building. Their study is a multi case study using a mixed methods approach. They provided a description of the physical parameters of the building with architectural drawings and energy usage monitoring, while at the same time investigating behaviours of the occupants using qualitative methods such as interviews and questionnaires. This approach provided insights into how the occupants adapted to the interventions in their households.

2.8.1 Separation between behaviour and belief

Even though there is a lot of information about the effects that climate change is having on the earth (Flannery 2005; Guggenheim 2006; Crichton, Nicol and Roaf 2009), this does not appear to be having an effect on the way people live (Stoknes 2014). Stoknes defines the 'climate paradox' as the disconnect between the desire for people to do something about combating climate change, but then not actually practising energy conserving behaviours. Individuals give reasons such as 'I'm only one person, what kind of difference can that really make?' to 'it's going to affect my lifestyle too much' (Stoknes 2014, p.164). Stoknes suggests that to resolve this disconnect more research needs to be done on social groups to better understand their behaviours around energy use, and to then make energy conserving recommendations to these groups.

In Australia there are various energy conservation campaigns and resources to inform individuals on how they can reduce their impact on climate change in their home (Ha 2011, Queensland Government 2012, Australian Government 2016). However, Moloney and Strengers (2014) found that campaigns have limitations in their effectiveness in reducing energy and the level of engagement by individuals. Going Green, for an individual householder, means engaging in small actions (remembering to turn off lights when leaving a room) or large actions (installing solar panels on your roof). They argue that the current Going Green discourse 'narrowly frames the scope of potential change around a set of actions, whilst ignoring the vast majority of consumption implicated in normal everyday practices' and 'argue the value of exploring an alternative approach drawing on social practice theories to reframe consumption as a by-product of taken for granted practices '(Moloney & Strengers 2014, p.105). They refer to the common daily practices of heating, cooling, bathing and laundering as being overlooked as areas for the reduction of energy consumption. In interviews some household occupants have realised that unless they make major lifestyle changes to conserve energy in their household, the number of actions an individual can make is limited. Actions like changing the type of light fitting from halogen to low energy LED, turning lights off when not in the room, switching appliances off at the wall to reduce standby power do not change everyday use of the appliances. Having shorter showers saves hot water, but having fewer showers saves even more. However, this change of behaviour challenges the practice of having a daily shower. Moloney and Strengers recognize that challenging the status quo is not an easy task. 'Reframing the discourse of Going Green to one focused on transforming social practices will require strong leadership, co-ordinated support from government agencies and a willingness to confront the many challenges involved in shifting and transforming everyday practices' (2014, p.105).

The power of following what peers are doing has been found to have a greater effect on people's actions than they would readily admit (Nolan et al. 2008). Nolan et al. conducted two studies to investigate the influence of witnessing other people's actions, on one's own actions. The first study surveyed 810 Californians about energy conservation. In the second study, householders received persuasive messages on leaflets hung on their front door handle, promoting energy conservation written in one of five ways:

- A descriptive norm (what your neighbours are doing to conserve energy).
- Self-interest (conserving energy can save me money).
- Environment (conserving energy reduces my impact on the environment).
- Social responsibility (conserving energy is the socially responsible thing to do)
- Information-only (conserving energy has these quantitative effects).

Four different energy conservation behaviours were promoted. They were 1) taking shorter showers, 2) turning off unnecessary lights, 3) turning off the air conditioning at night and 4) using fans instead of air conditioning. Interviewers contacted the householders a month after the leaflets were delivered and asked whether the four messages had motivated them to conserve energy. In addition to the self-reporting data collection, the researchers asked to access household power bills and read electricity meters four times during the study 1) prior to the intervention 2) same day first leaflets were delivered 3) same day fourth leaflets were delivered and 4) one month after the delivery of the last leaflet. Their results 'showed that normative social influence produced the greatest change in behaviour compared to information highlighting other reasons to conserve, even though respondents rated the normative information as least motivating' (Nolan et al., p. 913). Households that received the descriptive norm messages used the least electricity. Another finding was that although 'environmental reasons and social responsibility were rated as strong reasons for conserving energy in the survey, neither approach succeeded in reducing energy conservation in the field study' (Nolan et al., p. 921).

When individuals acting in a sustainable way see others acting around them in a more energy wasteful way this comparison can stop individuals from continuing their sustainable behaviour. This has been termed the 'free rider' effect; that some people consider it a waste of time to act in more sustainable ways when the majority is doing nothing (Ockwell et al. 2009).

2.8.2 'Thermal Mavericks' Living Outside the Comfort Zone

There are individuals with strong environmental values who choose to live a low energy lifestyle within their own homes. An Australian study tested the thermal preference of occupants in low energy houses, and whether these occupants were influenced by their environmental values (Daniel et al. 2015). Daniel et al. studied occupants of earth construction houses in Victoria and naturally ventilated open houses in tropical Darwin, and termed these people 'thermal mavericks'. These 'mavericks' choose to live in atypical dwellings that do not have assisted mechanical heating or cooling. Darwin has a hot humid climate (Köppen classification BSh) and Melbourne a cool temperate climate (Köppen classification Csb). Other households in the same location may rely heavily on air conditioners or other mechanical heating or cooling devices for comfort. To test the occupants' environmental attitude, an Environmental Attitude Inventory (EAI) survey was used to gauge the occupant's level of environmental concern based on 12 attitudinal scales (Daniel et al. cites Milfont and Duckitt 2010). The survey asked respondents to indicate their agreement or disagreement with 24 statements using a 7-point Likert Scale. Responses are sorted into two dimensions of environmental attitude: 'preservation' and 'utilization'. Preservation broadly reflects bio or eco-centric concern such as conservation and protection, whilst utilization reflects anthropocentric concern such as utilization of natural resources. Daniel et al. found respondents demonstrated higher levels of environmental concern, shown by greater preservation scores, and lower utilization scores, compared with normal population samples. The thermal comfort study on these households followed the standard method in ASHRAE 55 (2013). Occupants indicated their Thermal Sensation Votes on the seven point scale. Figure 2.5 shows the three middle Thermal Sensation Votes 'slightly cool' 'neutral' and 'slightly warm' plotted with the indoor and prevailing mean outdoor temperature. A large number of votes are above the upper 80% limit in the Darwin households (30.7%) and below the lower 80% limit in Melbourne (42.1%).

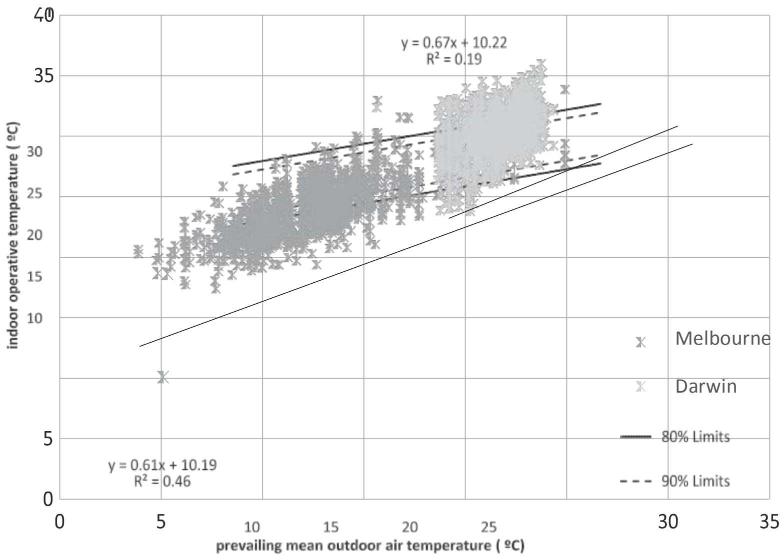


Figure 2.5 Thermal Sensation Votes Outside the Comfort Zone in Darwin and Melbourne (Daniel et al. 2015)

Daniel et al. found a relationship between higher levels of environmental concern and thermal preferences of comfort, outside the adaptive comfort limits. Although this is a study on residential buildings, they suggest that this relationship between occupants with high environmental values living within a wider scope of thermal comfort conditions, could be relevant to other building types (Daniel et al. 2015)

Daniel et al. asserted that these occupants accept living in a house that, for most people, would be too hot or too cold, because they believe that energy conservation is important and choose a lifestyle using less energy. These residents live outside the limits prescribed by the Adaptive Comfort Standard. Their lifestyles are less reliant on appliances to cool the interior in Darwin, and warm the interior in Melbourne, than the average population. In a school, getting occupants willing to accept and adjust to wider temperatures is more challenging. As in any workplace, schools have a group of people from differing backgrounds and beliefs coming together to work in the same environment. According to de Dear and Brager (1998), people have differing viewpoints about conserving energy, influenced by energy use practices at home and past thermal experiences at work.

2.9 The Australian School Context

The prevalence of air conditioning in various environments in Australia has increased over the last decade. Most office buildings are air-conditioned (Hyde et al 2013). Air-conditioner installation in Queensland households experienced a sharp rise between 1999 and 2004, from 24.8% to 58.2% (Australian Government 2006). In this context, it is useful to review the research around health, environmental and financial issues associated with air-conditioned classrooms.

Chatzidiakou et al. (2012) reviewed the literature on indoor air quality and found that indoor air quality classroom environment can influence children's performance. Mendell and Heath (2005) reviewed the literature and found links between heating ventilation, air conditioning systems, building characteristics, indoor pollutants and thermal conditions, to reduced attendance and / or impaired performance in schools. They found that poor indoor environmental quality in schools is common and adversely influences the performance and attendance of students, primarily through health effects from indoor pollutants. Poor indoor air quality in schools has been attributed to poor health symptoms (Daisey, Angell and Apte 2003). Low ventilation rates can also affect student performance (Clements-Croome et al. 2008). To support the case for more control over the classroom indoor environment through air-conditioning, Wargocki and Wyon (2013) studied the effect of heat on children and found it produces lethargy and a lack of concentration, reducing the children's academic performance. A simulation study by Ito and Murakami (2010), using a climate chamber, found improved academic performance through controlling the thermal comfort of the classroom using air-conditioning. Their climate chamber study estimated that academic performance improved by about 43% when room temperature was reduced from 28 to 26 degrees. However, in translating these conditions to a school building the energy consumption was estimated to increase by 40%. The study recommended that room air control with high accuracy and sensitivity is important in order to maintain both academic performance and energy consumption in buildings (Ito and Murakami 2010). Air conditioning can be used to provide cooler indoor environments for learning when the outside conditions are undesirably warm. But its use needs to be monitored to prevent it being used when outside conditions are favourable. Air conditioning overuse is an environmental concern as electricity is over consumed.

2.9.1 Energy Saving Practices in Australian Schools

In South East Queensland it is still relevant to conserve electricity use to reduce impact on climate change, as electricity from the grid is generated mostly from power stations using coal and gas (Queensland Government 2014). Another way to reduce the impact on climate change is by using electricity from renewable sources such as solar, roof mounted, photovoltaic (PV) panels. In Australia, the rate of solar photovoltaic panels on household rooftops is among the highest in the world at 15%. It is higher in South Australia at 25.27% of households, and Queensland at 24.31% (ESAA 2015). The National Solar Schools Program, from 2008 to 2013, provided $217 million to 5310 schools, almost 60% of all Australian schools, for the installation of mostly renewable energy systems, rainwater tanks and other energy efficiency measures (Australian Government 2016). The grants were worth $50K to each school and in Queensland were administered by the Department of Education and Training (2014).

However, if a school were to source electricity for air conditioners from photovoltaic panels alone, a large number of panels would be required. One classroom 4kW unit air conditioner turned on for 6 hours a day uses approximately 24kWh. A school with thirty classrooms would need 570 rooftop photovoltaic panels to be able to claim that all their air conditioners are powered by solar. A more realistic claim is that having a renewable energy source in schools reduces the amount of energy the school uses from the grid. Or if the school had a policy that not all air conditioners were on for the full six hours of the school day, in all rooms, then the number of panels could be reduced. Of all the electrical equipment present in a classroom, air-conditioners consume the most energy. To target reducing the use of these can be regarded as a sustainable behaviour in a school classroom.

In the Australian School Curriculum sustainability occurs when the "needs of the present don't compromise needs of the future" and it is a cross–curricular priority across core subjects (ACARA 2016). In the Australian states of Victoria, New South Wales, South Australia and Western Australia the state governments provide resources for sustainable schools in two ways; energy efficiency programs and curriculum support (Sustainability Victoria 2015, NSW Department of Education 2014, SA Government, Sustainable Schools WA). Queensland schools are encouraged to use a Sustainable Environment Management Plan (SEMP), an online tool provided by Education Queensland developed over 2009-2011. However, the supporting Queensland Sustainable Schools website has not been updated since 2012. Queensland schools seeking information about sustainability are redirected to the Australian Sustainable Schools Initiative (AuSSI) website (Australian Government 2016b). More information would be useful for schools in South East Queensland about how to occupy their existing buildings in a low energy manner.

2.10 Summary of Literature Review

This literature review has linked together fields of research relevant to the study. A summary of the key findings and how these have informed the research questions is discussed here.

This study is positioned in the field of adaptive thermal comfort. The Adaptive Comfort Model in ASHRAE 55 (2013) provides a definition of an acceptable comfort zone, the upper and lower thresholds of comfort, for occupants of naturally ventilated buildings. This definition has been referred to in this research project. Thermal comfort studies of children in naturally ventilated classrooms in tropical and sub-tropical Asian countries question whether to air-condition classrooms, as has been the practice in Western countries (Wong and Khoo 2003, Kwok & Chun 2003, Puteh et al. 2012, Hwang et al. 2009, Yang and Zhang 2008). Thermal comfort studies of Australian school children found that children prefer lower temperatures than those within the comfort range specified by the Adaptive Comfort Standard in ASHRAE 55 (2013) and that those schools from places with more varied outdoor temperature had higher adaptability (de Dear et al. 2015). The link between varying outdoor climatic conditions of a school location and the adaptability of the occupants could be studied further.

As this study investigates the impact of interventions implemented to a case study school, finding other studies that pursued similar aims would have provided precedent for research methods of investigation. However, no studies were found retrofitting school buildings or classrooms to reduce overheating in subtropical climates. The most relevant study was a heat abatement study in a pilot school in Hawaii. The Hawaiian study listed three types of recommendations: reduce solar gain, increase natural ventilation and use mechanical conditioning powered by solar energy (Goore 2015). These recommendations were yet to become interventions that could be studied. A Mediterranean research project of pilot schools in Greece, Spain and Italy demonstrated passive cooling using a bioclimatic approach to retrofitting (TEENERGY 2009). Strategies used in the schools and how they intended to reduce overheating were reported but impacts afterwards were not measured. Broadening the field of research for strategies that can be retrofitted to an existing school with overheating issues, the field of Urban Heat Island mitigation was reviewed for strategies of application of cool roof, shading hard paved areas with shade sails, and increasing vegetation (schoolyard greening). To provide specific research about the impact of retrofitting passive cooling strategies to existing schools in a subtropical climate the first research question for this study is:

1 How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

As the aim of retrofitting passive cooling strategies is to reduce temperature in the classrooms, obtaining knowledge of the extent of overheating in existing classrooms before interventions and then applying methods of evaluating their impact are required. An overheating metric has been developed for a portfolio of Australian schools to determine times of overheating and under-heating in classrooms, and to develop a policy on the extent of air conditioning across the portfolio (de Dear and Candido 2010). This overheating metric based on assessing the times the classroom temperature exceeds the upper threshold of the comfort zone, could be applied to the case study school. But to assess if any reduction to classroom temperature is enough to be within an acceptable comfort zone for the occupants the following question needs to be asked:

2 What is perceived to be an acceptable comfort zone for classroom occupants?

There are more factors that influence thermal comfort than the four environmental factors and two personal factors described in the heat-balance model of thermal comfort (Fanger 1970, ASHRAE 2004). Researchers in the field of adaptive thermal comfort (de Dear and Brager 2010; Nicol, Humphreys and Roaf 2012) argue that a contextual approach is needed to understand other factors that influence thermal comfort, that arise from the social, cultural and climatic context of building occupants. More study is needed to understand how social and cultural factors influence the thermal comfort of occupants, especially in other building types than offices and houses, such as schools.

Studies were reviewed that collected views of the occupants of their thermal environment combined with quantitative data from the built environment. In the seminal study of the impact of daylighting on academic performance in Californian schools, Heschong and Mahone Group collected and analysed both quantitative environmental data of the schools and qualitative data from the occupants (2003). Post occupancy evaluations of buildings typically obtain a tally of occupants' perceptions of environmental factors including thermal comfort, noise, glare, humidity, air quality and amount of daylight, from questionnaires (Deuble and de Dear, Leaman and Bordass 2007). If followed up with semi-structured interviews other factors influencing the occupant's satisfaction with the environment can be revealed (Yin 2014).

This research addresses existing school buildings in South East Queensland in the wider research context of the wicked problem 'How to maintain thermal comfort in buildings and reduce building carbon emissions to minimise impact on climate change?' (Roaf, Nicol and de Dear 2013). Sustainable retrofitting of existing building stock is needed to reduce building emissions (Swan and Brown 2013). Swan and Brown suggest the problem can be framed as a social-technical system (2013). As this case study investigates the impact of interventions in the physical and social context of the school, developing a framework of how to research social complex problems and develop an appropriate research design, required reviewing relevant studies that linked social and technical aspects of the environment in the same study. A study of domestic retrofits in the United Kingdom used a social-technical framework with a mixed method research approach, to understand the link between social aspects of lifestyle to the technical workings of their retrofitted households (Chiu et al. 2014). Put simply, a mixed methods research approach uses quantitative methods of data collection and evaluation for data results expressed in numbers, such as temperature, and qualitative methods for data collection and evaluation of values that are expressed in words, such as people's viewpoints and perceptions (Creswell and Plano Clark 2011). Converging results from the two phases of data collection and analysis forms the discussion of a convergent mixed methods study (Creswell and Plano Clark 2011, Creswell 2014).

A framework that examines subjective views of people in a problematic situation, is offered by Soft Systems Methodology (Checkland and Poulter 2006). Soft Systems Methodology is a cyclic learning process about an organisation of people (a system) that aims to create actions to improve a problematical situation (Checkland & Poulter 2006). Actions created from a study can be implemented back into the situation to provide another learning cycle, a method used in action research (Sankaran, Tay and Orr 2009).

The occupants of the case study school are in the problematic situation of perceiving times of overheating in classrooms yet how do they maintain comfort without using energy intensive air-conditioning? The adaptive thermal comfort model suggests that people in naturally ventilated buildings find a warmer range of temperatures acceptable if they have a range of ways to adjust their environment to restore their level of comfort (Humphreys and Roaf 2012). Behaviours of occupants in naturally ventilated buildings to restore comfort could be regarded as low carbon behaviours. As such behaviours include opening windows, using low energy ceiling fans, or moving to another location use very little or no energy. Importantly, they do not using energy intensive air conditioning to cool the room. Others argue that to understand ways buildings could be occupied in low carbon ways is to study how people adapt in times of heat (Hitchings 2009). Investigating the current adaptive actions of teachers in naturally ventilated classrooms could provide a better understanding of low carbon occupation of classrooms. Studies of children's adaptive behaviours in overheated classrooms have shown that teachers, rather than children, have control of the classroom environment (Bernardi and Kowaltoski 2006; De Guili, Da Pos and De Carli 2012). Therefore this research project primarily investigates the behaviours of teachers. The third research question is:

3 What adaptive actions do teachers currently practise to reduce discomfort from overheating in their classrooms?

To better understand the broader social context of this school, themes of sustainability and climate change as reasons for low carbon behaviours in Australian society were reviewed. Studying the everyday social practices of a group of people in building types, other than houses, is recommended to increase the scope of energy saving behaviours (Moloney and Strengers 2014). Australian householders with high environmental values live in wider temperature ranges than those defined in ASHRAE 55, and this relationship could be relevant for occupants of other building types (Daniel et al. 2015). The question of whether being sustainable and combating climate change are reasons for occupying classrooms in a low energy manner could be asked of teachers in the case study school.

2.11 Conclusion

This literature review has linked fields of research to provide reasons why the case study was needed and informed the research questions. On the basis of the previous research and identified areas of need, it was determined that an Australian study was required to investigate the retrofitting and impact of passive cooling strategies on existing typical, timber classrooms in a subtropical climate. This study, therefore, has been designed to explore the following research questions:

1 How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

2 What is perceived to be an acceptable comfort zone for classroom occupants?

3 What adaptive actions do teachers currently practise to reduce discomfort from overheating in their classrooms?

The research design is elaborated in Chapter 3, where the research methodology of a single case study with a mixed method approach is employed to address these questions.

Chapter 3 Method - The Case Study

3.1 Introduction

Chapter 2 provided a literature review of relevant studies to this study and a summary of how the review informed the research questions. The purpose of this chapter is to describe the design of the research and methods used to undertake the fieldwork. The research design is a single case study with a mixed methods approach to collecting and analysing data. An explanation of this type of study follows in this introduction.

As the purpose of this study was to identify how passive-cooling strategies can be retrofitted to existing school buildings to promote an acceptable comfort level for the occupants, information on existing school buildings, and the occupants' comfort levels were required. As previously discussed in Chapter 2, case studies (multiple and single case studies) have previously been used effectively to research this field.

According to Ying (2014), a defining feature of case study research is that it provides an in-depth examination of a case where a phenomenon has occurred within its real world context. Yin says that "compared to other evaluation methods such as surveys, experiments and quasi-experiments, case study evaluations can 1) capture the complexity of a case, including relevant changes over time and 2) attend fully to contextual conditions, including those that potentially interact with the case" (Yin 2014, p.220). Single case study designs were used to investigate proposed passive cooling strategies in a pilot study in a Hawaiian school (Goore 2015), and to investigate classroom conditions in a courtyard building in Australia (Rajapaksha and Hyde 2012). This research project explores the research questions using a single case study. In order to understand the impact of retrofitting passive cooling strategies to existing buildings, data collection of temperature levels in the buildings (quantitative data) and information around personal comfort levels of people using the buildings (qualitative data) are necessary.

Importantly, this research does not rely on temperature alone to evaluate the impacts of the interventions. Another data source is obtained from the qualitative analysis through the questionnaire and semi structured interviews with teachers. This qualitative phase investigates the physical and social aspects of the impacts of the interventions to the school.

In this chapter the research design and methods used for the quantitative and qualitative phases of the project are explained. But before describing the research design and methods, next this chapter describes the setting of the case study school and the passive cooling strategies implemented to the school. This is necessary to provide a better understanding of the research design and methods used in the case study.

3.2 The Setting

This section describes the setting of the case study school.

3.2.2 Background to the Research Project

At the end of 2011 the school's Parents and Citizens' Association put a call out for an architect within the school community to look at the problem of overheated classrooms. The first strategy actioned was to install insulation to accessible, flat ceiling areas of the classroom buildings. During 2009 to 2010 the Australian Government Home Insulation Program provided financial grants for homeowner occupiers to install ceiling insulation to in their homes (Hangar 2014). As the school buildings were a similar scale to houses it seemed like an appropriate first action. In January 2012 bulk insulation of R Value 3.0 was installed to the accessible flat ceiling areas of all classrooms, a total of ten buildings in the school (refer Appendix figure A.1). However, after the installation, teachers in classrooms in the older timber buildings still experienced them as hot. It was possible that the roof and ceiling might not be the primary source of heat load in classrooms and it became clear that a research project was required to investigate how to improve the thermal comfort for people occupying older, timber, classrooms.

3.2.3 The Location

The case study was undertaken in a state, primary school in Brisbane, the capital city of Queensland, shown in Figure 3.1. It is located six kilometres from Brisbane City in a suburban environment. In 2015 the school had a population of 837 children in 34 classes from Prep to Year 6 (Department of Education And Training 2016). Brisbane (Latitude 27.4° S and Longitude 153.1°E) has a subtropical climate with warm humid summers and mild dry winters, *Cfa* under Köppen climate classification. Other locations in the world classified as subtropical *Cfa* are south Japan, Taiwan, southwest China, southeast Brazil, parts of Italy including Venice and southeast USA (refer back to world map in Figure 2.3).

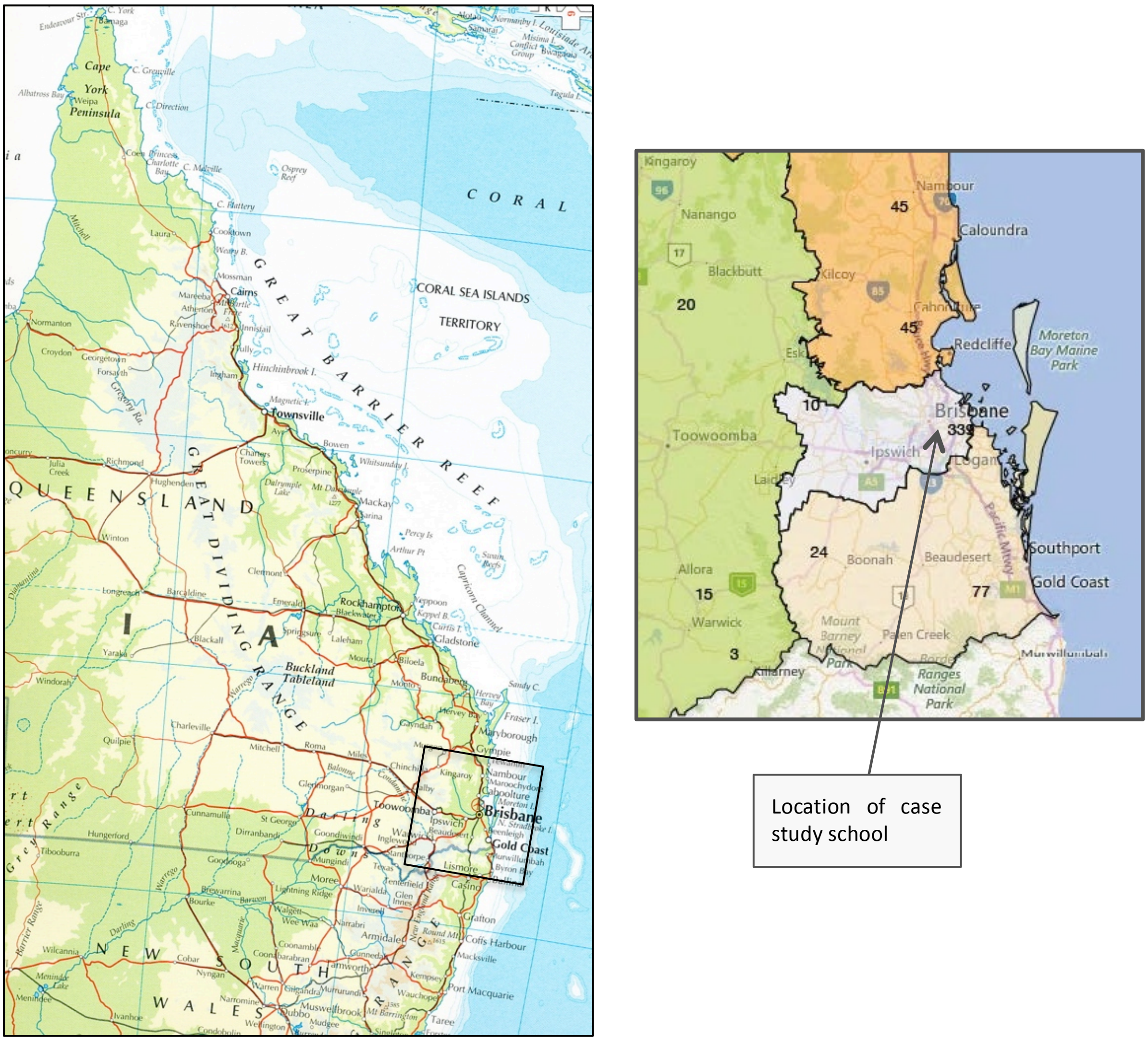


Figure 3.1 Queensland & Brisbane Region and School Location (The Times Atlas 1995, Department of Education and Training 2016)

3.2.4 The School Buildings and Classrooms

The buildings in this case study were the warmest buildings in the school, shown as buildings A B C D F and G in Figure 3.2. They were observed as 3°C warmer than outside for the whole afternoon, over two sunny weeks in November 2012 (refer to Figures 4.4 and 4.5 in the temperature results chapter).

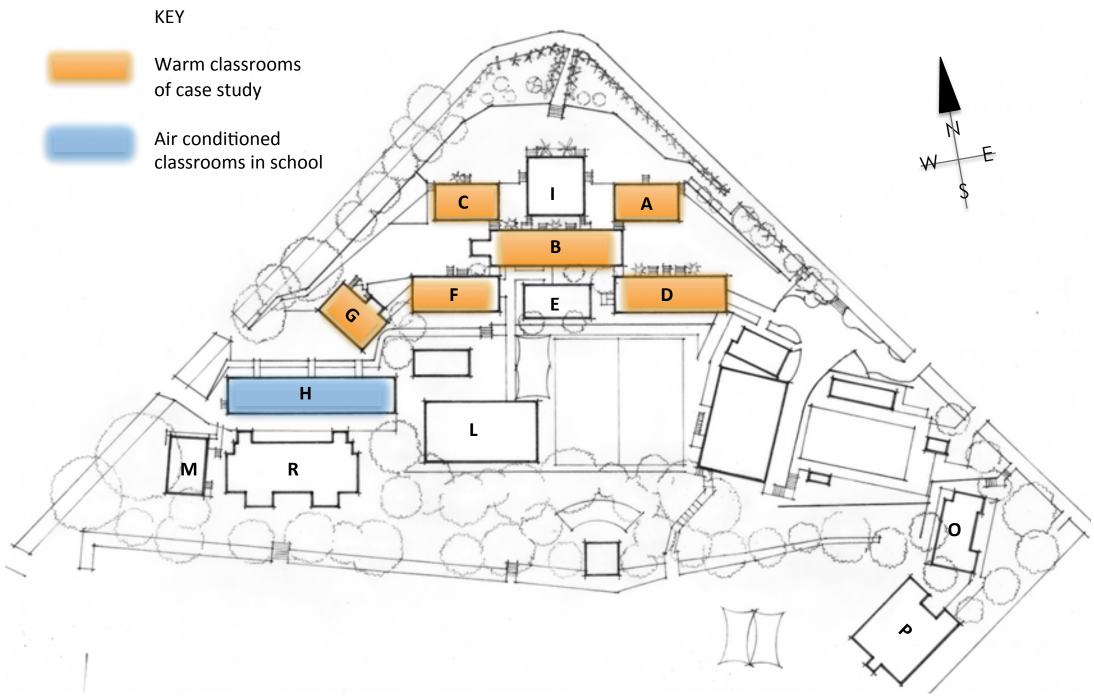


Figure 3.2 Case Study Buildings and Air-Conditioned Classrooms in 2012

These five timber buildings are good examples of the *Sectional School* type, the dominant classroom type built in Queensland between 1920 and 1950. The school was established in 1929 with one building, building B, shown in Figure 3.3. Subsequent buildings A, C, D, and F were added over the next decade in a radial layout, connected by verandas shown on the plan in Figure 3.2. Sectional School buildings were constructed of similar materials and similar form to the Queenslander vernacular house; timber and tin, with verandas. Orientation of the building type was intended to optimise natural light and cross-ventilation. A veranda is on the north, east and west sides of the classrooms and large windows face south (Burmester, Pullar, Kennedy 1996). Desks were arranged so they faced the teacher and the west. Light came in from the south, the left hand side of the children, shown in the plan of the original school building in Figure 3.4.

Figure 3.3 The School Established in 1929 (Brisbane City Council images)

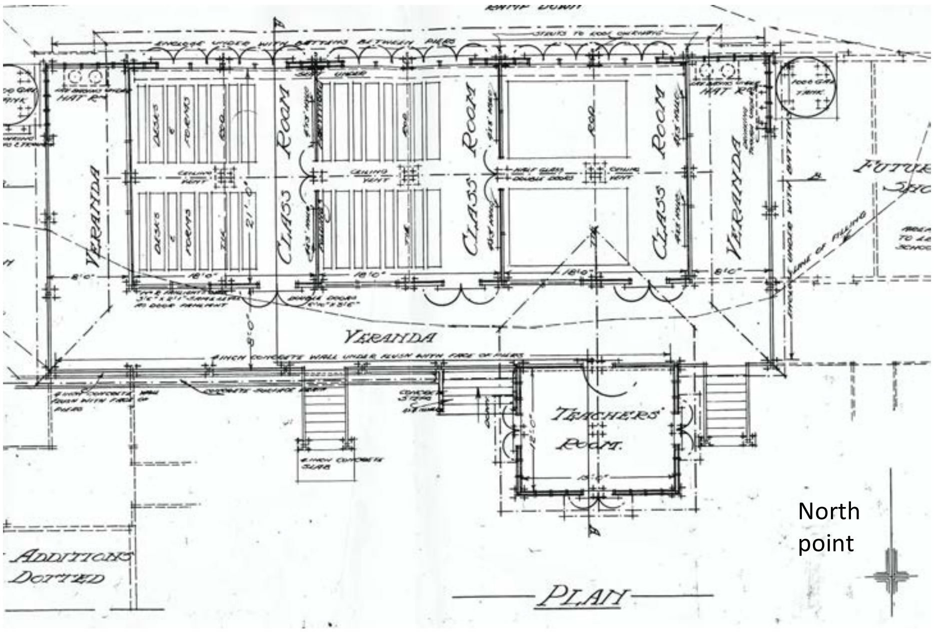


Figure 3.4 Proposed State School (Brisbane) plan (Department of Works March 1928)

Original construction materials of the school buildings and major alterations are described in Table 3.1. In the late 1990's the north verandas to buildings A B C D and G were enclosed to increase classroom size as part of the Building Better Schools initiative (DET 1999). Awning windows were added to the north facades of buildings A, C and G as seen in Figure 3.5. Building F remains the only intact example of the Sectional School building type with an open north veranda, refer to Figure 3.6.

Table 3.1 Description of Building Construction 1929 to 1953

BUILDING	DATE	TYPE	ORIGINAL CONSTRUCTION SIMILAR TO BUILDINGS	ALTERATIONS TO BUILDINGS SIMILAR	BUILDING DIFFERENCES	C'ROOMS
A	1934	**Sectional School**	Corrugated metal roof sheeting painted red B C F G galvanised roof to A D No insulation or roof sarking Hardwood timber frame roof, walls, floor structure	1990s Verandah enclosed, N wall with hopper windows and french doors removed, aluminum framed awning windows on top of bag racks. Roof overhang to windows reduced to 300mm.	1946 Three rooms built underneath for extra classes in baby boom years. Low ceiling height. Now used as Art room, Uniform Shop, Store room.	A1 A2
B	1929		Softwood timber T&G ceiling underside raking roof rafters, flat ceiling in centre of classroom Softwood T&G wall lining Timber weatherboard cladding	Carpet and Linoleum floor	1990s Flat plasterboard ceiling ht 3.0m above floor Open underneath with storerooms to N	B1 B2 B3
C	1933		T&G hardwood floor boards Concrete posts and half ht retaining walls		Open underneath	C1 C2
D	1948		Concrete slab on ground Timber french doors to N Timber hopper and upper level awning windows to N wall Timber casement and upper level awning windows to S wall		Two rooms underneath to SE	D2 D3
F	1937		Timber bag rack to N verandah Timber balustrade to stair verandahs	No alterations - Only intact example of SS building in school.	Retained north verandah	F1 F2
G	1953	Boulton & Paul modular building	Same construction materials as above only prefabricated. Enclosed stair to ground Flat fibre cement ceiling ht 3.3m	1990s Verandah enclosed,	Room underneath to W used as School Tuckshop until Hall built in 2008.	G1 G2

Figure 3.5 North facades of Buildings A C D and F, east and west facades of B, in 2013

Figure 3.6 North facades of Buildings F and G in 2013

Building G was built in 1954, a prefabricated building type similar in construction fabric to the Sectional School but with a covered stair linking the classroom to underneath. Building G has a different orientation than the other buildings with its long facades facing northeast and southwest as seen in plans in Figures 3.2.

In Queensland, most school buildings up to 1960 were constructed in timber and fewer than fifty had brick buildings, recorded in a conservation study of 2000 Queensland schools in 1996 (Burmester, Pullar, Kennedy). The typical classroom building form was rectilinear in plan with a north veranda, the classroom floor elevated off the ground, and play space underneath until 1965, as seen in Figure 3.6.

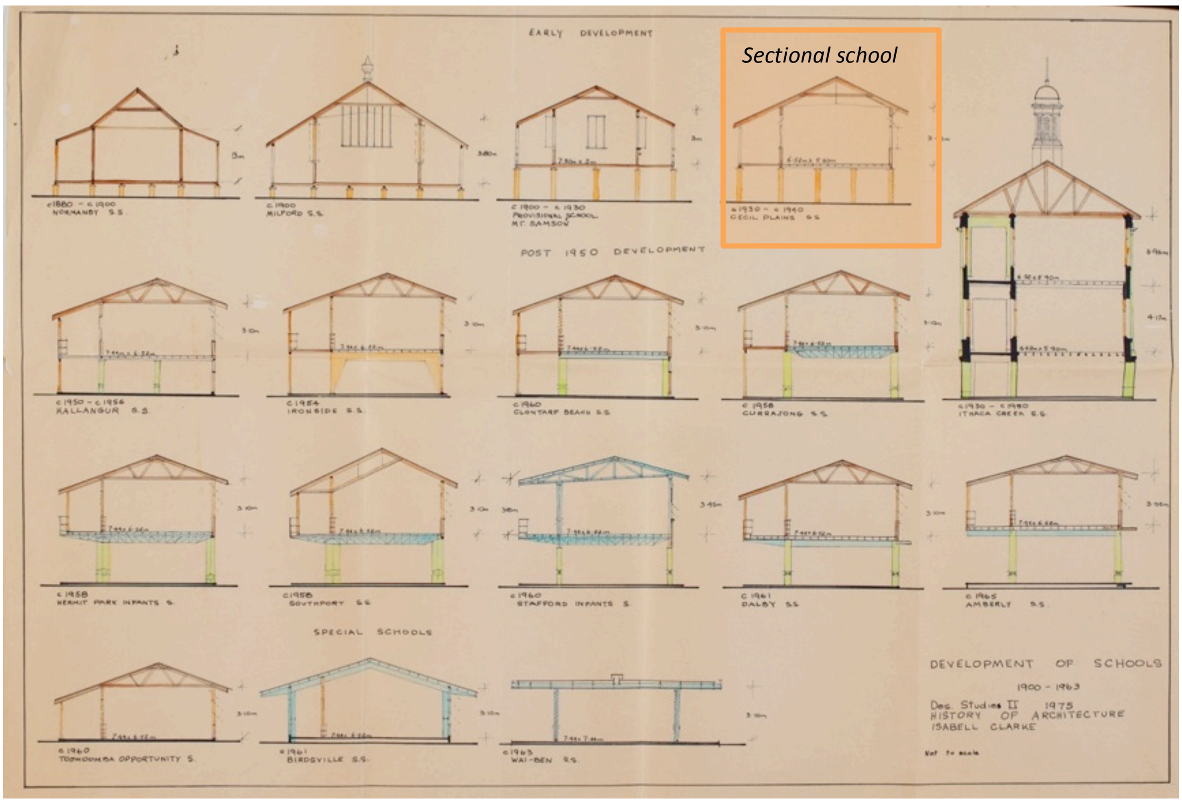


Figure 3.7 Development of Queensland Schools 1880 to 1965 (Clarke 1975)

To estimate how many Sectional School buildings are still in use, a comparison was made between listed current Queensland state schools (Department of Education And Training 2015) and establishment dates of schools in Queensland (Department of Education And Training 2013). In 2015 there were 1236 state schools open in Queensland and 918 of these were primary schools (Department of Education And Training 2016). Sixty percent of current state schools were established from 1850 to 1949 as shown in Figure 3.8. Over the near thirty years from 1920 to 1949, Sectional Schools were built and there were 145 schools established. During this time as school populations grew, additional classroom buildings in older schools established from 1850-1919 were also Sectional School building types. State secondary schools in Queensland expanded in 1957 (Clarke 1984) with new buildings constructed. Secondary school buildings differed from the one storey building type of primary schools, by having two storeys and containing more classrooms per building.

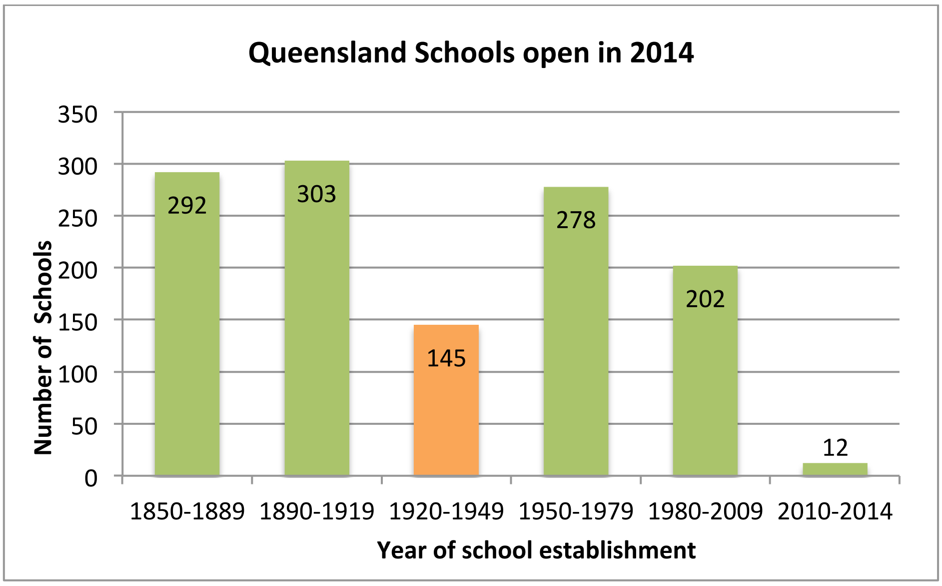


Figure 3.8 Queensland Schools Open in 2014 with Year of Establishment

When visitors enter this school through the front gate they see the Sectional School buildings first, the view of Buildings A and C in Figure 3.5. These buildings form part of the school's identity and evoke memories for past students. This group of buildings is a relatively intact example of a Sectional School, and they are included on the Brisbane City Council's Heritage Register (Brisbane City Council 2012). For these cultural and historical reasons these buildings are likely to remain in use for years to come.

Retrofitting existing building stock is a sustainable exercise. The process of demolition and replacing of older buildings with new ones uses energy and material resources. New construction materials are manufactured and transported to the site and the demolition of old buildings results in materials that, if not repurposed for other uses, become landfill. Retrofitting existing building stock to improve their indoor conditions needs to be investigated before considering their removal with a new, climate-responsive building. Of interest too is the fact that not all new buildings are designed to be climate responsive and provide occupants with comfortable indoor conditions without using air conditioning. This was the case when a new classroom was recently added to the school grounds, Building R.

3.2.5 The Spaces between Buildings.

In the early years of the school, rocky ground surfaces caused injury to children when they ran and fell (Clark 1978). In the late 1930s to 1940s asphalt was applied to ground spaces between buildings providing a smoother and low maintenance cover, good for ball games. The buildings of the school are located on levelled terraces that step down the south side slope of a hill, not ideal for capturing summer breezes in Brisbane (Kennedy et al 2012). These terraces are lower than the natural ground surfaces of the downward sloping hill as noted in Figure 3.8. Retaining walls around the north of each terrace could also be having a small, canyon effect to the cluster of buildings and closeness of the buildings to each other reduces the effect of breezes, creating its own microclimate (Oke 1987; Errel et al 2012). The lightweight, timber school buildings provide little resistance to heat transfer from outside, so the influence of the surrounding hard, paved areas need to be considered if a passive, design strategy is used to provide cooler, internal temperatures in the classrooms.

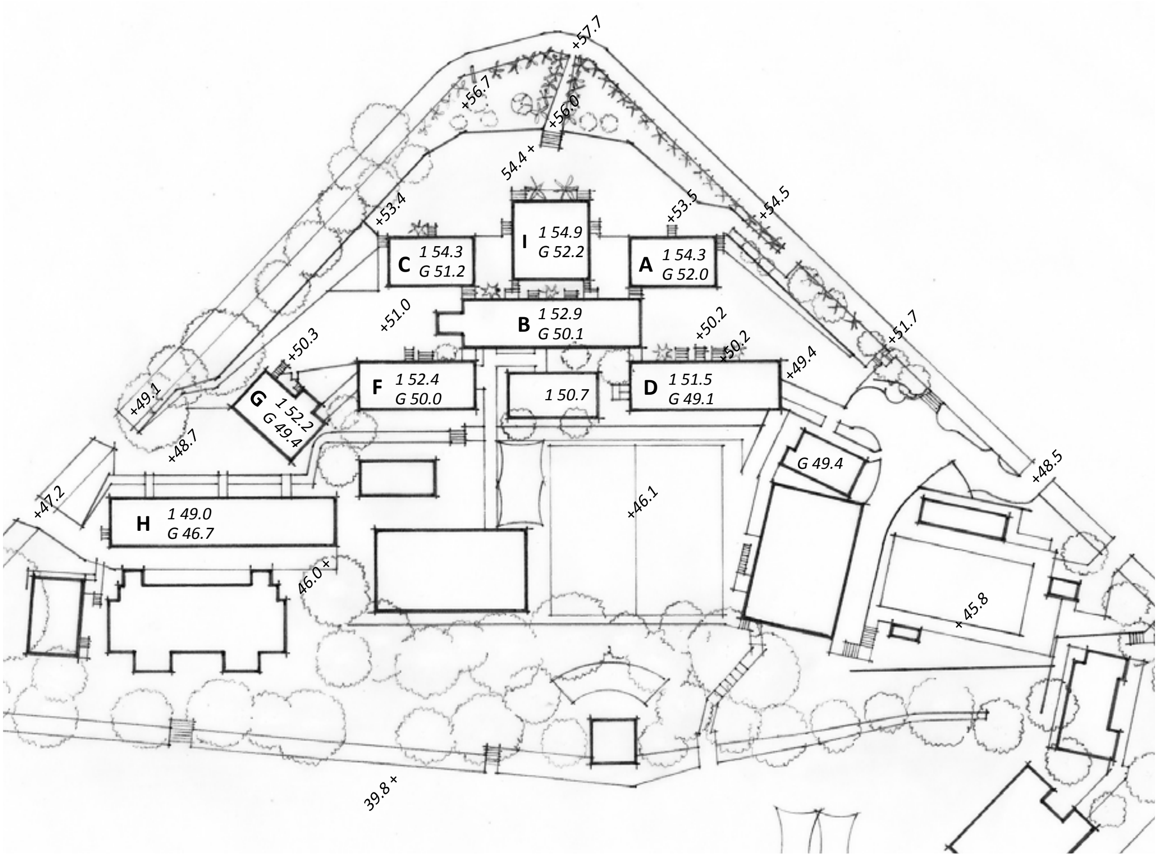


Figure 3.9 Plan with Spot Levels Taken from Site Survey (Department of Works, 1990)

Asphalt covered spaces between school buildings, or in the 'quadrangle', is a common morphology as illustrated by a sample of aerial photographs of Brisbane schools in Figure 3.9. Although in some schools, over the last decade, there has been a 'sea change' of removing the asphalt to reduce the effects of heat sink, glare and the reflection of ultraviolet radiation from these areas (DET 2007).

Figure 3.10 Asphalt Covered Surfaces in School Grounds (Nearmap 2013-2014)

3.2.6 The Climate

Brisbane's climate is subtropical (*Cfa* under Köppen). Details of sunshine and daylight, temperature, humidity, and rainfall are shown in Figure 3.11.

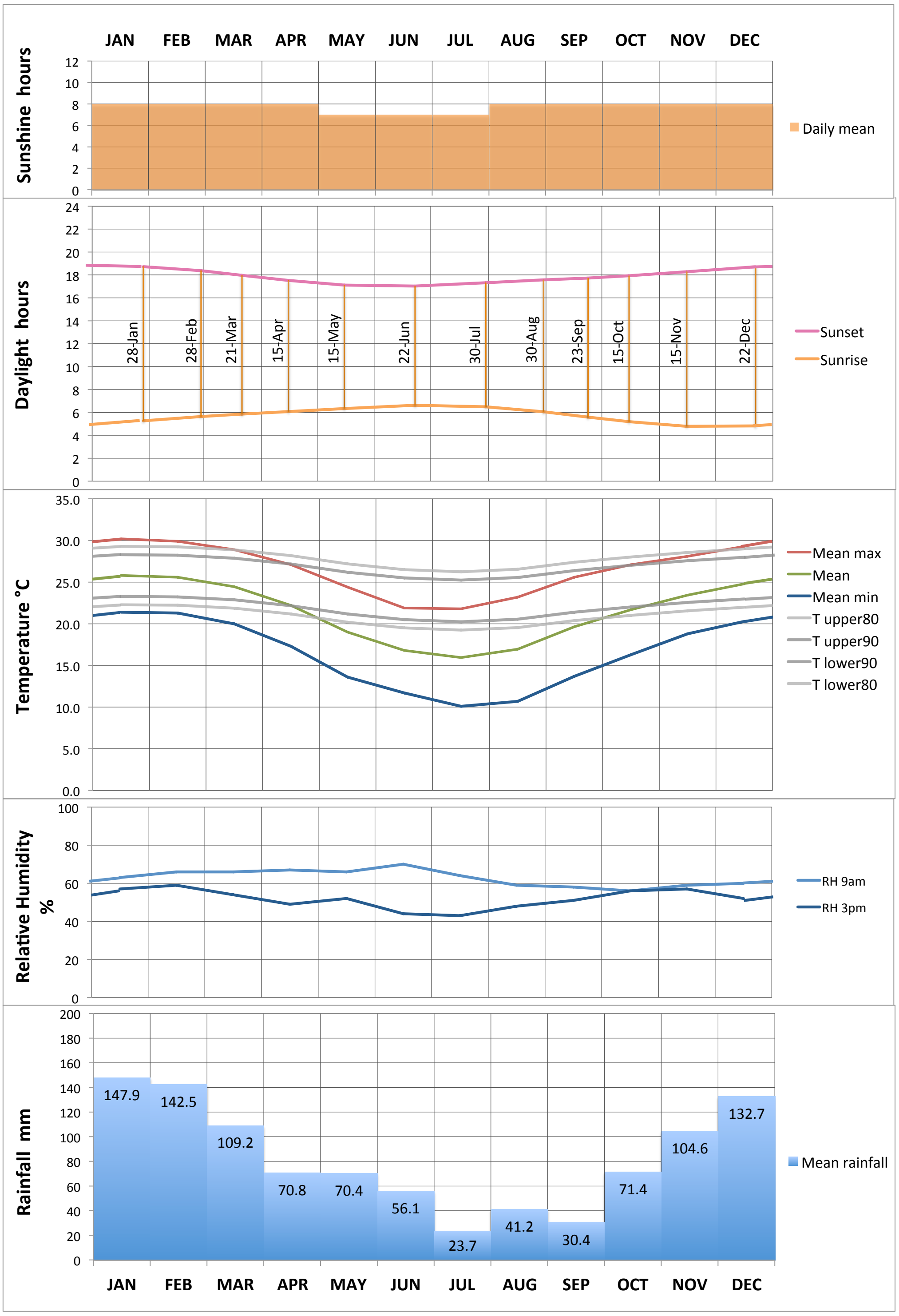


Figure 3.11 Climate Composite Display for Brisbane (Data from Bureau of Meteorology 2016, Szokolay 2006, based on Koenigsberger et al. 1973)

Daylight hours are shown for dates of the equinox (21 March and 23 September), winter solstice (22 June), and summer solstice (22 December) (Szokolay 2008).

Brisbane's rainfall occurs mostly during the warmer months from November to March increasing cloud cover but because daylight hours are longer there are on average more sunshine hours per day from August to April, compared with drier winter months, May to July. Humidity is always highest in the morning (RH 55-70%) but in summer and spring it is also high in the afternoon (RH 50-60%). Extreme weather events that occur in Brisbane are tropical thunderstorms and heat waves (Bureau of Meteorology 2016).

The Adaptive Comfort Zone is plotted on the temperature section of the graph, using Brisbane monthly mean temperatures (ASHRAE 2013). As minimum temperatures occur at night or dawn it is more useful to look at the upper part of temperatures from mean to maximum for considering how Brisbane temperature ranges compare with the comfort zone. There is an overlap between the comfort zone and the mean temperature from October to May. This suggests that for a large time of the year Brisbane has a benign climate. However, discomfort occurs in summer on hot days with high humidity. In Brisbane's mild winters people can adjust with additional layers of clothing when cooler day temperatures fall below the comfort zone.

Givoni recommends passive cooling strategies for this climate including shading windows from direct solar gain, increasing cross ventilation and carefully located thermal mass to assist night cooling (1998). Yet these strategies are most applicable when designing new buildings as the architect has control of the placement of openings and thermal mass. Any passive cooling strategies considered for this school had to be retrofitted to the existing buildings without making major changes to windows and building fabric. What strategies were implemented and how they were selected to this existing school are discussed next in this chapter.

3.3 Passive Cooling Strategies

The passive cooling strategies implemented at the school were cool roof, stack ventilation with night flushing to one building, shade sails and schoolyard greening.

3.3.1 Cool Roof

A cool roof is a typically bright white coating applied to a roof, that reflects the full spectrum of solar radiation including visible and thermal ranges, reducing transfer of heat through the roof (total solar reflectance value of 98%). Two buildings had a cool roof applied at the school (Figure 3.12). Buildings A and D had weathered galvanised corrugated iron roofs (reflectance value of 30-50%) before the interventions (Figures 3.5 and 3.20). Cool roof applied to unpainted roofs is a better choice for application, as the existing surface can be prepared more effectively, compared to previously painted roofs that need more preparation work to remove existing paint.

Figure 3.12 North elevations of Buildings A and D

3.3.2 Stack ventilation

Stack ventilation relies on the basic principle that warms air rises, and can then be replaced with cooler air from outside. In tall spaces this convection process creates its own air current when warm air at the top of the stack is evacuated and cooler outside enters at the lower level (Kwok and Grondzik 2007). On these buildings, during daylight hours roof fans exhaust hot air from the attic space, creating a current that draws warm, classroom ceiling air up through ceiling vents. As warm air moves out of the classroom, floor vents let cooler air from underneath the building into classrooms as shown in Figure 3.22. This occurs when the building is closed at the end of the school day and night. However during the school day outside air comes in through windows and doors. The strategy intent is to evacuate warm air from the classroom rather than having it trapped inside during the afternoon and overnight. In Building A, where there are rooms underneath the floor, wall vents and door vents can provide the same function.

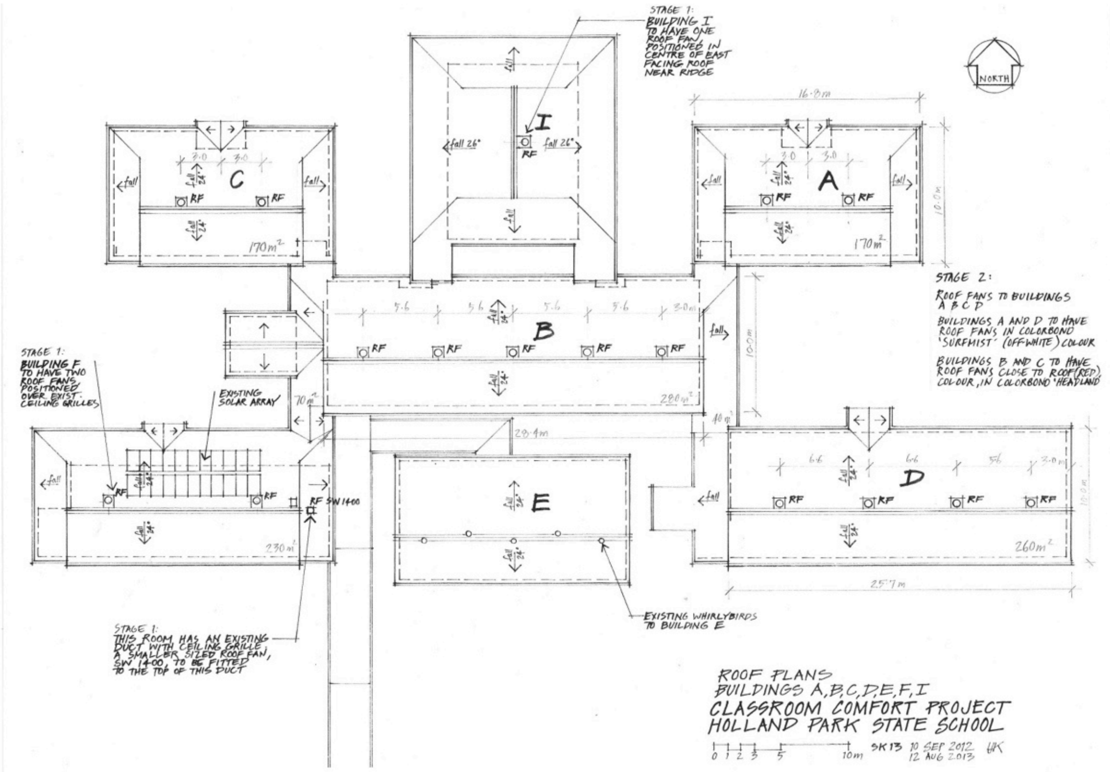


Figure 3.13 Buildings A B C D E I: Roof Plans Showing Roof Fan Locations

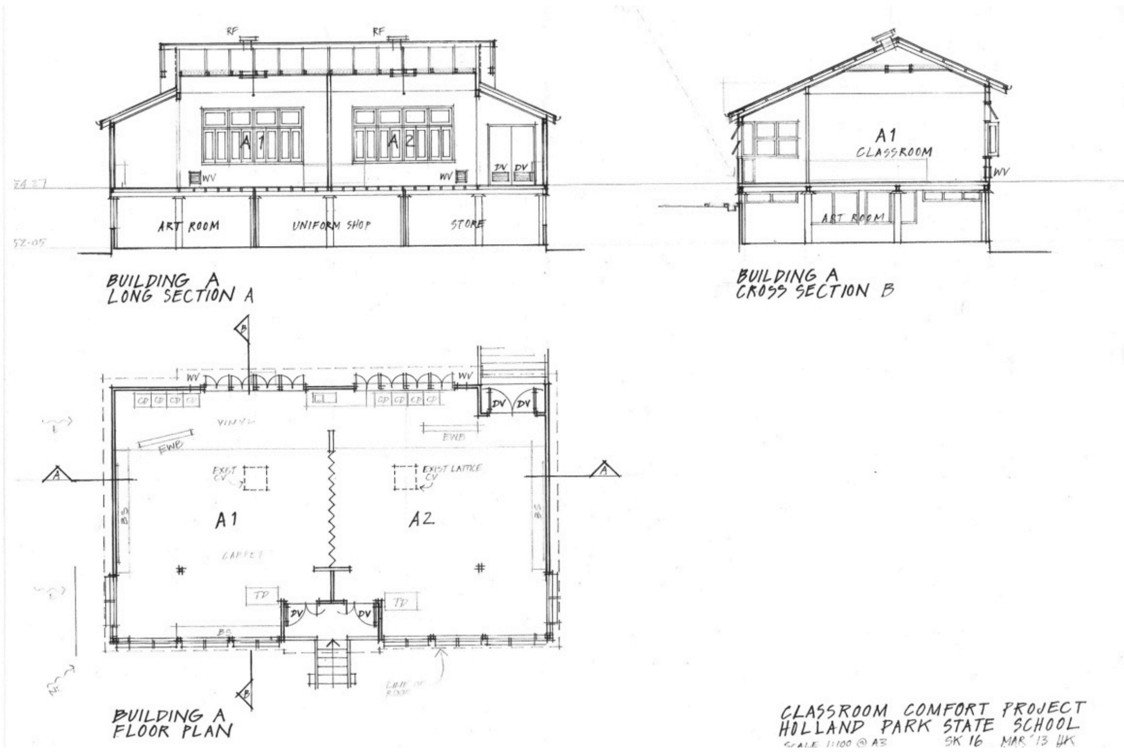


Figure 3.14 Building A: Floor Plan & Sections Showing Stack Ventilation Elements

3.3.3 Night Flushing

Night flushing is a strategy where daytime heat is 'flushed out' of the building interior with cool, night air. The strategy works best when there is a difference between day and night time temperature of 8 degrees or over (Givoni 1998). It is used for buildings that have high thermal mass elements such as concrete floors that have absorbed the heat of the day and reradiate the heat at night. Cooler moving air carries warmed air away. In the school the aim was to reduce the classroom temperature to close to the minimum, outside temperature that occurs pre-dawn. Occupants arrive in the morning to a cooler interior as surfaces have lost their radiant heat. Building B was selected for this strategy, as it is located in the centre of the group of buildings that block breeze paths to its classrooms, reducing cross-ventilation. Five roof fans were installed for stack ventilation and three roof fans continue to operate at night, using electricity via an additional plug-in connection kit, The night operation is switched on and off by a thermostat located in the centre classroom of Building B (as shown in Figure 3.15).

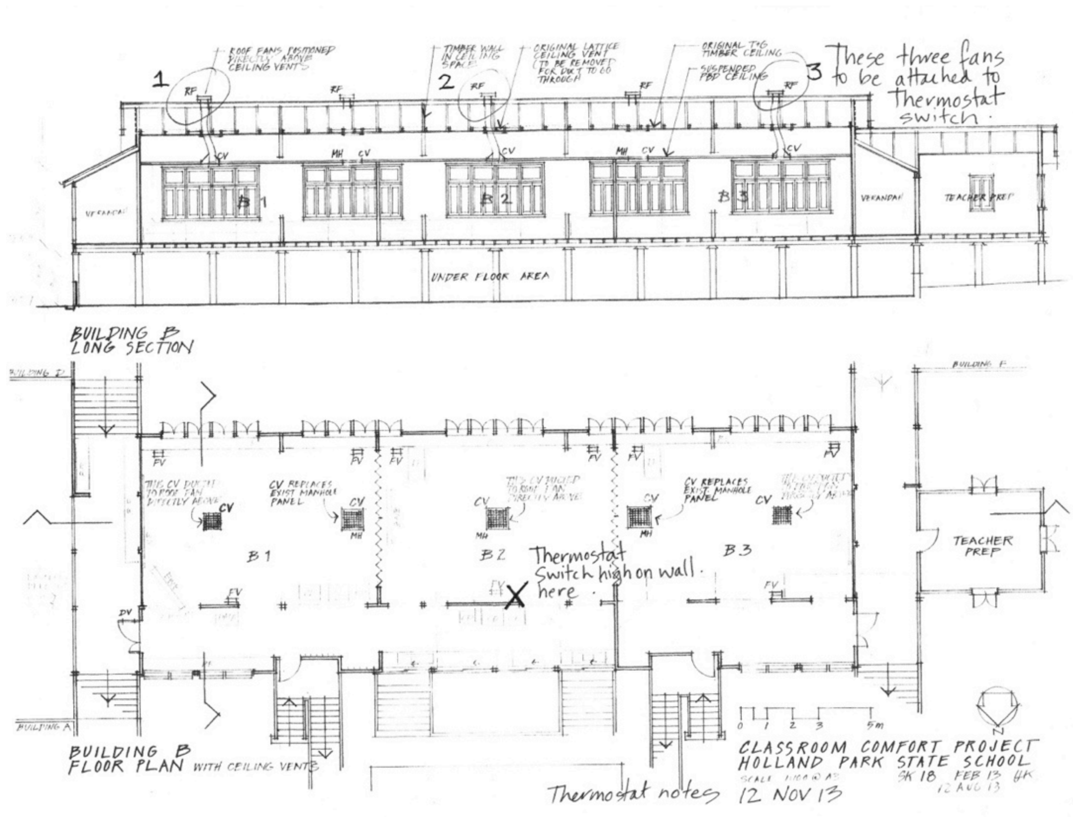


Figure 3.15 Building B: Floor Plan & Section Showing Stack Ventilation & Night Flushing Elements

3.3.4 Shade sails

Shade sails shade the courtyard ground surface reducing the amount of solar heat absorbed by asphalt. The fabric of the shade sails is a light cream colour to reflect more solar radiation (Figure 3.16). The sail forms have been designed to be open on all sides, have high points to scoop in easterly breezes and low points tipped to the west to provide shade from the afternoon summer sun. These points are marked 'H' and 'L' on plans shown in Figures 3.17 and 3.18.

Figure 3.16 Shade Sails over East and West Courts

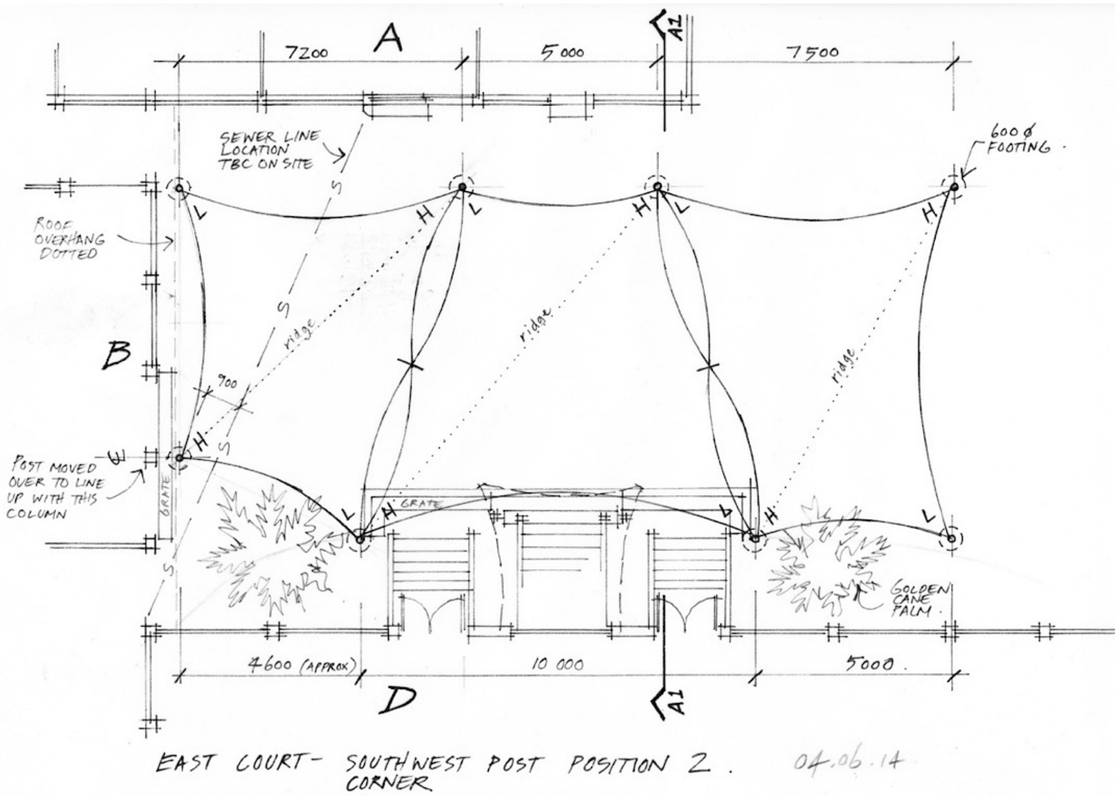


Figure 3.17 East Court: Shade Sails Plan

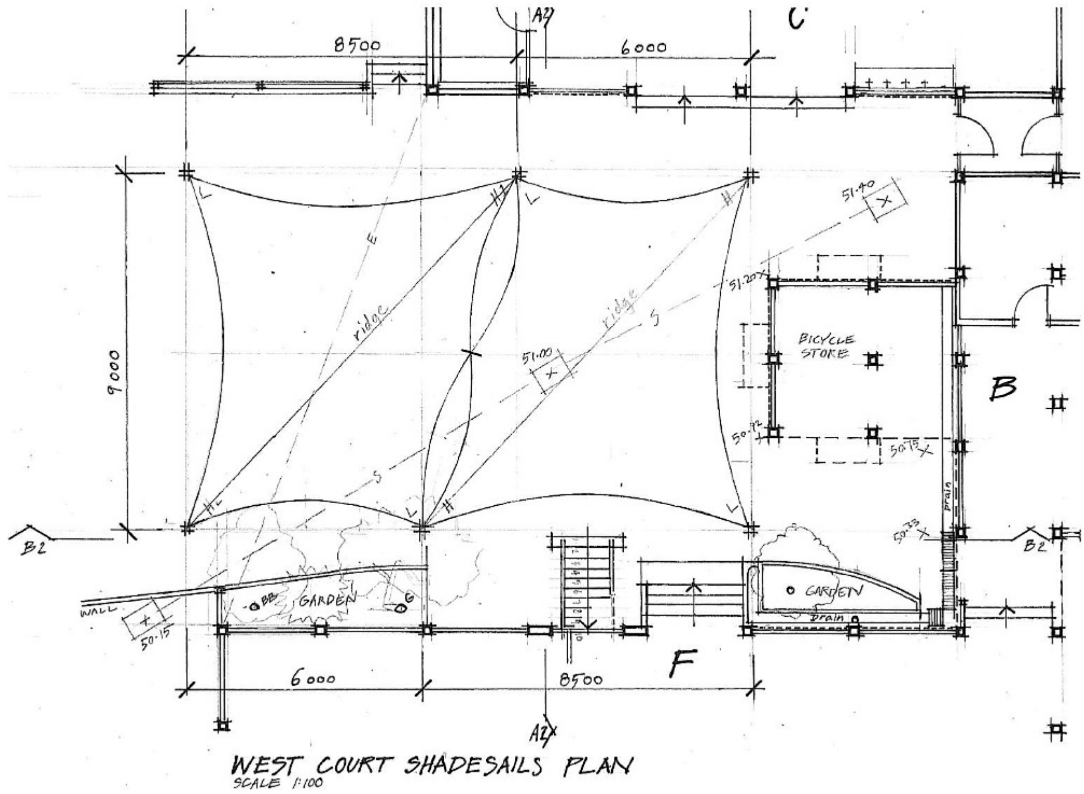


Figure 3.18 West Court: Shade Sails Plan

3.3.5 Schoolyard Greening.

Increasing vegetation near buildings provides cooling effects in a number of ways; plants absorb solar radiation, plants cool the air by evapotranspiration, and trees shade asphalt surfaces, reducing the amount of solar radiation being absorbed, and which would otherwise be released into the air later at night (Bowler et al 2010; Block et al 2013).

Designing the Front Garden involved the principal and teachers in August 2013. A variety of mostly Australian native plants were selected in the garden design for their quick establishment, drought hardiness, and bird and butterfly attracting qualities (refer to Appendix D for planting drawings D.1 and D.2 for plant species).

In Stage 1 of the Front Garden, July 2014, a landscape contractor removed 300m^2 of asphalt area from the 800m2 former parade ground, constructed the garden beds and planted ten shade trees (*cupaniopsis anacardioides*). Stage 2 of the Front Garden involved the school community in two events in 2014 planting 200 understory plants; Year Ones' Arbor Day planting of 167 plants supplied by Brisbane

City Council on 15-17 October 2014, and a working bee with parents of 40 plants provided by the Parents and Citizen's Association and parent donations, on 22-23 November 2014. The plants grew significantly after one year as shown in Figure 3.19.

Figure 3.19 Front Garden (Stages 1 and 2) and One Year Later

3.3.6 Passive Cooling Strategies Work Together.

This section refers to illustrations to describe the strategies together. The aerial photographs in Figure 3.20 show the school before and after the interventions. On the plan in Figure 3.21 each intervention is listed per building. Each of the passive cooling strategies is designed to reduce heat load into the classrooms. In Figure 3.22 a section of Building A illustrates how the strategies work together.

Figure 3.20 Before & After Aerial Photos of the School Buildings with Interventions (Nearmap 2012-2015)

Figure 3.21 Passive Cooling Strategies for Each Building

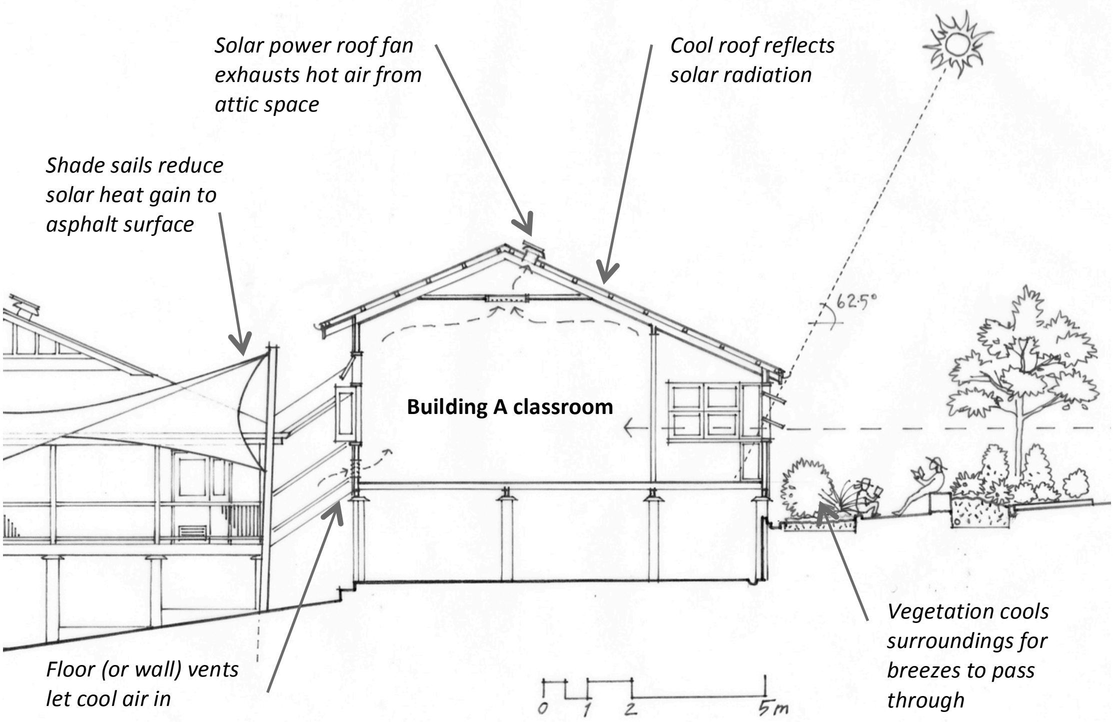


Figure 3.22 How the Strategies Work Together

When urban heat around the school building envelope is reduced by shade sails and schoolyard greening, then the sixth strategy, opening windows for cross ventilation, may be more effective. Figures 3.23, 3.24 and 3.25 show the strategies in place.

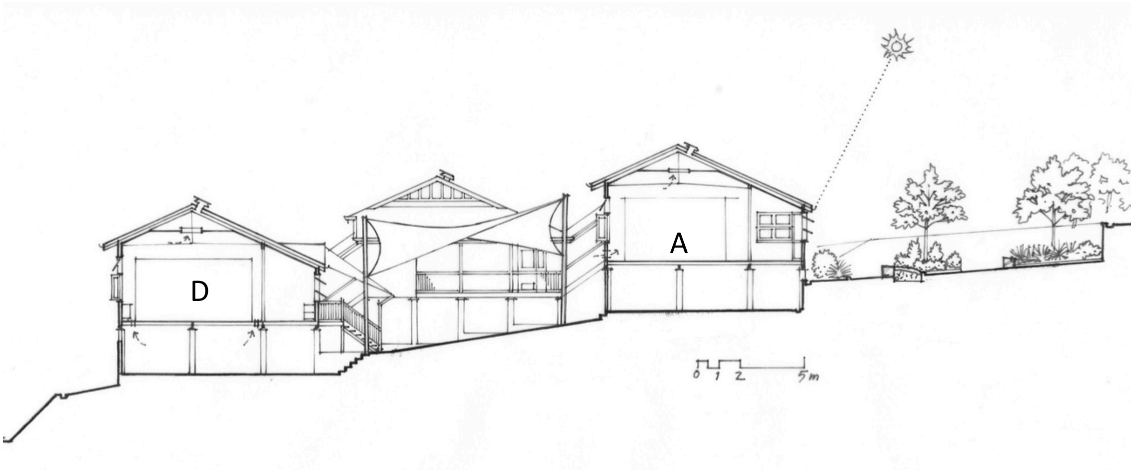


Figure 3.23 Sections of Building D and Building A

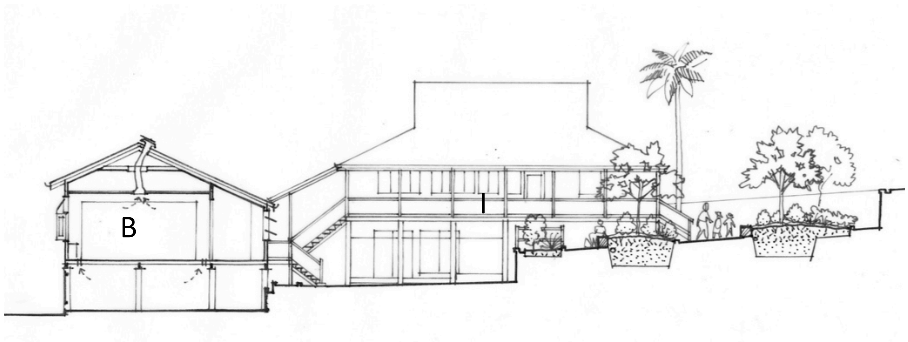


Figure 3.24 Section of Building B

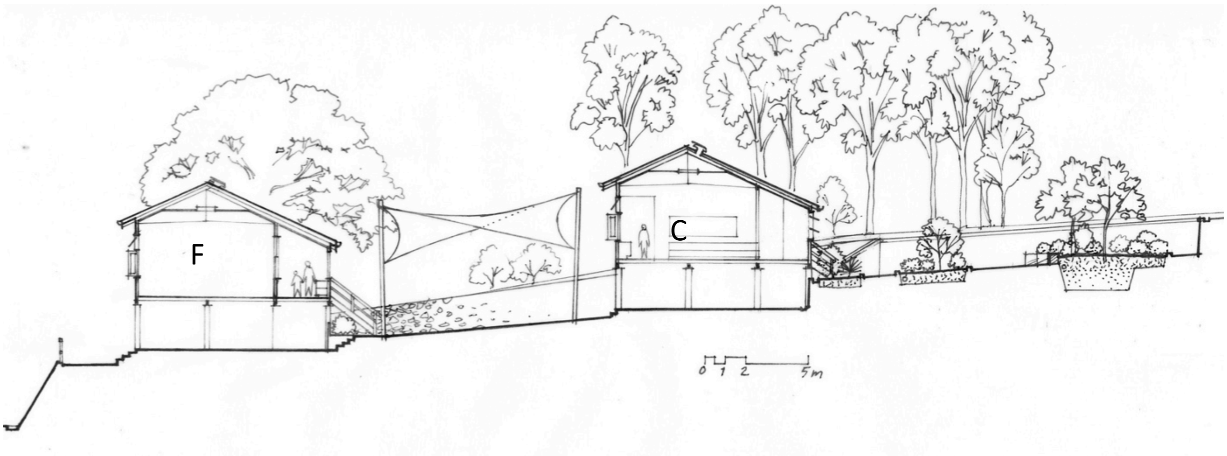


Figure 3.25 Sections of Building F and Building C

3.4 Procedure

For the development and implementation of passive cooling strategies in this school, it was clear funds were required to purchase and construct the strategies and the passive cooling strategies had to be selected according to predetermined criteria.

3.4.1 Funding of Strategies

The school's Parents and Citizen's Association was approached for funding. This Association is a group of community minded people, mostly parents with children at the school, which provides assistance to the school, sometimes in the form of funding for specific projects. Additional resources are also funded through fundraising activities in the school, from outside organisations that provide grants to schools, and from individual donations. The Parents and Citizen's Association funded the stack ventilation (parts 1 and 2) and some of the shade sails. The majority of the shade sails were funded from a Gambling Community Benefit Fund Grant of $35 000. Funding sources for each of the strategies are included in Appendix B.

The funding source influenced the selection process for the strategies.

3.4.2 Selection of Passive Cooling Strategies

In order to be suitable for this project, passive-cooling strategies had to be approved by the Parents and Citizens' Association and they had to fit site practicalities. Conditions to be considered included:

1) A preference by the school community for strategies that could be spread across the most classrooms or shared between buildings.
2) All strategies needed to be of low capital cost and have little or no running costs.
3) Strategies had to be suitable for retrofitting into timber buildings.
4) They had to cause minimal disruption to the normal operations of the school.

Before developing the cooling strategies, factors were identified that could be some root causes of overheated classrooms. A cause and effect analysis of heat inside the classrooms was based on current knowledge around the design of sub-tropical buildings in Queensland and how to mitigate heat in buildings and their surrounds. This identified factors influenced the development and implementation of passive cooling strategies for this school.

The first factor identified involved the school building envelope. There was little or no insulation in the roofs, walls or floors, which offered little resistance to the transfer of heat into the interior of the classroom. In January 2012 bulk insulation was installed to accessible flat ceiling areas of classrooms. However raked ceiling areas remained un-insulated (66-70%). Installing blanket insulation to these raked ceiling areas was considered. Either the installation method would involve lifting off existing roof sheeting and reinstalling in exactly same locations (a method fraught with the risk of having exposed screw holes) or reroofing with new sheeting and blanket insulation; an expensive option. Pumping in cellulose fibre was discussed with insulation contractors and the school administration, but it was decided this was not a safe choice for asthmatic children. Looking at other attributing factors could possibly provide some direction.

The second factor was that the ground surfaces between and surrounding these lightweight timber buildings were covered in asphalt. Asphalt and concrete are hard-paved surfaces that absorb solar radiation and re-release this as heat into the air, a well-documented effect, Urban Heat Island (Akbari *et al.* 2010). The field of Urban Heat Island mitigation research has informed three passive cooling strategies: heat reflective roof paint or cool roof (Santamouris 2012), shading the asphalt by installing shade sails and decreasing the asphalt areas of the school by implementing schoolyard greening (Block et al. 2013).

The third factor was that solar gain passes directly through north, east and west windows. Buildings A, B, C and D have inadequate roof overhangs (300mm width) to shade north facing windows from the sun (refer to Figure 3.23). The west facing windows of Buildings A, C, and D are exposed to low-angle hot afternoon sun. Building G differs in orientation from the other buildings and has large, southwest facing windows. Shading the windows was not considered as a suitable strategy because the Parents and Citizens' Association preferred strategies that could be applied across the largest number of classrooms (such as roof fans) or could be shared between buildings (such as shade sails). To install window shading to four buildings was regarded as too expensive as it would benefit only those few classrooms.

The fourth factor relates to the low amount of cross ventilation in classrooms. Increasing cross ventilation is an important way for occupants to feel cooler especially in climates of high humidity (Givoni 1998). Higher air velocities increase the evaporation rate of the skin enhancing the cooling sensation. Air speeds of 0.8m/sec can make a space feel 2°C cooler, at 60% humidity (Allard 1998). Closeness of buildings in the group reduce breezes to classrooms; Building I blocks southeast and northeast breezes to Building B (Figure 3.21). Cross ventilation is further reduced by window type and use. Air movement through awning windows is limited to the bottom or sides of an open window. Casement windows are effective in catching breezes, when opened out wide enough. A challenging aspect of classroom ventilation is that at the end of the school day windows and doors are closed, trapping warm air that has accumulated in the afternoon. In a house an occupant can flush out accumulated warm air by opening windows in the late afternoon and night.

A fifth factor was the use of windows in the classrooms by the teachers. A thorough understanding was needed of how windows were used, and what other adaptive actions teachers might use. In early field observations it was noticed some windows are not opened at all, due to broken handles or because they were out of reach.

These factors resulted in the development of six strategies, which were communicated to the school community during 2013 and illustrated in Figure 3.26. Five of these interventions are to the building or their immediate surrounds, and, as they require little or no involvement from occupants, are regarded as passive cooling strategies. The sixth strategy aims to improve window use by the teachers and is an active strategy.

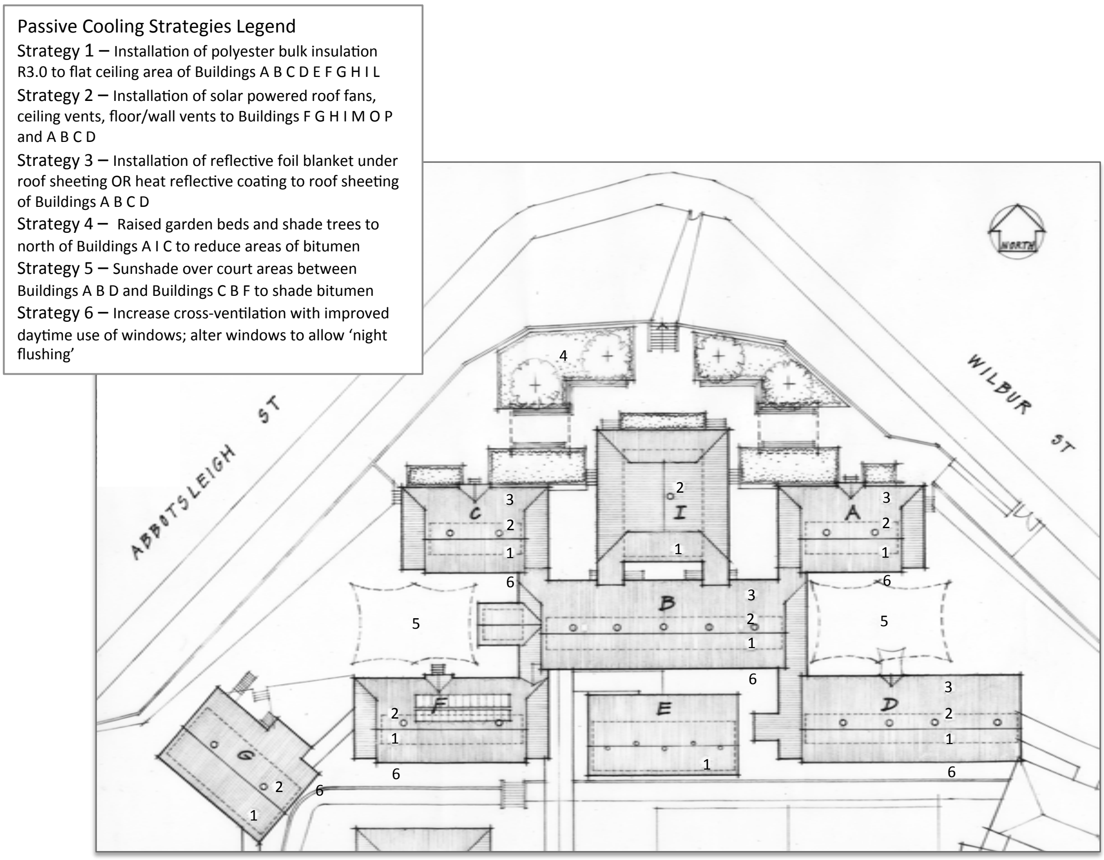


Figure 3.26 Passive Cooling Strategies Plan (By author 09.04.2013)

3.4.3 Time Line for Strategy Implementation

At the start of 2013 only the stack ventilation strategy was to be funded by the Parents and Citizens' Association. Funding later become available from the Department of Education and Training and other sources, but resulted in the timing of the interventions becoming ad hoc, combined with the constraints of working with an operational school.

Between 2012 and 2014 the four passive cooling strategies were implemented in the school; ventilation, cool roof, shade sails and schoolyard greening. These are listed in order of implementation as Interventions 1 to 5 in Table 3.2 The stack ventilation strategy was implemented in two parts, Interventions 1 and 3. The schoolyard greening was in two stages; Stage 1 was the construction of garden beds in Intervention 4 and Stage 2 as additional planting in Intervention 5. Shade sails were implemented in Intervention 4, at same time as Stage 1 of the garden. Costs of each intervention are included in Appendix B.

Table 3.2 Order of Passive Cooling Strategies Interventions and Scope of Work

INTERVENTION #	DATE	PASSIVE COOLING STRATEGY	LOCATION BUILDING	C'ROOM	AREA m2	VOLUME m3	SCOPE OF WORK Elements	FUNDING SOURCE
1	Dec 2012 - Jan 2013	**Stack ventilation Part 1**	F	F1	60	214	2 CVE, 2 FV1, 1 RF	P&C
				F2	60	214	2 CVE, 2 FV1, 1 RF	
			G	G1	72	227	2 CV1, 2 FV1, 1 RF	
				G2	69	220	2 CV1, 2 FV1, 1 RF	
2	Sep 2013 - Oct 2013	**Cool roof**	A	A1	Roof			DET Cool Roof School Trial
				A2				
			D	D1	Roof			
				D2				
3	Dec 2013 - Jan 2014	**Stack ventilation Part 2**	A	A1	70	212	2 CVE, 1 WV1, 1 DV1, 1 RF	P&C
				A2	68	204	2 CVE, 1 WV1, 1 DV1, 1 RF	
			B	B1	82	206	2 CV2, 3 FV2, 1 DV1	
				B2	82	206	2 CV2, 3 FV2	
				B3	82	206	2 CV2, 3 FV2	
							1 TS, 3 NP	
			C	C1	68	204	2 CV3, 3 FV2, 1 RF	
				C2	71	212	2 CV3, 3 FV2, 1 RF	
			D	D2	95	341	2 CV3, 3 FV2, 1 RF	
				D3	86	308	2 CV3, 3 FV2, 1 RF	
4	Jul 2014 - Aug 2014	**Shade Sails**	East courtyard between A B D				3 sails cover area 9m x 20m mesh fabric cream colour	GCBF grant P&C
			West courtyard between C B F				2 sails cover area 9m x 14.5m mesh fabric cream colour	
		Front garden Stage 1	Courtyard north of A I C				4 garden beds, widen 2 exist beds total 300m2	NSSP (via DET)
							49 sandstone blocks, subsoil drainage, topsoil, bark mulch	
							10 'tuckeroo' trees	
5	Oct 2014 - Nov 2014	**Front garden Stage 2**	Courtyard north of A I C				162 native plants	BCC
							36 native shrubs and 7 fruit plants	P&C, donations

Stack Ventilation Elements	
CVE	Ceiling vent existing 600x600mm timber lattice
CV1	Ceiling vent round 300 diam.closable, white plastic
CV2	Ceiling vent 400x400mm alum square grille, closable
CV3	Ceiling vent 600x600mm alum square grille
DV1	Door vent 600x300mm alum fixed lovures, 25mm wide
FV1	Floor vent 150x300mm plastic, closable
FV2	Floor vent 150x300mm alum, closable, powdercoated
WV1	Wall vent 400x400mm alum fixed louvres 50mm 2 layers
RF	Roof fan solar-powered with 25W panel, max. 3000L air changes per hourr, metal cowl powdercoated to match roof colour

3.4.4 Changes in the School During the Project

During the research project the school context changed. At the start of the project in 2012, it was a school with mostly naturally ventilated classrooms (Figure 3.2). There was only one classroom building that had air conditioners, Building H. In 2010, air-conditioners were installed to the five upper storey classrooms of Building H when excessive noise and dust from the construction of adjacent Building R required windows to be closed. By 2014 the school had thirteen air-conditioned classrooms and twenty-one non air-conditioned classrooms, as shown in Figure 3.27.

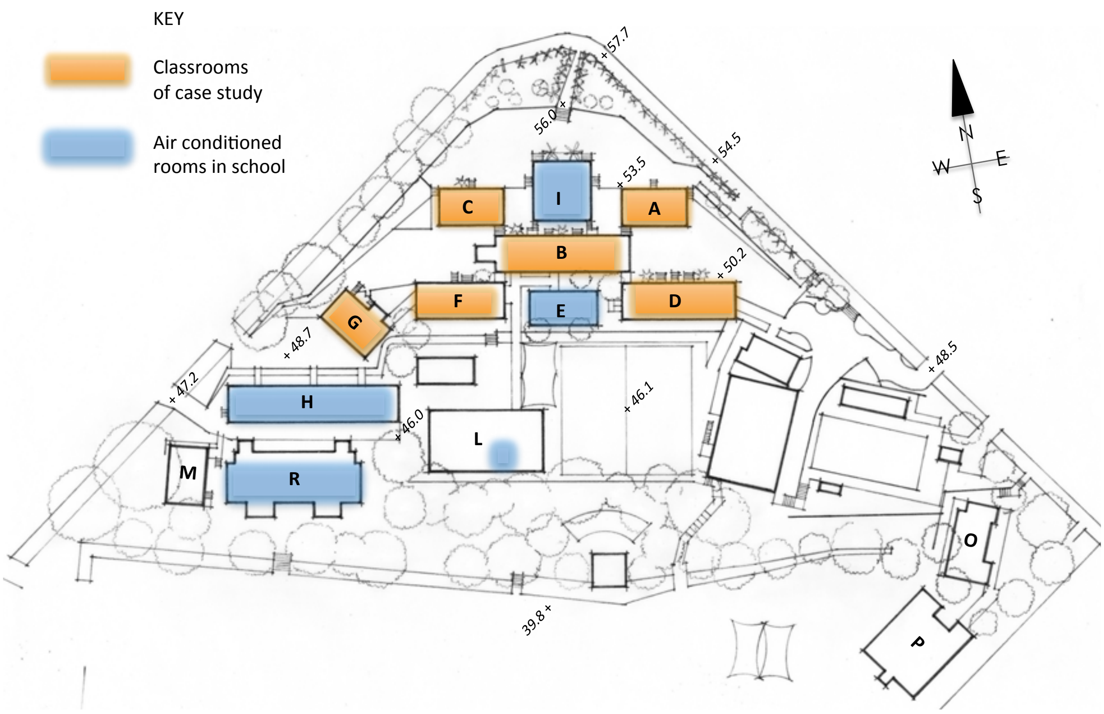


Figure 3.27 Case Study Classrooms & Air-Conditioned Rooms in 2014

In February 2014 the school installed air conditioning to areas other than classrooms; Building I administration offices, Building E staff room and Building L music practice room. Then in April air conditioning was installed to Building R's eight classrooms by the Department of Education and Training as a measure to rectify 'hot and stuffy' conditions experienced by teachers and children in its first year of occupation. Building R is a two-storey building with concrete block walls, concrete floors, steel frame and metal sheet clad wall and roof, constructed in 2010 under the Building Education Revolution (BER) funded by the Federal Government. The cause of thermal discomfort was reduced airflow in the classrooms due to the small number of operable window area per classroom. Only a third of the windows were operable, either sliding or upper level small awning windows, with a dense security mesh ('Crimsafe') installed over the openings that further reduced breezes.

In August and September 2015, around the same time interviews were being conducted for this project, the school Principal, his deputies and the Parents and Citizen's Association executive were considering air conditioning more classrooms. In October 2015 the Parents and Citizen's Association decided to fund the installation of air conditioners in all classroom buildings, to occur in 2016.

3.5 Research Design

This research takes a pragmatic stance to address the wicked problem of how to maintain thermal comfort in an existing building type and lessen building emissions to reduce impact on climate change. A pragmatic stance means a researcher will use any methods available to gain knowledge for a research aim; both quantitative and qualitative methods can sit with the same research project (Tashakkori and Teddlie 2010).

The design of the research aims to answer the three research questions. Research Question 1 asks if the passive cooling strategies impacted on classroom temperature; has it reduced classroom temperature due to the interventions. This case study can be regarded an evaluation of the impact of passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds, upon classroom temperature.

Question 2 asks if any reduction was enough to be within an acceptable comfort zone for the occupants. Thermal comfort is defined as 'state of mind which expresses satisfaction with the thermal environment' (ASHRAE 2013). Conventional thermal comfort studies measure factors that influence satisfaction with the thermal environment, that are parts of the heat balance model of thermal comfort (Fanger 1970, ASHRAE 2004). Environmental factors measured are air velocity and direction, humidity levels, ambient air temperature and radiant heat of surfaces. Personal factors measured are the level of clothing worn by occupants, metabolic rate of occupants. In addition body size and number of occupants in a room can be noted (ASHRAE 2013; de Dear et al. 2013). The Adaptive Comfort Model is based on extensive field studies providing statistical data to define conditions that a percentage of occupants (80% and 90%) in naturally ventilated buildings find thermally comfortable. It is based on a dynamic relationship between indoor and outdoor temperature. But some factors that influence satisfaction, such as social and cultural factors, are immeasurable in a quantitative sense, and need another kind of analysis. A qualitative analysis was required to capture an understanding of these factors.

Question 3 explores the current adaptive behaviours the teachers engage in the classrooms. The case study can be regarded as an exploration into the current adaptive behaviours that teachers engage in to reduce discomfort from overheating in classrooms (Nicol et al. 2012). An understanding of current social practices of teachers in naturally ventilated classrooms could be a pathway to increasing low carbon behaviours in schools in South East Queensland (Moloney & Strengers 2014).

Both analyses of data are regarded as equally important in this research as both quantitative and qualitative data is needed to answer Research Questions 2 and 3. Quantitative data of classroom temperature provides a reference for determining when the classrooms were warm or overheated when discussing the impacts of the interventions with the occupants in the qualitative phase of the project.

3.5.1 Mixed methods methodology

As the purpose of each intervention is to reduce heat load to classrooms and the unit of heat measurement is temperature, quantitative data, in the form of classroom temperatures was collected by data loggers from November 2012 to March 2015. This second data set was the qualitative data, the teachers' and principal's perceptions of the impact of the interventions. The qualitative data was collected using an online questionnaire and interviews, between June and September 2015.

A convergent mixed method design was used, where the two data sets were analysed separately, then converged to respond to the research questions (Creswell and Plan Clark 2011). The data collection periods for the quantitative and qualitative phases are represented in Figure 3.28.

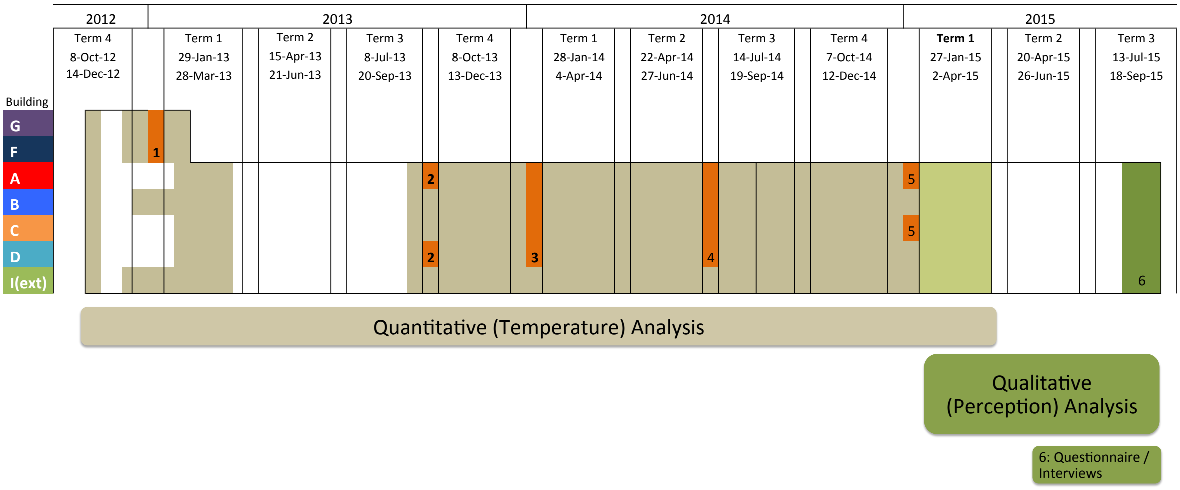


Figure 3.28 Quantitative & Qualitative Data Collection

3.5.2 Ethical Procedures

The qualitative phase of the study required ethics approval to be obtained from the Human Research Ethics Committee at the University of Queensland, and permission from the gatekeeper of the participating school, the Principal. This was a low risk type of study, asking adults about their occupancy of classroom buildings as part of their everyday lives.

The ethics process involved forwarded information about the research project to participants (refer Appendices G and H). All teachers were invited to participate in the research by completing an anonymous online questionnaire. Teachers interviewed in the case study group of buildings provided signed consent.

3.5.3 Quantitative Data (Temperature) Collection

This first phase of the study was the quantitative data collection of temperatures at the school. This section will discuss the scope and method of data collection of classroom temperatures and external temperature at the school. The three methods of temperature analysis will be discussed in the next section 3.5.4.

Scope of Temperature Data Collection

The scope of temperature data collection was from November 2012 before any of the interventions, through to March 2015 after the interventions. Temperature data monitoring at the school is shown in Figure 3.29. Interventions occurred between January 2013 and November 2014, usually during school holiday periods and are between school terms and are numbered as Interventions 1 to 5.

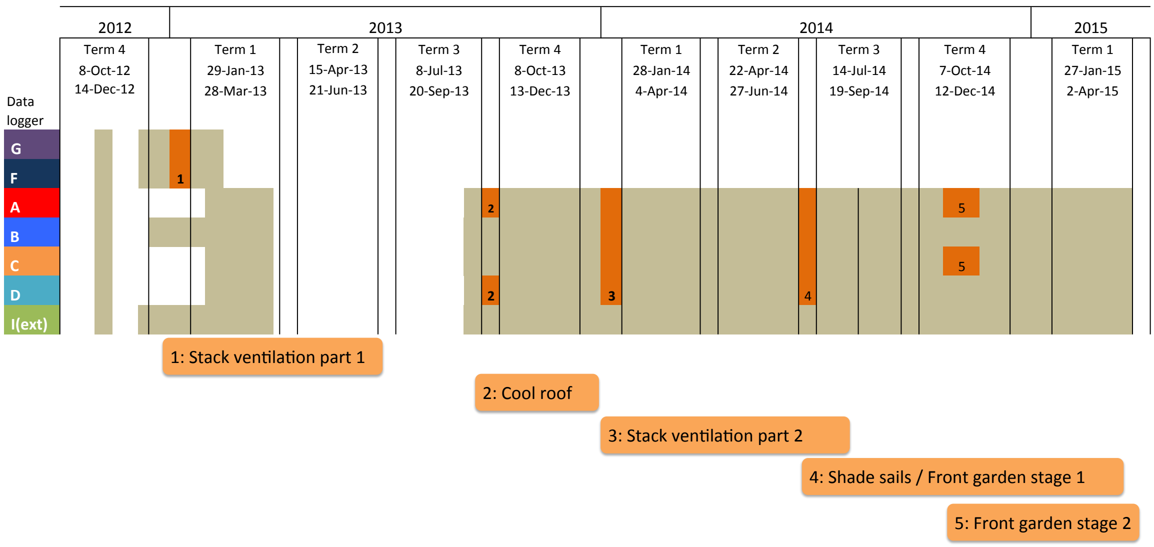


Figure 3.29 Temperature Data Collection & Timing of Interventions

Early in the research project (Term 4 2012 to Term 1 2013) some data loggers were used on other classrooms in the school and under the classroom floor of buildings A B C and D, to investigate cooler pockets of air for the stack ventilation strategy. Monitoring was consistent from September 2013. A full year of temperature data in 2014 was obtained from four buildings A B C and D, extending to end of March 2015.

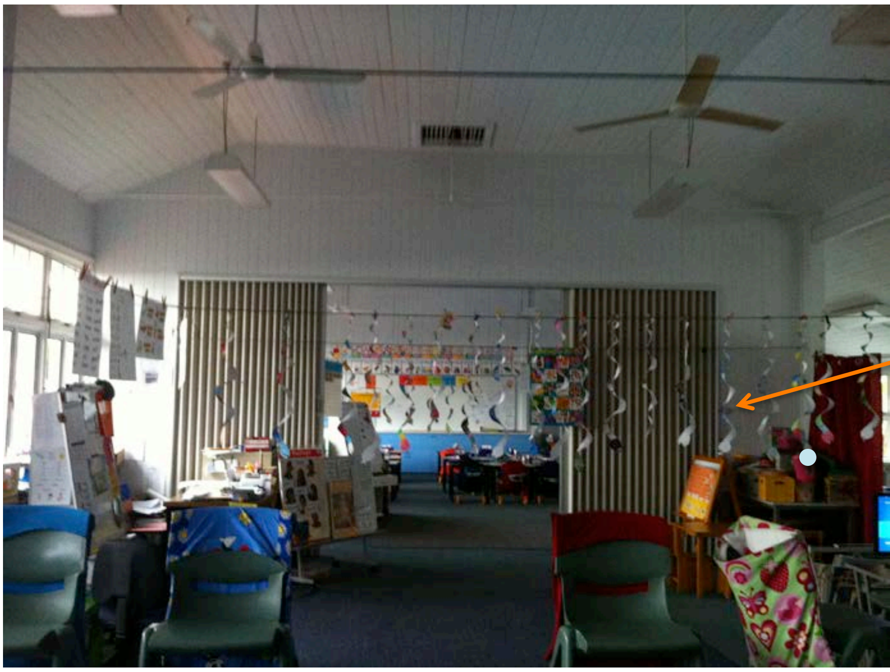
Data Collection Method

Temperature data was collected by battery-operated data loggers (type: HOBO U10 Temp/RH) placed inside classrooms and outside buildings. HOBO data loggers are small and unobtrusive (the size of a matchbox), can be temporarily adhered to a wall surface, affordable ($90 each), can be pre-programmed to start monitoring at a certain time and date and left alone for months at a time.

Locations of data loggers in buildings A B C D F and G and I(ext) are shown in Figure 3.30. Data loggers were placed according to logical and pragmatic considerations.

1) The aim of the research was to monitor differences before and after interventions rather than conduct full thermal comfort studies at different points of time in the research period. The location of the data loggers in the beginning of the research period was kept consistent during the research period to be a constant to compare with the variables of the research project; the interventions, climatic and other variable factors in the environment.
2) Loggers were placed inside classrooms on the partition wall between tow classrooms in most cases, as shown in Figure 3.31. The front wall of the classroom had a lot of learning resources adhered to the wall and the logger may be removed or covered over by a teacher when deciding to change the display. In many classrooms the front wall was also the wall facing east or west, subject to radiant heat from direct sunlight outside the wall. The back wall, the partition wall to the adjoining classroom, was the better location for the data logger so it would not be removed for the long time it was to remain there.
3) Loggers were placed a similar distance away from the north wall in each building.
4) Loggers were positioned 1.5m from the floor, at eye level, so they could be seen and not removed from the wall by the teacher as shown in Figure 3.31.
5) The small data loggers blink a red light so keeping it on the back wall would not be a distraction to children that generally face the front of the class.
6) The data logger for the school outdoor air temperature I(ext) was placed behind the administration building's opening plaque on the north facing veranda wall, shaded from direct sunlight and 1.5m from floor as shown in Figure 3-32. The administration building is Building I, is central to the group of case study buildings as shown in Figure 3.30.

Figure 3.30 Data Logger Locations in the School



Data loggers measure Temperature and Humidity at half-hourly intervals inside the classrooms

Figure 3.31 Typical Location of Data Logger Inside Classroom

Figure 3.32 Location of Data Logger I(ext)

Readings of temperature and humidity were set at 30 minute intervals to occur on each hour and half hour of the day. This was decided for two reasons. Firstly, to capture the closest hour of the start and end of the school day 9.00am (8.55am start) and 3.00pm (2.55pm end) and secondly, to obtain 48 points of temperature monitoring to adequately plot a descriptive curve of rise and fall of temperatures per day for the diurnal graphs in Method 2.

Data from loggers downloaded and were viewed in HOBOware. The temperature files were exported as a CSV files and imported into Excel. Temperature analysis methods were carried out using graph and equation tools in Excel.

3.5.4 Methods of Temperature Analysis

Three methods are being used to investigate effect on classroom temperature across the buildings. These are listed here by their titles and then explained in further detail in this section.

Method 1: $T_{upper\ 90}$ threshold method

Method 2: Diurnal graph method

Method 3: Binned temperatures

Method 1: $T_{upper\ 90}$ Threshold

For Method 1 an overheating metric process developed by De Dear and Candido was applied to this research (2012). The metric counts the frequency of time that temperatures in classrooms occur above the upper thresholds that represent 80% and 90% of the population, as defined by adaptive model in ASHRAE 55 (2013). However, there were some differences between how the metric was applied in the New South Wales schools study (de Dear et al. 2015) and in this research, namely in Step 1 and Step 3. The difference to *Step 1: Monitoring indoor thermal conditions*, is that in the NSW study the external temperature used for the input into the metric calculations was obtained from the nearest BOM stations was; for reasons given in 4.2 the external temperature at the school I(ext) is used in this research. The difference to *Step 3: Tallying the number of occupied hours*, is that in the NSW study school hours were 8.00am to 4.00pm. School hours 9.00am to 3.00pm were used in this research.

The steps used to apply Method 1 were as follows:

Step 0. Identify local threshold temperatures. Both upper thresholds $T_{upper90}$ and $T_{upper\ 80}$ are referred to in this research.

Step 1. Monitoring indoor thermal conditions across the buildings. The metric been applied to classrooms in six Buildings A B C D F G of the case study school using the external temperature at the school I(ext) as the input.

Step 2. Monitoring outdoor weather conditions across the property portfolio for heat-wave criteria. A heatwave is defined by de Dear when two or more consecutive days are over the upper 3% percentile maximum temperature for that month and two consecutive nights over the upper 3% percentile for minimum temperature (2012). Table 3.3 shows the Bureau of Meteorology temperature percentile maps for Brisbane, including the highest and 90th percentile temperatures for each month. Heat wave days have been removed from the data as noted in Table 3.4. Other individual days were very hot, but still included were 05 March 2015 and, so close to heat wave criteria, 09 - 10 March 2015.

Table 3.3 Brisbane Highest Percentile Temperatures

Sourced from BOM Temperature Percentile Maps 1950-2005				
	Brisbane Maximum Temperatures °C		**Brisbane Minium Temperatures °C**	
Month	**Highest percentile**	**90th percentile**	**Highest percentile**	**90th percentile**
January	30-33	30-33	21-24	21-24
February	30-33	30-33	21-24	21-24
March	30-33	27-30	21-24	18-21
April	27-30	27-30	18-21	15-18
May	24-27	24-27	15-18	15-18
June	21-24	21-24	12 to 15	9 to 12
July	21-24	21-24	12 to 15	9 to 12
August	21-24	21-24	15-18	9 to 12
September	27-30	24-27	15-18	12 to 15
October	27-30	27-30	18-21	15-18
November	30-33	27-30	18-21	18-21
December	30-33	30-33	18-21	18-21

Table 3.4 Brisbane Heat Wave Days Excluded from Data

	Brisbane Temperatures °C		**Excluded from**
Date	**Max temp**	**Min temp**	**data**
3-Jan-14	34.5	22.7	No
4-Jan-14	38.7	23.8	Yes
5-Jan-14	33.6	23.9	Yes
6-Jan-14	34.8	25.9	Yes
27-Oct-14	34.0	20.5	Yes
28-Oct-14	34.2	21.2	Yes
29-Oct-14	30.7	17.5	Yes
30-Oct-14	28.8	18.2	No
31-Oct-14	30.4	21.6	No
15-Nov-14	32.2	21.4	No
16-Nov-14	38.9	23.0	Yes
17-Nov-14	30.3	23.4	Yes
18-Nov-14	28.3	22.3	No
19-Nov-14	30.0	24.0	No
5-Mar-15	36.1	21.5	No
9-Mar-15	31.6	22.8	Yes
10-Mar-15	30.6	23.6	Yes
19-Mar-15	33.5	19.8	No
20-Mar-15	32.4	23.9	No

Step 3: Tallying the number of occupied hours in an operation year. Days when children are in attendance are regarded as school days. A school day at starts at 8.55am and ends at 2.55pm. As the data loggers monitor on the half hour the start and end times will be 9.00am and 3.00pm. Although some teachers occupy the classroom for much longer periods of the day this varies with each teacher and from day to day. This study focuses on the time the children are learning and when the teacher is in contact with the children.

Step 4: Calculating the exponentially weighted running mean outdoor temperature. The exponentially weighted running mean outdoor temperature for each day T_{rm} is calculated using equation 1 (de Dear and Candido 2012).

$T_{rm}= 0.32T_{od-1} + 0.23T_{od-2} + 0.16T_{od-3} + 0.11T_{od-4} + 0.08T_{od-5} + 0.05T_{od-6} + 0.03T_{od-7}$ (eq 1)

Where T_{od-1} refers to the day before, T_{od-2} refers to the day before that, so on for seven days.

Step 5: Calculate daily adaptive acceptable temperature thresholds. The optimum comfort temperature $T_{comfort}$ is derived using the adaptive model in ASHRAE 55 (2013).

$T_{comfort}= 0.31 \times T_{rm} + 17.8$ (°C) (eq 2)

T_{comf} is in the centre of a comfort zone band for 80% of the population that has upper and lower thresholds $T_{upper80}$ and $T_{lower\ 80}$ 7°C apart and for 90% of the population upper and lower thresholds $T_{upper90}$ and $T_{lower90}$ are 5°C apart. The upper threshold and lower threshold limits using T_{rm} were calculated using the following equations:

$T_{upper80} = 0.31T_{rm} + 21.3$ (°C) (eq 3)

$T_{upper90} = 0.31T_{rm} + 20.3$ (°C) (eq 4)

$T_{lower90} = 0.31T_{mm} + 14.3$ (°C) (eq 5)

$T_{lower80} = 0.31T_{mm} + 15.3$ (°C) (eq 6)

Step 6: Tally all temperatures that exceed the thresholds. The number of times the classroom temperature was over $T_{upper80}$ and $T_{upper90}$ was tallied for all school days. Temperature was monitored every half hour from 9.00am to 3.00pm inclusive, giving thirteen counts each day. The results of the tally are reported as actual counts and as a percentage of counts for school days each month.

Step 7: Decision regarding remediation of comfort conditions. The temperature results will be considered together with the qualitative data and implications for decision makers, discussed in the chapter 6.

Method 2: Diurnal Graph

Method 2 refers to graphs of temperature for five consecutive school days in a week. Graphs show rise and fall of classroom temperature for each day and were compared with I(ext). Weeks selected for observation were when maximum daily temperatures range 25-32°C, days were mostly sunny and fine (8-12 solar hours) and there was little or no rain. These weather conditions are when solar radiation has maximum effect on the building envelope and surroundings. Other factors such as wind direction, cloud cover and humidity levels are included in the Brisbane climate data table that accompanies each graph obtained from Brisbane City weather station 040913, to observe any impact these variables may have on classroom temperature.

Typically in lightweight timber buildings rising temperature outside is echoed in a temperature rise inside as outside heat passes through the low thermally resistant roof, walls and floor (Hyde 2000; Givoni 1998) refer Figure 3.33. In the afternoon and night as outside temperature falls so does the inside temperature. What is of concern in these classrooms is that temperatures remained elevated for the whole afternoon, compared to outside temperature that typically peaked at 1.00pm and fell in the afternoon (refer Fig 4.3 Evidence of Overheating). When comparing graphs of classroom temperature before and after each intervention any reduction of the duration of time classroom temperatures are elevated is noted in the discussion.

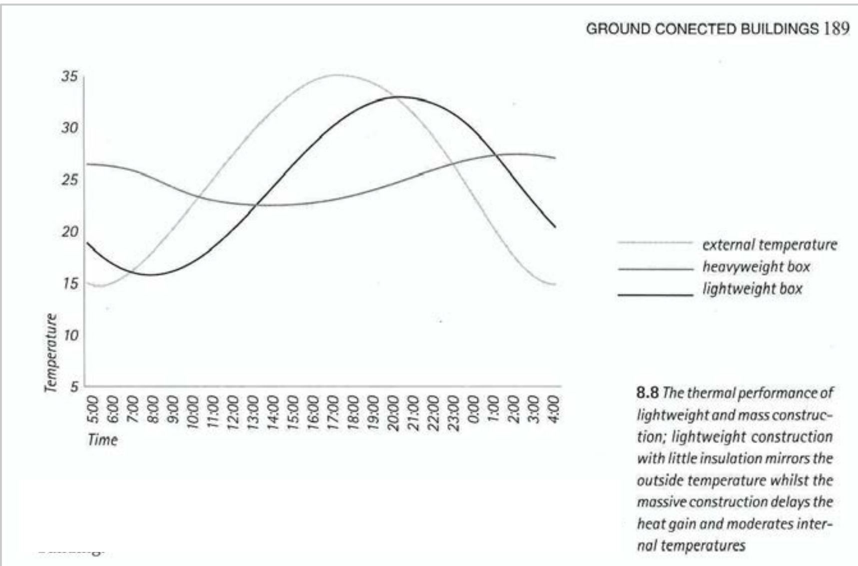


Figure 3.33 Daily Temperature Swings of Lightweight & Mass Construction (Hyde p.189)

For the threshold method the values of $T_{upper90}$ and $T_{lower90}$ have been calculated for each school day. These values are included on the diurnal graphs as two horizontal grey lines 5°C apart for each school day. End points of each horizontal line are at 9.00am and 3.00pm. How much the classroom temperature is within, over or under these thresholds can be observed. In these graphs temperatures are compared between classrooms and the external temperature I(ext) consistently shown as the green coloured line.The comparison before and after an intervention was usually done by comparing weeks of the same month, for example March 2013 to March 2014. Except early in the research project when data available for before the interventions were two weeks in November 2012 and weeks in February and March 2013 of differing durations for various buildings (for durations refer to Figure 3.29).

Method 3: Binned Temperatures

While Method 1 presents the frequency of half hour counts that occurred in each classroom above upper thresholds $T_{upper80}$ and $T_{upper\ 90}$, it does not capture by how much the temperature is over the threshold.

Method 3 is a tally of the extent of temperature in classrooms. The number of half hourly temperatures greater than or equal to values of 28°C, 29°C, 30°C, 31°C, 32°C and 33°C have been tallied for each school day during summer months for Buildings A B C and D. The data is displayed in a histogram with a specific coloured bar for each building (for colours refer Figure 3.30). A histogram is a tally of frequency between a range of values, in this research an interval of 1°C is appropriate. The tally shown in the histogram is a count of temperatures ≥28°C, ≥29°C and so on to ≥33°C. The first bar cluster is always the tallest showing the frequency of classroom temperature at T≥28°C. The second bar is shorter as the frequency of higher temperatures in decreases; these histograms are all skewed to the right.

January and April have been excluded from this method as there are only four school days in January and when Easter occurs each year affects the amount of April school days from year to year.

3.5.5 Qualitative Data (Perceptions) Collection

This section describes the collection of the qualitative data phase of the case study, the Teachers' perceptions of their classroom and school environment. The next section 3.5.6 describes the analysis of the data.

The qualitative data was collected in three ways.

1. Online Teacher Questionnaire
2. Interviews with teachers
3. Interview with the Principal.

In addition some field observations of classroom conditions were made. Photographs of classroom interiors were taken with prior permission from the classroom teachers.

Questionnaire Design and Semi-structured Interview Questions

The questionnaire design was informed by two relevant studies in schools reviewed in the literature (Heschong Mahone Group 2003; De Guili, Da Pos and De Carli 2012) and the Post Occupancy Evaluation form used in the PROBE projects (Leaman and Bordass 2007). The questionnaire to teachers in Heschong Mahone Group's seminal day lighting study of classrooms investigating how this aspect of classroom environment affected student academic performance was reviewed for its structure and content of survey questions (2003). The second questionnaire reviewed was the survey used in Venice schools that asked children about their adaptive behaviours in the classroom (De Guili, Da Pos and De Carli 2012).

In addition to these studies, anecdotal comments from teachers in the school informed the list of adaptive actions to be investigated. In the quantitative phase of the project, whilst in the classrooms downloading data from the data loggers, comments from teachers were received on what they did to try and cool themselves and the children down when the classroom was hot. Other comments were also received from other teachers and the Principal at other times. These described actions were noted and included in the list for question that asked about current adaptive actions, Question 11.

Many of the questions in the questionnaire were bespoke and deisgned to pursue the research aims. Instead of piloting the questionnaire on a small group of teachers that would then be asked a second time the improved questions of the same questionnaire, the questions were reviewed by the Principal Supervisor of this thesis.

The questions for the Online Teacher Questionnaire, Teacher Interviews and Principal Interview were grouped according to the research aims. These questions are in a table in Appendix G. Most questions in the Online Teacher Questionnaire, Questions 2 to 29, were multiple-choice, with opportunity for the respondents to add further comments. Questions 30 and 31 explored energy conservation and sustainability in the curriculum. Question 32 and Question 36 were open ended and participants answered in their own words. Only Question 1, "Do you agree to participate?" was compulsory.

All teachers with a classroom in the school were invited to participate in the online questionnaire. The Principal emailed the invitation to teachers, to avoid collecting individual teacher's emails, respecting the teacher's privacy. The questionnaire was designed using Survey Monkey. It was recommended that the questionnaire be answered while the teacher was in their classroom, for easier recall of physical features of the classroom and perceptions from memory of what the classroom was like, during Term 1, the most recent summer.

Teachers were interviewed in their classrooms. Some teachers had occupied the same classroom for three years, the time period of the research project. Similar questions to the questionnaire were asked, however more context and detail was sought from responses. The semi-structured approach allowed emergent themes to be discussed that were not envisioned in the questionnaire.

An interview with the Acting Principal had questions from each question group, with additional consideration given to the social and cultural context of the school. Conducting an interview with the principal, the elite of the organisation of the school aims to better understand and reveal the workings of the school (Easterby-Smith, Thorpe, Jackson 2015).

3.5.6 Methods of Qualitative Data Analysis

To analyse the interview transcriptions a coding process was used. Keywords defined by Soft Systems Methodology were manually applied to the interview transcriptions to articulate themes. Definitions of the keywords, *roles, norms* and *values* and their relationships to each other, were explored. Other keywords, *power* and *commodity,* were also used. The interview transcriptions coded with these keywords enabled emerging themes to develop. In this research Soft Systems Methodology is applied as a framework to view the interventions at the school as a purposeful activity. The problematical situation at the case study school is the wicked problem of how to maintain thermal comfort from overheated classrooms in a low energy manner? Soft Systems Methodology has three analytic strands of an intervention to a problematical situation: the intervention analysis, a social analysis and a political analysis. The social analysis searches for roles, norms and values that people in a problematical situation hold. A definition of roles, norms and values are provided by Checkland and Poulter (2006):

- *Roles* are social positions, which mark differences between members of a group or organization. They may be formal (the Principal) or informal (a 'boat-rocker').
- *Norms* are the expected behaviours that are associated with, and help to define, a role.
- *Values* are the standards, the criteria, by which behaviour-in-role gets judged.

Norms, roles and values are in relationship with each other as shown in Figure 3.34

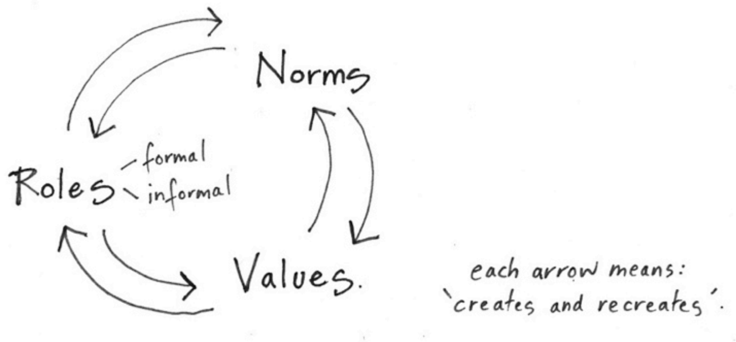


Figure 3.34 Model of Norms, Roles & Values (adapted from Checkland and Poulter 2006, p.33).

For example, the role of Principal will have behaviours expected of a Principal that are different from a teacher and the performance of the role will be judged according to local standards or values (Checkland and Poulter 2006). Using this approach will provide a comprehensive understanding of the social and cultural context of the school.

3.5.7 Convergence of Results

The quantitative analysis used quantitative methods (Temperature Methods 1, 2, 3) and the qualitative analysis used qualitative methods (questionnaire, semi-structured interviews). The quantitative analysis is used to answer Research Question 1 and the qualitative analysis for Research Question 3. But both data sets are needed to answer Research Question 2. As a full year of temperature data was collected for 2014 and the questions asked in interviews discussed discomfort for both winter and summer periods, the two data sets were compared and are discussed in Chapter 6. The side-by-side display is suggested by Dickinson to converge results from two phases of a mixed methods study, such as a quantitative phase and qualitative phase (Dickinson, Chapter 19 in Tashakkori and Teddlie 2010).

3.7 Limitations of Research Design

There are some limitations to the research design that are discussed here.

3.7.1 Humidity is a Factor for Thermal Comfort

It is recognized that high humidity in a sub-tropical climate is a contributing factor to thermal comfort. A limitation of this research is that humidity differences in the classrooms were not monitored. The aim of the passive cooling strategies was to reduce heat inside the classrooms, and the unit of measurement for heat is temperature, therefore humidity was not measured. The passive cooling strategies are linked to outside conditions. During the day when windows are open and a strong level of outdoor air is circulating through the classroom it is expected that humidity levels could be similar to those outside. The strategies studied here were designed to improve thermal comfort but not to actively change the humidity, as is the case with air-conditioning, which dries the air out.

3.7.2 Selection of Passive Cooling Strategies

The passive cooling strategies studied in this research are not the only strategies that could have been implemented in the school. For example, shading windows from direct sunlight would most likely improve the thermal comfort in buildings G, A, and C, however, this strategy did not fit the criteria used in this study and described earlier in this chapter.

3.7 Conclusion

This chapter explained the research design used in this research project: a single case study with mixed method approach to data collection and analysis. In this chapter, before discussing the research design the setting of the case study school and the passive cooling strategies implemented to the school were described in detail. Presenting information about the school was necessary to better understand the data collection methods used in the case study. A mixed method approach was used to collect and analyse data from the school; collection of temperature levels in classrooms used quantitative methods and information around personal comfort levels of people using the buildings used qualitative methods. This research does not rely on temperature alone to evaluate the impacts of the interventions. Another data source is obtained from the qualitative analysis through the questionnaire and semi structured interviews with teachers. Importantly the qualitative phase investigates the social and cultural aspects of occupying the classrooms from the teachers' and principal's points of view, to provide a more in-depth understanding of the social context of the school.

The next chapter, Chapter 4, discusses results of the quantitative temperature analysis. This is then followed by Chapter 5 results of the qualitative perceptions analysis of the project. In the beginning of Chapter 6 the two data sets for the year 2014 are brought together and findings and implications are discussed.

Chapter 4 Results - Temperature Analysis

4.1 Introduction

The previous chapter explained the methods used for collecting and analysing data in the quantitative and qualitative phases of the study. This chapter contains the results of the quantitative phase, the temperature analysis. It presents temperature data in response to the first two research questions:

1: How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

2: What is perceived to be an acceptable comfort zone for classroom occupants?

The chapter commences with the comparison of the school external temperature with the nearest weather station. Then temperature results are presented in chronological order starting with the time period of November 2012 before any of the interventions and all classrooms are observed to be overheating. Classroom temperature data after each intervention is analysed by three methods. Data using each method is displayed in the following formats and results discussed.

Method 1 $T_{upper\ 90}$ threshold method (table)
Method 2 Diurnal graph method (graph) with Brisbane weather data (table)
Method 3 Binned temperature method (histogram)

Then results of applying the overheating metric, Method 1, to buildings A B C D from Term 4 2013 to Term 1 2015 for $T_{upper\ 90}$ and $T_{upper80}$ thresholds are discussed.
The chapter finishes with a summary of the key findings of the temperature analysis.

4.2 School External Temperature Used as Input for Adaptive Comfort Model

As discussed earlier in 3.5.3 this research used the external temperature at the school for the input to the Adaptive Comfort Model, instead of the temperature from the nearest Bureau of Meteorology weather station Brisbane City 040913, located in East Brisbane. Three comparisons of temperatures from both locations are discussed here to demonstrate why.

4.2.1 Temperature Comparison 1

School temperatures I(ext) were compared to weather station Brisbane City for five weeks in November 2012 and March 2013 as shown in Table 4.1.

Table 4.1 Comparison of Brisbane with I(ext) 2012-2013

		Brisbane City Station 040913				Case study school I (ext)		Difference between locations	
School Days		**Min °C**	**Max °C**	**Rain mm**	**Sun hours**	**Min °C**	**Max °C**	**Min °C**	**Max °C**
M	12-Nov-12	15.3	25.8	0	11.7	16.5	25.7		
T	13-Nov-12	14.1	26.8	0	11.9	16.4	26.8		
W	14-Nov-12	14.8	27.9	0	12.3	18.4	27.7		
T	15-Nov-12	17.8	28.5	0	11.6	19.3	28.4		
F	16-Nov-12	17.9	31.1	0	12.1	20.4	30.7		
Averages		**16**	**28**		**11.9**	**18.2**	**27.9**	**2.2**	**-0.1**
M	19-Nov-12	17.6	34.4	16.6	12.4	19.6	34.1		
T	20-Nov-12	18.2	28.1	0	12	20	29.2		
W	21-Nov-12	17.7	28.1	0	12.1	19.7	28.3		
T	22-Nov-12	18.1	28.9	0	9	20.6	29.4		
F	23-Nov-12	22.4	28.1	0	8.6	23.4	28.5		
Averages		**18.8**	**29.5**		**10.8**	**20.7**	**29.9**	**1.9**	**0.4**
M	11-Mar-13	19.7	28	0.8	8.4	21.1	28.4		
T	12-Mar-13	18.9	27.6	0.2	8.5	20.6	28.2		
W	13-Mar-13	19.3	28.5	1.4	8.9	20.5	29.4		
T	14-Mar-13	17.9	29.9	0	8	19.3	30.5		
F	15-Mar-13	18.3	30.8	0	10.5	20.4	30.3		
Averages		**18.8**	**29.1**		**8.9**	**20.4**	**29.4**	**1.6**	**0.3**
M	18-Mar-13	20.3	27.1	0	7.2	21.8	28		
T	19-Mar-13	17.5	26.8	0	8.4	19.3	27.1		
W	20-Mar-13	20.3	27.2	0	1.2	21.3	27.2		
T	21-Mar-13	19.2	26.9	5	5.6	20.1	26		
F	22-Mar-13	20.8	28.1	0.4	4.9	22.1	27.9		
Averages		**19.6**	**27.2**		**5.5**	**20.9**	**27.2**	**1.3**	**0**
M	25-Mar-13	19.5	30.8	21.2	10.3	20.9	31.5		
T	26-Mar-13	19.7	29.1	0	10.8	22.1	30		
W	27-Mar-13	20.7	28.2	0.4	9.3	22.6	28.7		
T	28-Mar-13	19.4	28.2	0.6	9.6	21.5	28.6		
F	29-Mar-13	18.7	30.2	0.2	6.8	20.7	30.9		
Averages		**19.6**	**29.3**		**10**	**21.6**	**29.9**	**2**	**0.6**

Maximum temperatures at the school and Brisbane were similar but minimum temperatures at the school were warmer by 1.3°C to 2.2°C. A lesser difference between maximum and minimum temperatures in a location compared to rural areas can indicate urban heat island effect occurring (Givoni 1998). This comparison is between a Brisbane suburban school and the Brisbane weather station, indicating a local urban heat effect. However, five weeks of comparison is a sample size. To investigate this trend further, two comparisons of temperatures from the two locations for the year 2014 have been done.

4.2.2 Temperature Comparison 2

The second comparison used the monthly mean temperatures from each of the two locations as the input for the adaptive comfort model, shown together on a graph in Figure 4.1. The process for calculating monthly mean was derived from the definition in the ASHRAE 55. 'Monthly mean temperature (T_{mm}) is the simple arithmetic average of the daily minimum mean and daily maximum mean for each month.'

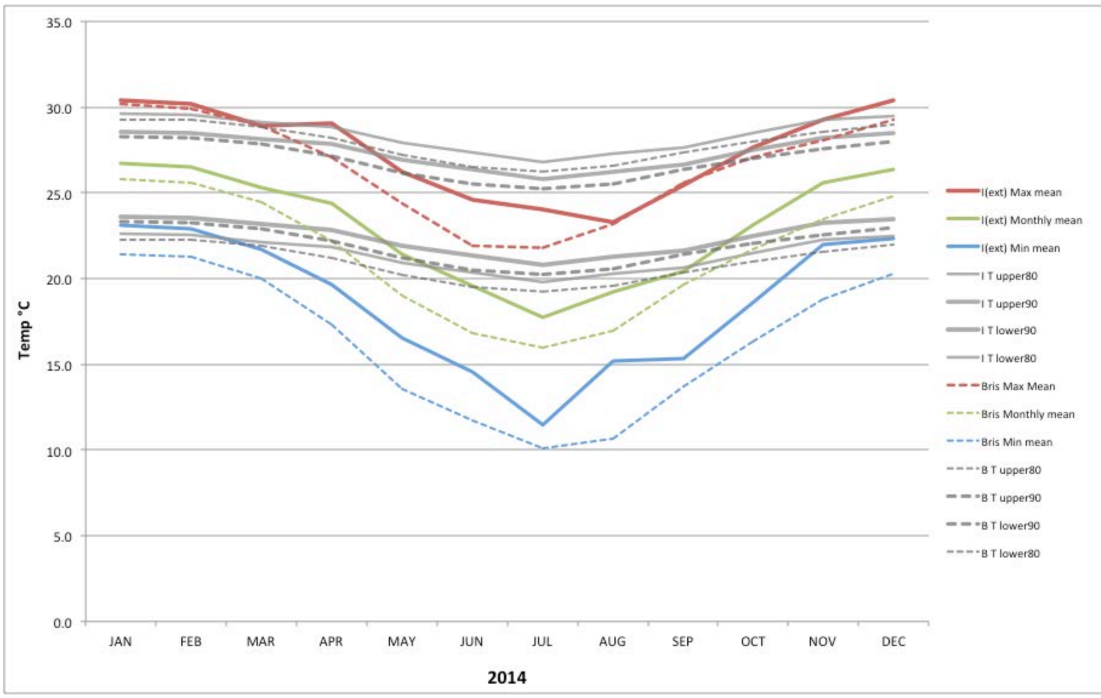


Figure 4.1 Adaptive Comfort Zones of I(ext) for Brisbane

In both locations from August to March the maximum mean temperatures were similar. However from April to July the maximum mean temperatures at the school were warmer than Brisbane by 2°C. Throughout the year minimum mean temperatures at the school were 2 to 4°C warmer than Brisbane. These warmer temperatures result in the comfort zone for winter months April to August to be one degree higher than the comfort zone for Brisbane. Note that the comfort zones in Figure 4.1 appear over simplified compared to the graphs generated in temperature comparison 3 (Figures 4.2 and 4.3).

4.2.3 Temperature Comparison 3

The overheating metric process described in 3.5.4 has been applied to the temperatures from each location as shown in Figures 4-2 and 4-3 on the next page.

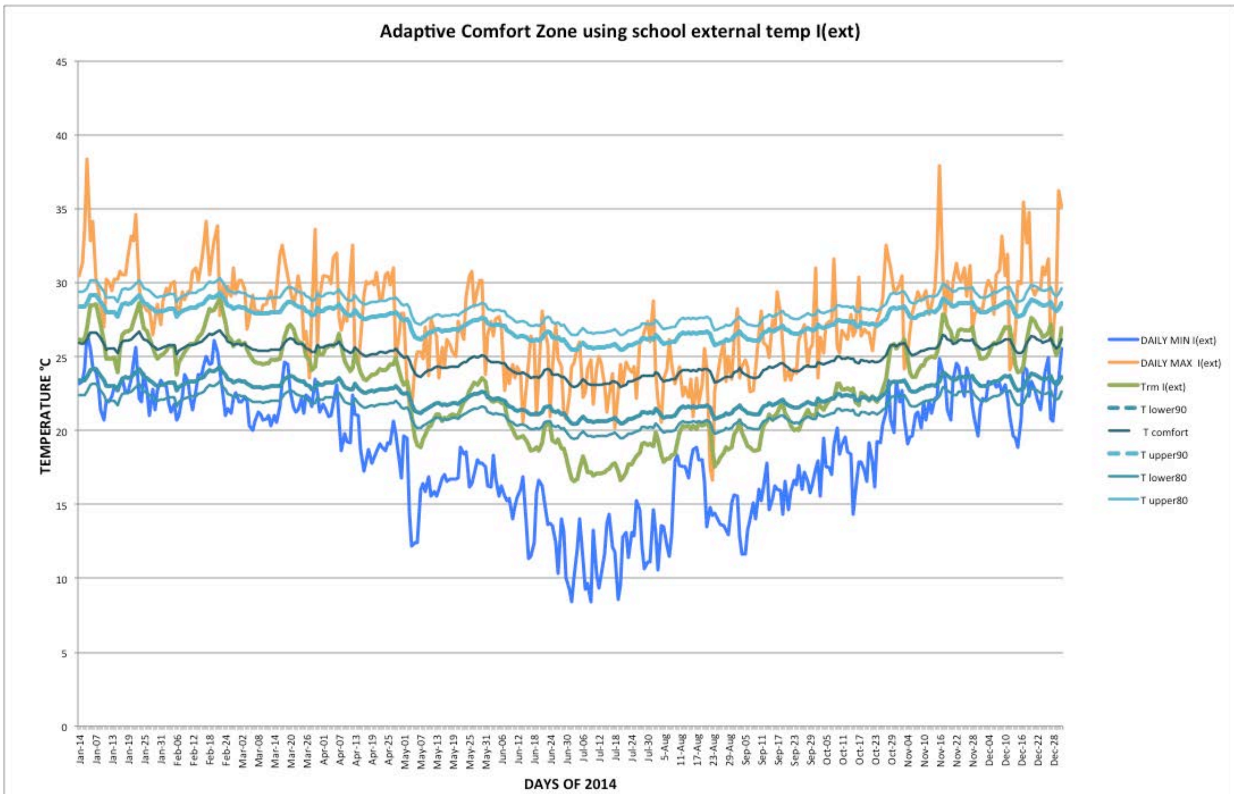


Figure 4.2 Daily Minimum & Maximum Temperatures, Running Mean Temperature & Adaptive Comfort Standard of I(ext) for 2014

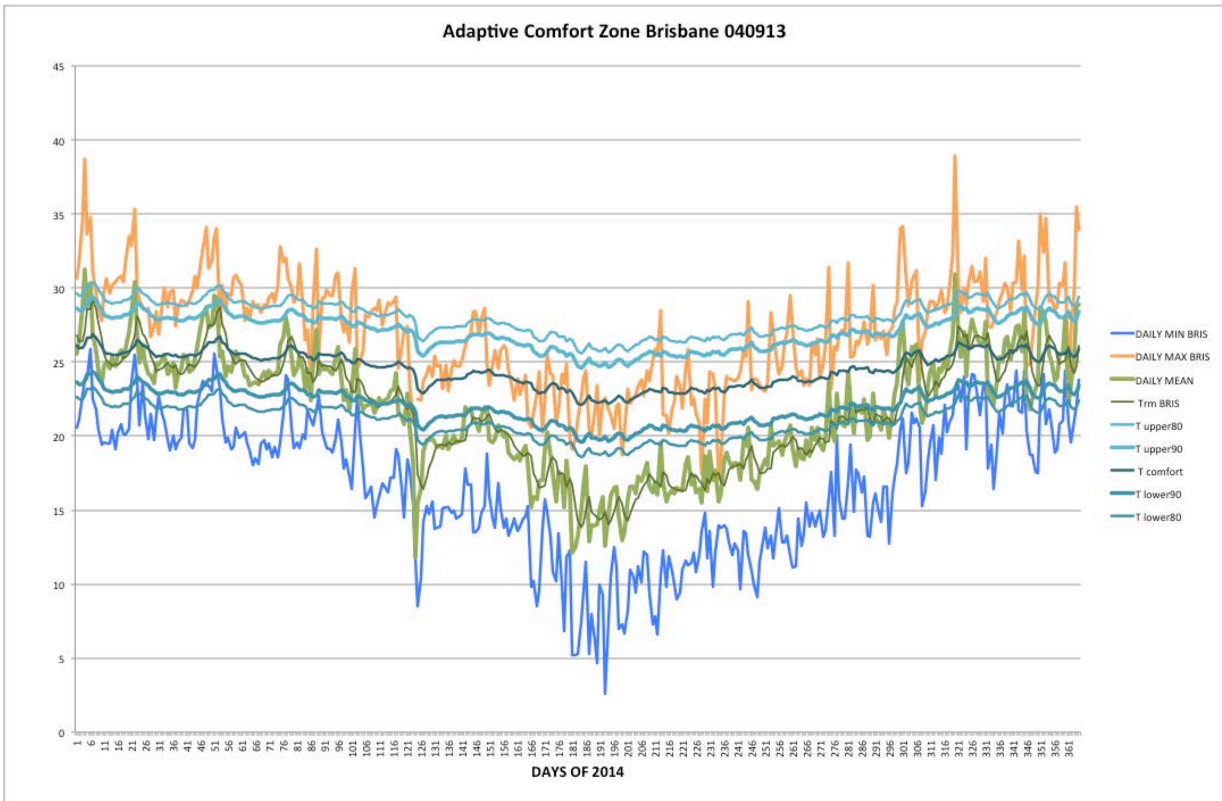


Figure 4.3 Daily Minimum & Maximum Temperatures, Running Mean Temperature & Adaptive Comfort Standard in Brisbane, 2014

Figure 4-2 shows results for the school I(ext) and Figure 4-3 for Brisbane. All daily minimum and maximum temperatures were collected, daily mean temperature and upper thresholds ($T_{upper90}$, $T_{upper80}$) and lower thresholds ($T_{lower90}$, $T_{lower80}$) calculated, resulting in the adaptive comfort zone for each location. In comparing these two graphs daily maximum temperatures at the school were similar to the temperatures at Brisbane. Yet at the school, minimum temperatures were warmer than at Brisbane. In Figure 4.2 at the school in January, February and March the minimum temperatures remained above 20°C. In Figure 4.3 at Brisbane in January and February the minimum temperature fell below 19°C and cooler in March, November and December. At the school in Jun and July the minimum temperature fell a few times below 10°C whereas at Brisbane it fell below 5°C. At the school the smaller difference between maximum and minimum temperatures results in the daily mean being up to a degree warmer than the daily mean for Brisbane. At the school from about mid-November to March the value of $T_{upper\ 90}$ averaged 28°C. In the coldest time of the year, end of June through July, $T_{upper90}$ averaged 25°C and $T_{lower90}$ averaged 20°C.

These three comparisons of school temperature I(ext) to weather station Brisbane City have provided reason for using the external temperature at the school as the input to the adaptive comfort model. The outside temperatures of the cluster of school buildings differed to the Brisbane city temperatures, probably because of the local environmental factors of hard paved surfaces surrounding the buildings; the cluster has its own microclimate (Oke 1987; Erell et al. 2012). The adaptive comfort zone is a dynamic relationship between outside and inside temperature. To reflect this more accurately the outside temperature of the specific location should be used, not the outside temperature from another location with different environmental ground and microclimate factors. In this research the input for the adaptive comfort model is the external temperature at the school I(ext).

4.3 Evidence of Overheating Problem in Buildings A B C D F and G

The first temperature monitoring in all buildings A B C D F and G occurred in November 2012 before any interventions. All classrooms were overheated as can be seen in graphs in Figures 4.4 and 4.5. For buildings A B C and D another time period before interventions was February and March 2013 (for duration of monitoring, refer back to Figure 3.29).

Each building is identified by a colour in the diurnal graphs and binned temperature charts consistently through this study, refer back to Figure 3.30. The colour used for the external temperature at the school, Building I(ext), is green.

4.3.1 $T_{upper\ 90}$ Threshold

Table 4.2 shows that for eleven days in November 2012, building D had the most time over $T_{upper90}$ threshold at 71% of the time, followed closely by A, then F, C, B and G at 56%. All classrooms were over the $T_{upper90}$ threshold (calculated to be 27.5°C to 27.9°C) for more than half of school hours.

Table 4.2 Buildings A B C D F & G: Tupper90 Tally Before & After Intervention 1

				Counts exceeding $T_{upper90}$ threshold											
				Counts per building						Percentage of time					
Year	**Month**	**School Days**	**Half hour counts**	**A**	**B**	**C**	**D**	**F**	**G**	**A**	**B**	**C**	**D**	**F**	**G**
2012	NOV	11	143	100	87	95	102	96	80	70%	61%	66%	71%	67%	56%
	INTERVENTION 1: Stack ventilation Part 1														
2013	FEB	18	234	95	80	84	97			41%	34%	36%	41%		
	MAR	15	195	62	58	60	86			32%	30%	31%	44%		
	FEB	12	156					43	42					28%	27%

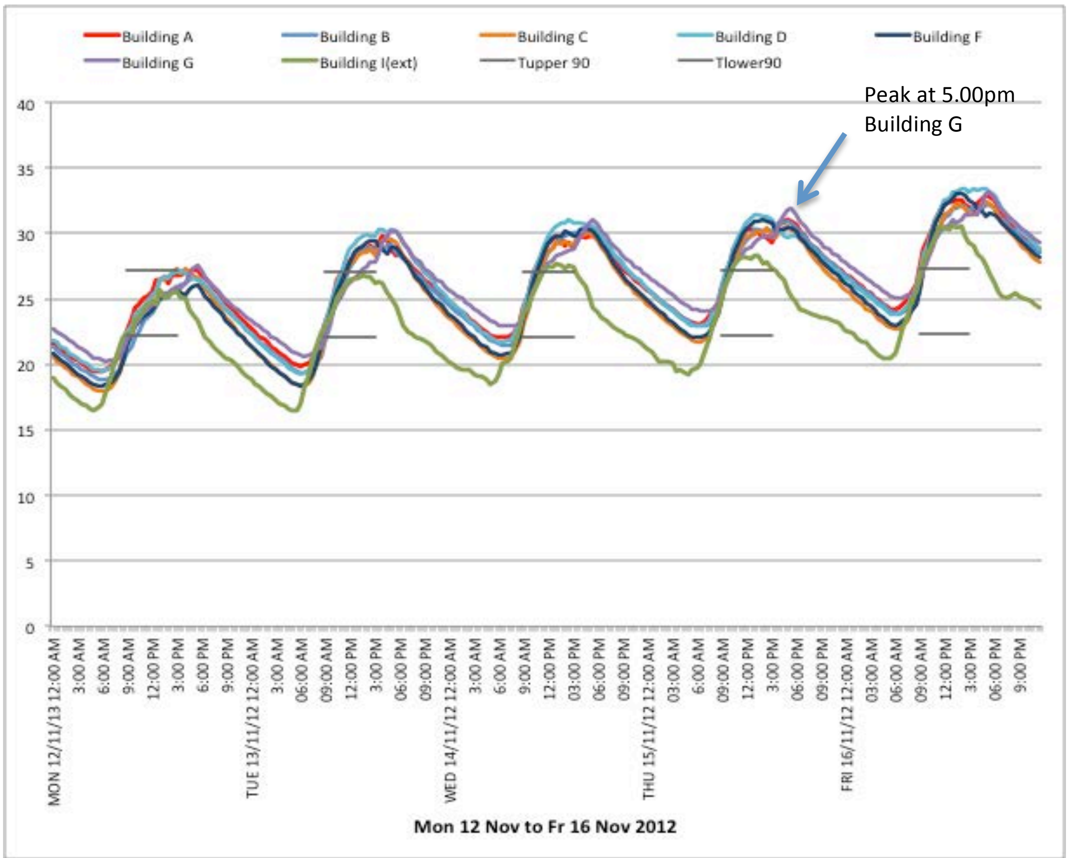


Figure 4.4 Buildings A B C D F & G: November 12 to 16, 2012

Table 4.3 Brisbane Weather: November 12 to 16, 2012

DATE	12-Nov-12		13-Nov-12		14-Nov-12		15-Nov-12		16-Nov-12	
MIN Temp °C	15.3		14.1		14.8		17.8		17.9	
MAX Temp °C	25.8		26.8		27.9		28.5		31.1	
RAIN mm	0		0		0		0		0	
SUN hours	11.7		11.9		12.3		11.6		12.1	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	21.8	24.2	23.4	25.5	24.3	26.3	25.7	27.1	27.4	28.9
RH %	58	45	50	48	53	56	56	59	39	59
Cld 8ths	7	2	1	2	1	1	1	2	1	1
Wind Dir	SE	E	WNW	NNE	N	NNE	NE	NE	NW	NE
Wind Speed	9	13	4	9	6	13	6	13	7	13

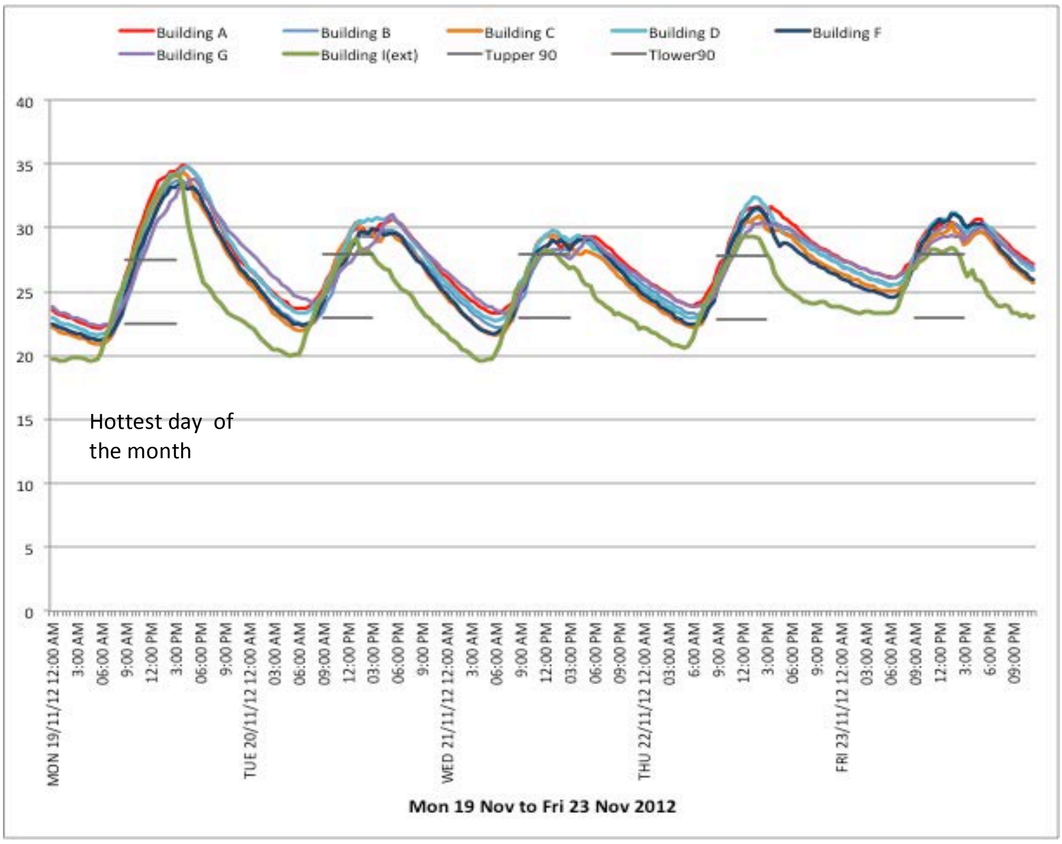


Figure 4.5 Buildings A B C D F & G: November 19 to 23, 2012

Table 4.4 Brisbane Weather: November 19 to 23, 2012

DATE	19-Nov-12		20-Nov-12		21-Nov-12		22-Nov-12		23-Nov-12	
MIN Temp °C	17.6		18.2		17.7		18.1		22.4	
MAX Temp °C	34.4		28.1		28.1		28.9		28.1	
RAIN mm	16.6		0		0		0		0	
SUN hours	12.4		12		12.1		9		8.6	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	26	33.7	23.4	25.7	25.5	24.7	25.1	27.1	26	25.7
RH %	71	20	44	43	56	61	58	57	58	60
Cld 8ths	1	2	6	1	4	4	2	7	3	7
Wind Dir	W	WNW	S	ENE	SE	E	W	NNE	ENE	ENE
Wind Speed	6	2	6	1	9	4	4	7	7	7

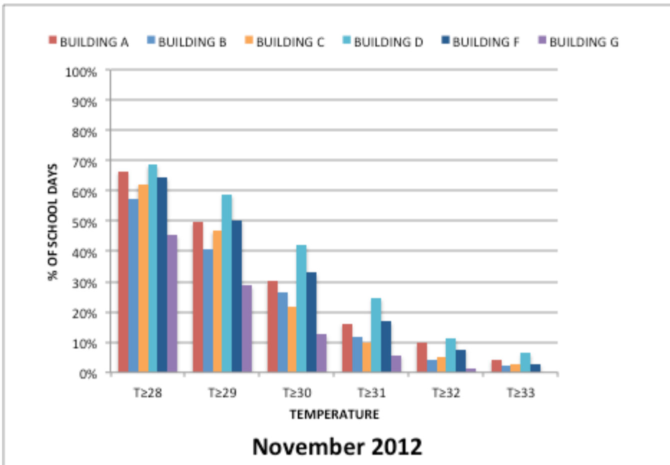


Figure 4.6 Buildings A B C D F & G: November 2012

4.3.2 Diurnal Graph

Classroom temperatures were observed over two sunny weeks in November 2012 as shown in Figures 4.4 and 4.5. Weather data for Brisbane for these weeks are in accompanying Tables 4.3 and 4.4.

Figure 4.4 shows overheating in Buildings A, B, C, D and F compared to outside temperature I(ext) by up to to 3°C. The pattern of temperatures followed a similar trend; typically I(ext) peaked each day at 1.00pm then fell, however all classroom temperatures remained elevated (plateaued) for the afternoon within one degree of their maximum temperature from 12.00pm to as late as 7.00pm.

Building G temperature had a different trend. This classroom was cooler than others during the school day but was warmer in late afternoons peaking regularly at 5.30pm. Building G has a large windows in its southwest wall unshaded from the late afternoon sun. Solar gain passing through these windows could be attributing to this peak. Warmer night temperatures result in this building compared to others. All buildings had warmer minimum temperatures than outside, from +2.3°C in F to 3.5°C in A. Typically the minimum temp of the day occurred before dawn at 5.30am.

In Figure 4.5 on Monday (the hottest day of November) the I(ext) temp was max 34.2°C at 3.00pm and fell 4 degrees to 30.4°C at 4.30pm. Inside the classrooms temperatures remained at 33°C until 6.00pm. For all five days of this week classroom temperatures were above the $T_{upper90}$ threshold of 27.5-27.9°C after 10.30am. Thursday and Friday were cloudy in the afternoon and this seems to have affected Building G as the 5.30pm peak is not observed.

4.3.3 Binned Temperatures

In Figure 4.6 for the eleven school days in November 2012 buildings B C F A and D temperatures were ≥28°C for more than 57% of time; G was lower at 45% of the time. D has the highest tally of high temperatures of the six buildings for November 2012. Building F and A also had high temperatures. The other buildings in decreasing order are C, B and G. It was very hot inside classrooms ≥33°C for 2-6% of the time.

4.4 Intervention 1: Stack Ventilation Strategy to Buildings F and G

Intervention 1: Stack Ventilation was implemented to two Buildings F and G in January 2013. For the comparison of temperatures before and after intervention 1, the time period before was November 2012 and after was February 2013.

4.4.1 $T_{upper\ 90}$ Threshold

In Table 4.2 in February 2013 the percentage of time temperatures were over $T_{upper90}$ in Buildings F and G were less compared to November 2012; Building F was 28% of compared to 67% and G was 27% compared to 56%. For February 2013 the $T_{upper90}$ threshold averaged 28°C. This comparison could indicate the stack ventilation has reduced classroom temperatures in F and G.

4.4.2 Diurnal Graph

Figure 4.7 shows the sunniest week for February 2013. February is the month with second highest rainfall for Brisbane, as shown in the climate graph for Brisbane in Figure 4.2. Brisbane weather data for the week in Table 4.5 shows there were three sunny days on Monday, Tuesday and Thursday, with a little rain on Wednesday and Thursday. In Building G the trend of maximum temperature peak (32.0°C) at 5.30pm is observed on Monday. On Tuesday afternoon cloud cover there is no peak and the maximum temperature for G occurred at the same time for I(ext) at 1.30pm (29.5°C and 29.7°C). Building G temperature was generally cooler during these school days compared to Buildings D and C, except for Monday.

Buildings C and D with no intervention are shown for comparison to F and G. In Building F temperature was cooler than Building D but only within a degree. Building C temperature was very similar to F and had times slightly above F whereas before in November there were times when F was warmer than C.

The next graph in Figure 4.8 takes away buildings C and D to show only F and G with I(ext) and the $T_{upper90}$ and $T_{lower90}$ thresholds. Building F temperature at 9.00am in the morning was two degrees cooler than I(ext) but rose at a faster rate than I(ext) so by 11.00am became warmer than outside. Another time period after interventions for Building F is Term 1 2015.

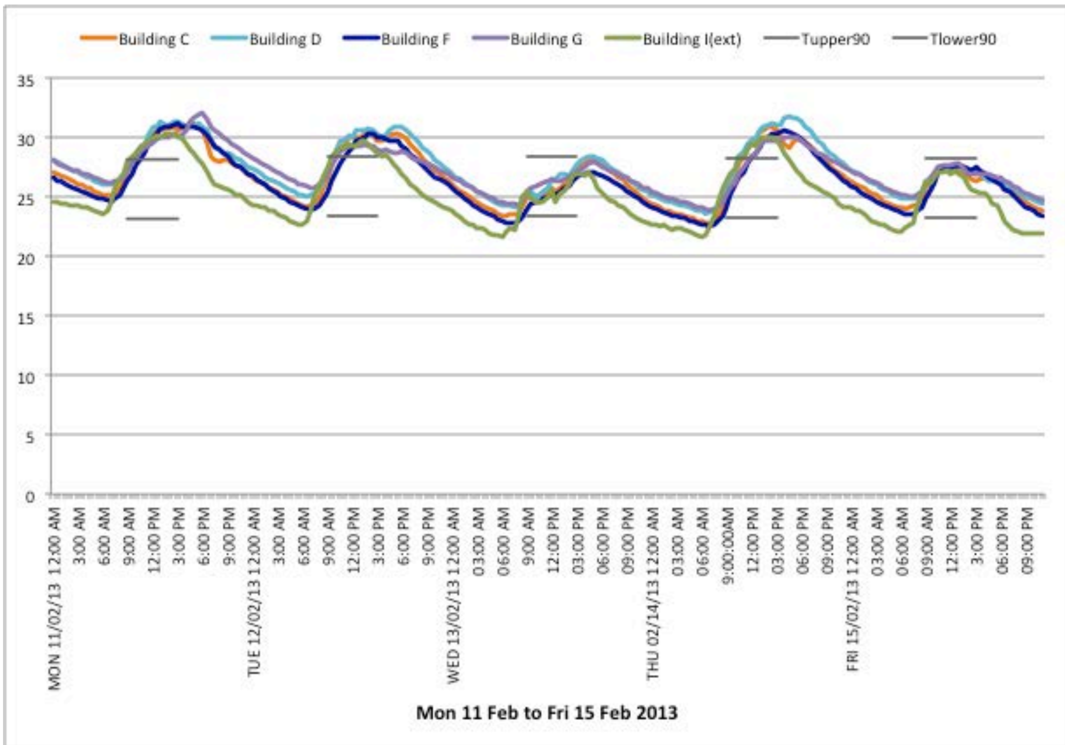


Figure 4.7 Buildings C D F & G: February 11 to 15, 2013

Table 4.5 Brisbane Weather: February 11 to 15, 2013

DATE	11-Feb-13		12-Feb-13		13-Feb-13		14-Feb-13		15-Feb-13	
MIN Temp °C	21.8		20.4		19.6		20.2		20.8	
MAX Temp °C	29.4		29		26.6		29.4		27.9	
RAIN mm	0		0		1.2		1.6		0	
SUN hours	12.2		9.1		3.6		9.5		3.7	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	27.2	28.5	26.7	26.8	24.8	26.2	26.1	28.4	25.2	23.2
RH %	56	54	55	57	65	54	58	51	69	85
Cld 8ths	5	3	2	7	7	7	3	5	7	8
Wind Dir	SE	E	ESE	E	SSE	ESE	SE	ESE	ESE	ESE
Wind Speed	9	13	11	15	15	15	9	15	13	6

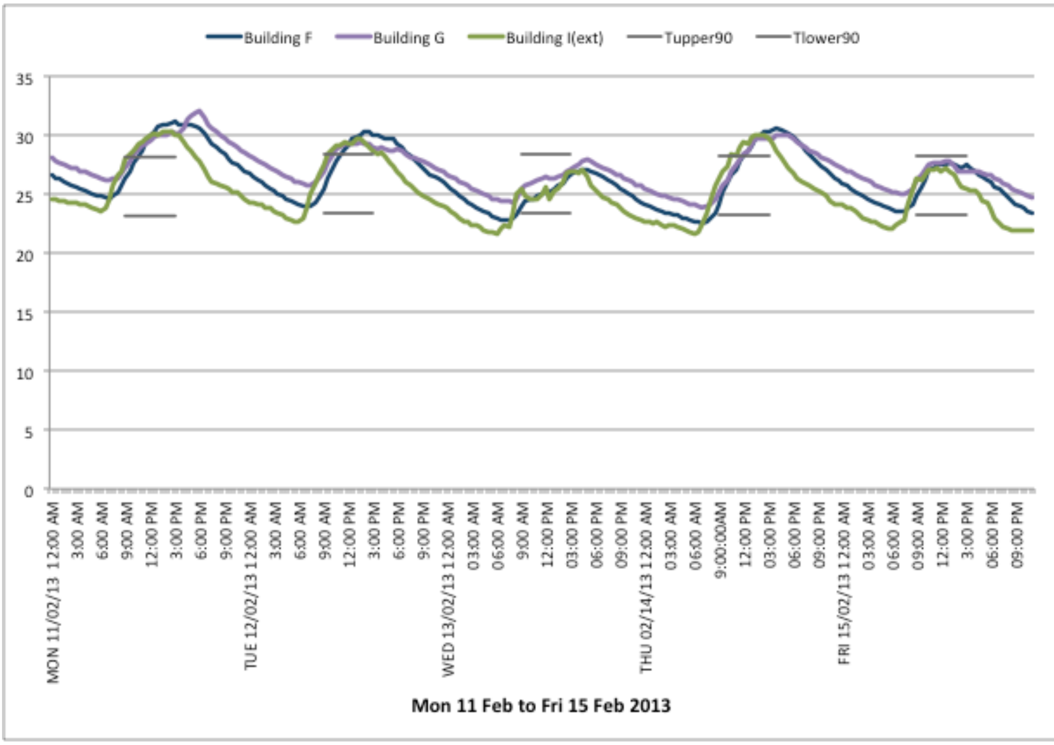
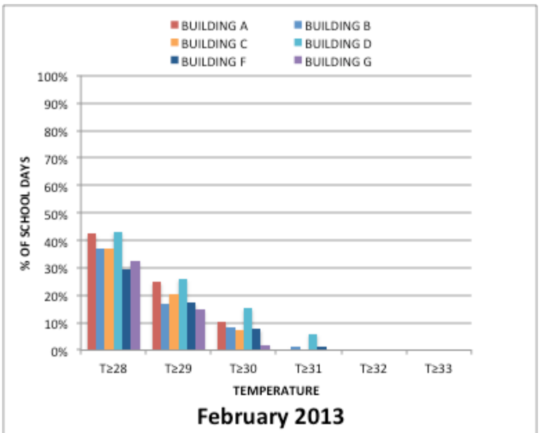


Figure 4.8 Buildings F & G: February 11 to 15, 2013



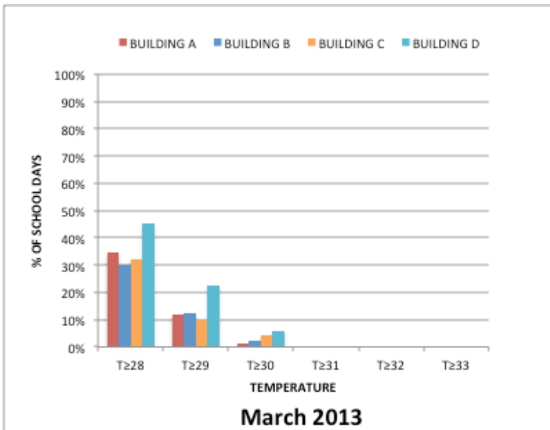


Figure 4.9 Buildings A B C D F & G, February + Buildings A B C & D, March 2013

4.4.3 Binned Temperatures

Figure 4.9 shows Building D in February 2013 had consistently higher temperatures than the other buildings; F and G had the least of high temperatures. F had ≥28°C for 30% of the time, G at 33% and D at 43% of the time. In the next temperature ranges G has the least of the high temperature ≥29°C at 15% of the time. Again in March, building D stands out as being warmest at ≥29°C for 22% of the time.

From this point in the research project Building G was excluded due to its differing trend of the late afternoon peak. Building G has different building characteristics to other buildings; it is orientated with long axis SE and NW (rather than E and W) and has large unshaded southwest windows. To reduce the variables between buildings for comparison the case study group of buildings became A B C D.

4.5 Intervention 2: Cool Roof to Buildings A and D

Intervention 2: Cool roof was applied to Buildings A and D during the school holidays of October 2013. In this discussion there will be comparison of Building A to very similar Building C and Building D to similar volume Building B. Refer to building descriptions in Table 3.1.

4.5.1 $T_{upper90}$ Threshold

Table 4.6 shows after the cool roof application in October and November 2013 the percentages of time temperatures in Buildings A and D were over $T_{upper90}$ were less, almost half, compared to November 2012. However, from month to month in October, November and December the percentages of time increased slightly. Cool roof paint is expected to be the most effective in its performance of reflecting solar radiation when it is first applied. Over time the effectiveness wanes slightly as the roof accumulates dust. Then again, this trend of increasing percentages of temperatures observed over the short period of three months could be merely coincidental or due to weather variables.

4.5.2 Diurnal Graph

Classroom temperatures were observed in two sunny weeks after the cool roof intervention as shown in Figures 4.10 and 4.11. In Figure 4.10, Building D is the coolest of the four buildings on Monday and Tuesday. On Wednesday and Thursday buildings A and C are of similar temp and cooler than D and B. Building B is the warmest for both weeks and Building C has the lowest minimum temperatures for both weeks. It is worth noting Building C has tall eucalypt trees to its west, casting shade over its roof and surroundings in the afternoon, quite possibly attributing to this cooler difference at night.

Table 4.6 Buildings A B C & D: Tupper90 Tally Before and After INT 2

				Counts exceeding Tupper90 threshold							
		School	Half hour	Counts per building				Percentage of time			
Year	**Month**	**Days**	**counts**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
2012	NOV	11	143	100	87	95	102	70%	61%	66%	71%
	INTERVENTION 1: Stack ventilation Part 1										
2013	FEB	18	234	95	80	84	97	41%	34%	36%	41%
	MAR	15	195	62	58	60	86	32%	30%	31%	44%
	INTERVENTION 2: Cool roof										
2013	OCT	17	221	80	105	94	79	36%	48%	43%	36%
	NOV	21	273	146	164	147	131	53%	60%	54%	48%
	DEC	10	130	72	83	86	74	55%	64%	66%	57%

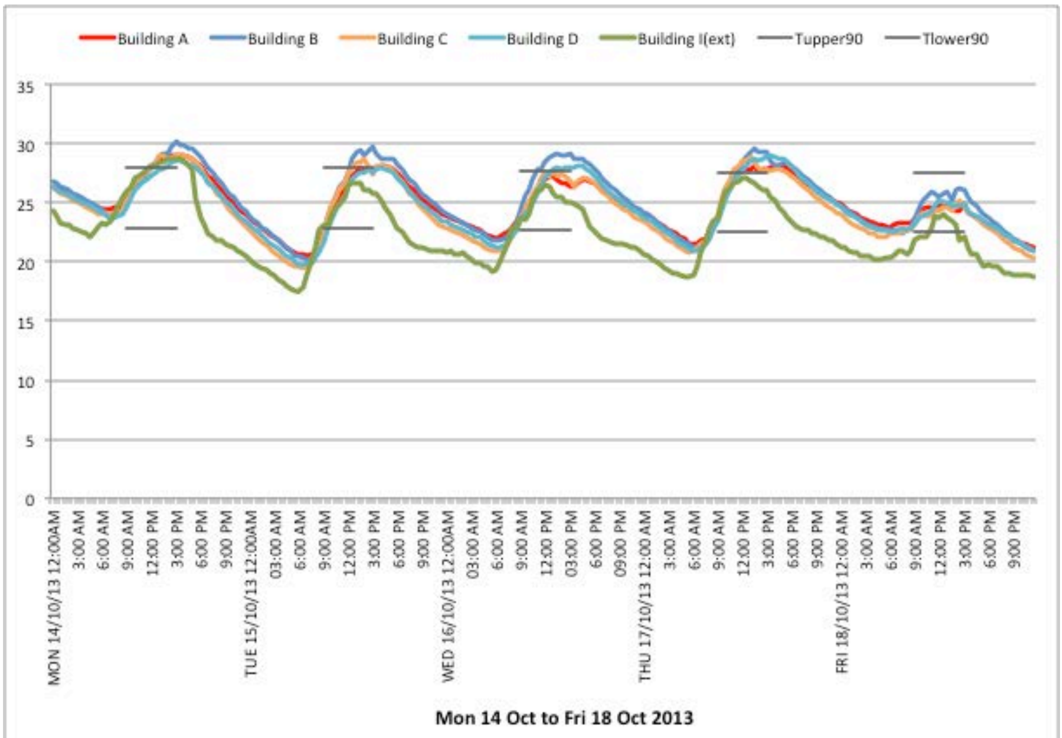


Figure 4.10 Buildings A B C & D: October 14 to 18, 2013

Table 4.7 Brisbane Weather: October 14 to 18, 2013

DATE	**14-Oct-13**		**15-Oct-13**		**16-Oct-13**		**17-Oct-13**		**18-Oct-13**	
MIN Temp °C	20.9		13.8		16		15.8		18.4	
MAX Temp °C	29.0		27.0		26.6		27.8		24.8	
RAIN mm	0		0		0		0		0	
SUN hours	11.7		12.2		8.8		11.8		2	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	24.9	28.3	22.8	24.9	23.2	24.0	25.8	25.4	22.3	20.0
RH %	26	14	53	40	54	51	48	57	72	88
Cld 8ths	1	0	2	1	2	6	1	2	7	7
Wind Dir	W	SW	N	ENE	N	NE	N	NNE	S	SE
Wind Speed	13	9	4	11	7	15	9	15	7	6

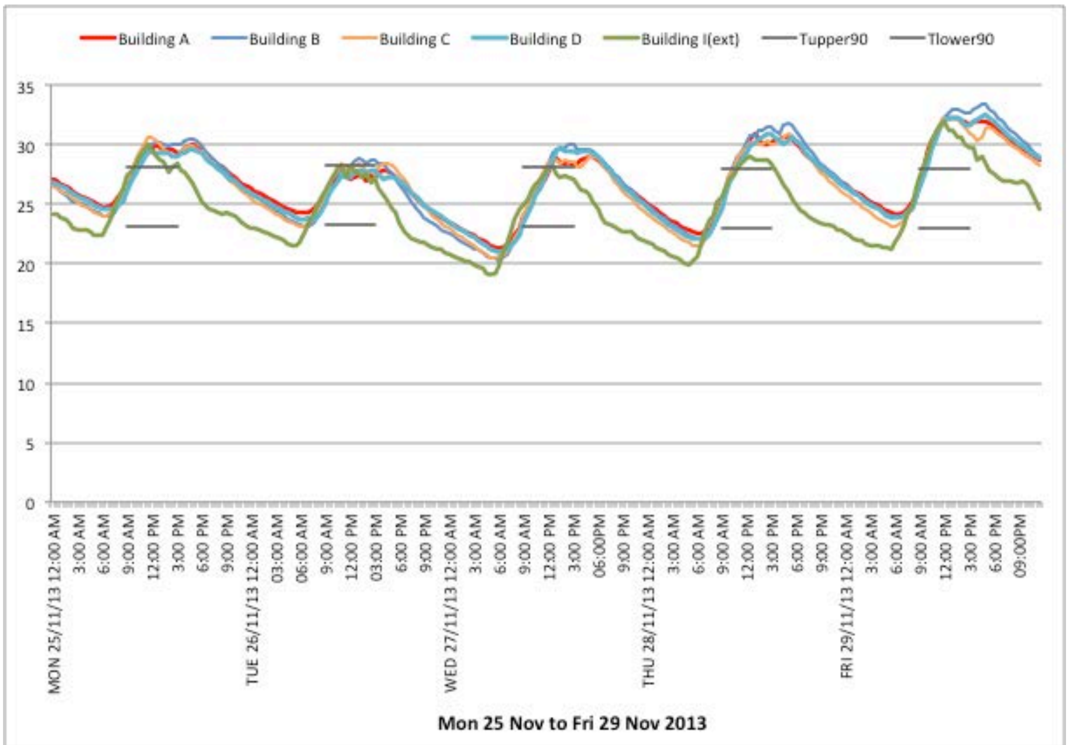


Figure 4.11 Buildings A B C & D: November 25 to 29, 2013

Table 4.8 Brisbane Weather: November 25 to 29, 2013

DATE	25-Nov-13		26-Nov-13		27-Nov-13		28-Nov-13		29-Nov-13	
MIN Temp °C	20.2		20.4		16.3		17.1		18.4	
MAX Temp °C	29.3		27.2		27.1		28.9		33.5	
RAIN mm	8.8		0		0		0		0	
SUN hours	11.3		11.5		12.7		12.9		10.1	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	27	26	25.2	25.5	24.3	25.2	25.4	27.1	27.4	29.6
RH %	59	61	54	55	45	49	56	56	49	60
Cld 8ths	4	7	5	2	1	2	1	1	5	7
Wind Dir	SSE	E	SE	ESE	S	ENE	NNE	NE	W	NNE
Wind Speed	4	15	6	15	6	11	6	11	6	11

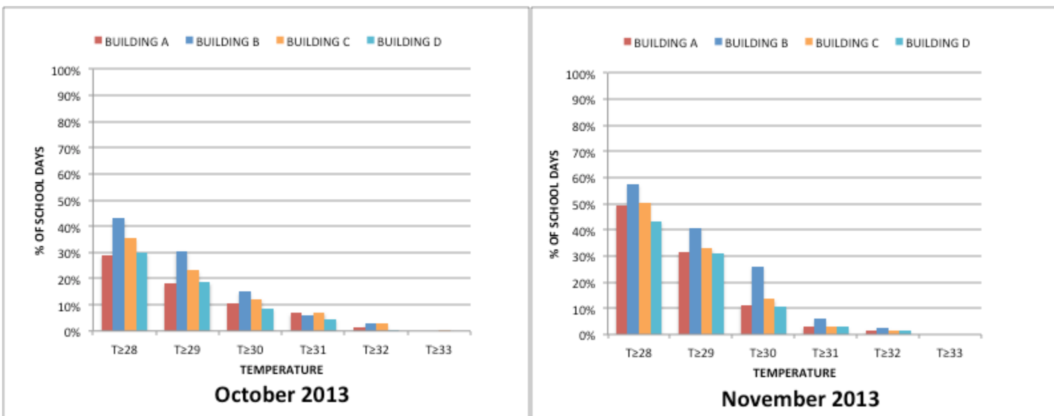


Figure 4.12 Buildings A B C & D. October & November 2013

4.5.3 Binned Temperatures

In Figure 4.12 shows both October and November Buildings A and D have the least tally of temperatures ≥28°C, ≥29°C and ≥30°C. Building B consistently had the highest tally for these temperatures.

4.5.4 Other Observations

The final coating of cool roof paint was applied Thursday morning 3rd October and an reduced classroom temperature effect was observed as shown in Figure 4.13. During this holiday week doors and windows were closed in Building A. Building D was occupied for a few hours in the morning by teachers. Comparing Building D to Building B before and after 3rd October the temperature lines have changed pattern. Building D had warmer maximum temperatures than B before 3rd October. After this date Building B was warmer than D. Buildings A and D had very similar temperatures for this holiday week. However, when Term 3 started and buildings were occupied, the difference in temperatures of A and D compared to C and B were not as noticeable. Windows and doors were opened during the day letting warm outside air into the classroom.

To observe more closely the effect caused by windows open on a school day compared to windows closed on a weekend day, a Friday and Saturday with similar outside temperatures has been plotted in Figure 4.14. On the Friday, the temperatures of buildings A B C and D followed a similar curve, increasing to warmer than outside by 10.00am with B the warmest after 1.00pm. On the Saturday temperatures in buildings A and D followed an almost identical curve pattern (difference <0.2°C). Building C was the warmest of the four at 2.30pm (30.6°C) then building B at 3.30pm (30.1°C) then both buildings A and D at 4.00pm (28.8°C and 28.9°C). I(ext) maximum was at 12.30pm (27.9°C). Building C was the coolest classroom at night over these two days and as observed in Figures 4.10 and 4.11.

From this comparison of cool roof Buildings A and D to red corrugated iron roof Buildings C and D, it can be inferred that when windows and doors were closed temperatures inside A and D were noticeably cooler than Buildings C and D. The cool roof paint application has made an observed difference to the classroom temperatures by reducing the heat load through the roof. However when buildings were occupied classroom temperatures were only slightly cooler in Buildings A and D compared to C and B. When windows and doors were opened warmer outside air from surrounding areas with hard paved surfaces flowed into the classroom.

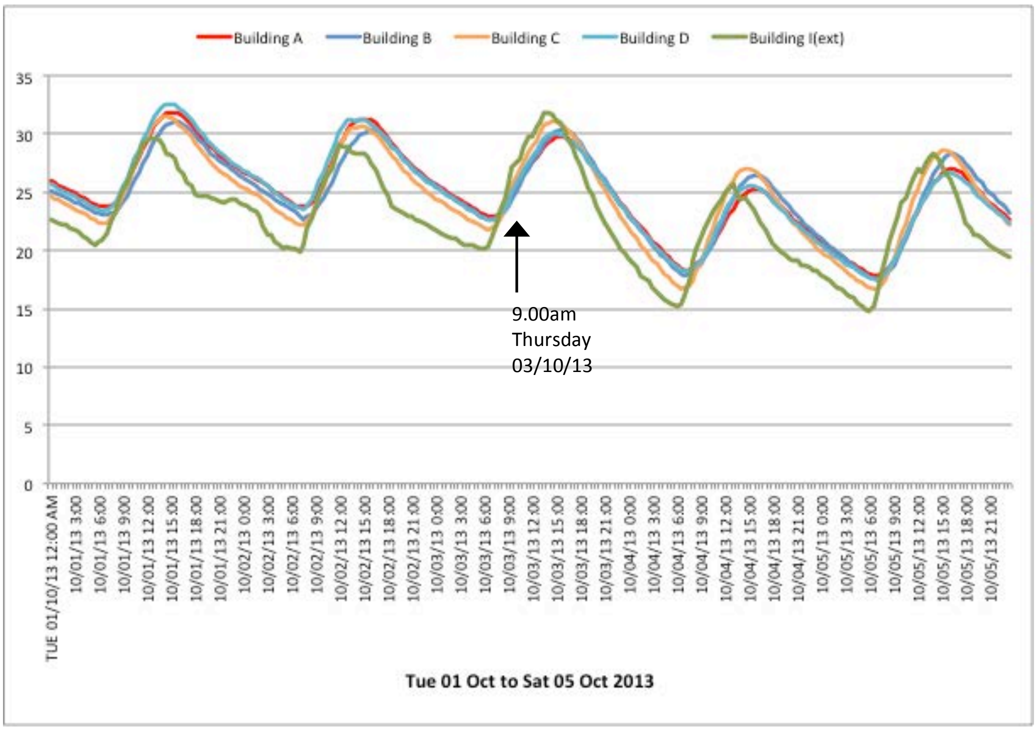


Figure 4.13 Buildings A B C & D October 1 to 5, 2013

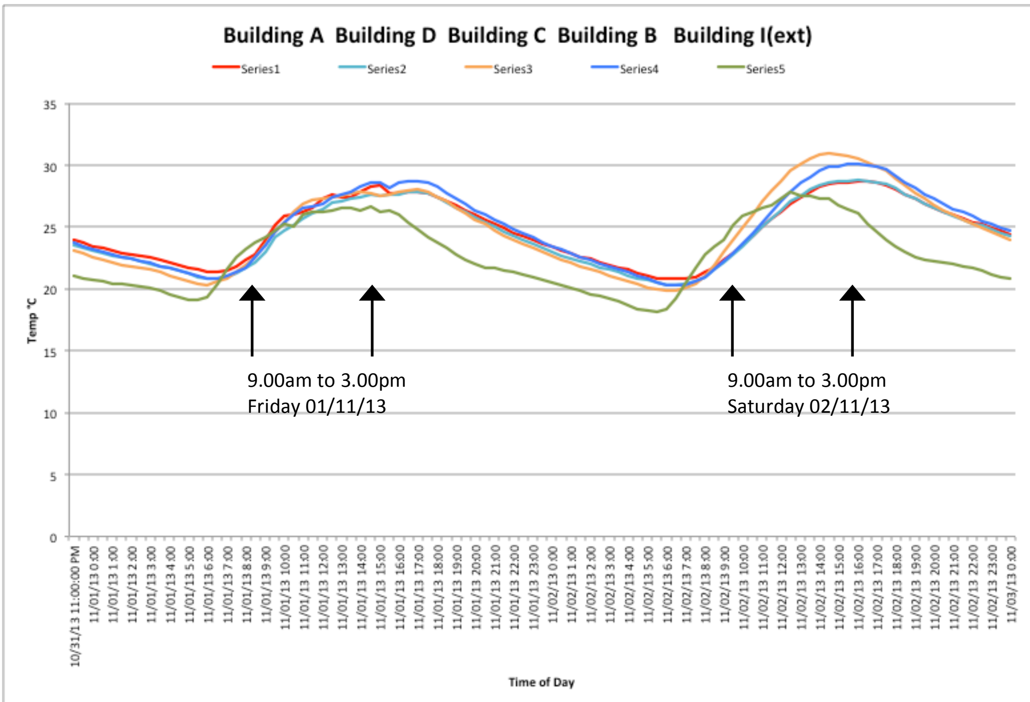


Figure 4.14 Building A B C & D, November 1 & 2, 2013

4.6 Intervention 3: Stack Ventilation to Buildings A B C D

Intervention 3: Stack ventilation strategy stage 2 was implemented over holidays of December 2013 to January 2014 to Buildings A B C D. This intervention includes a 'night flushing' strategy to Building B. Refer to the descriptions of passive cooling strategies in Chapter 3.

4.6.1 $T_{upper90}$ Threshold

In Table 4.9 January 2014 had only four school days and these were unusually cool days for the month, so there are less percentages of time over $T_{upper90}$ in all classrooms. In February there were greater percentages of time over the $T_{upper90}$ threshold in Buildings A B C D than in February 2013. Same trend occurred in March for Buildings A B C. Only Building D has less, 36% of the time in March 2014 compared to 44% of the time in March 2013.

4.6.2 Diurnal Graph

Figure 4.15 show temperatures observed in a sunny week in March 2014. Building C was the coolest during the day with maximum temperatures inside matching outside I(ext). The other buildings overheated after 12.00pm. However there is more of a curve shape to these temperatures whereas in November 2012 the shape was more of a plateau. Buildings A and D had similar temperatures at night. Both Building B and C were cooler at night than A and D. The night powered roof fans appear to be having an effect on temperature in B; although temperature is warmest in building B during the day the temperature drops more steeply in the late afternoon and over night than in other buildings.

Table 4.9 Buildings A B C & D: Tupper 90 Tally Before & After Intervention 3

				Counts exceeding $T_{upper90}$ threshold							
			Half	Counts per building				Percentage of time			
		School	hour								
Year	Month	Days	counts	A	B	C	D	A	B	C	D
2012	NOV	11	143	100	87	95	102	70%	61%	66%	71%
	INTERVENTION 1: Stack ventilation Part 1										
2013	FEB	18	234	95	80	84	97	41%	34%	36%	41%
	MAR	15	195	62	58	60	86	32%	30%	31%	44%
	INTERVENTION 2: Cool roof										
	INTERVENTION 3: Stack ventilation Part 2										
2014	JAN	4	52	13	14	9	10	25%	27%	17%	19%
	FEB	20	260	158	161	157	152	61%	62%	60%	58%
	MAR	21	273	105	115	112	97	38%	42%	41%	36%

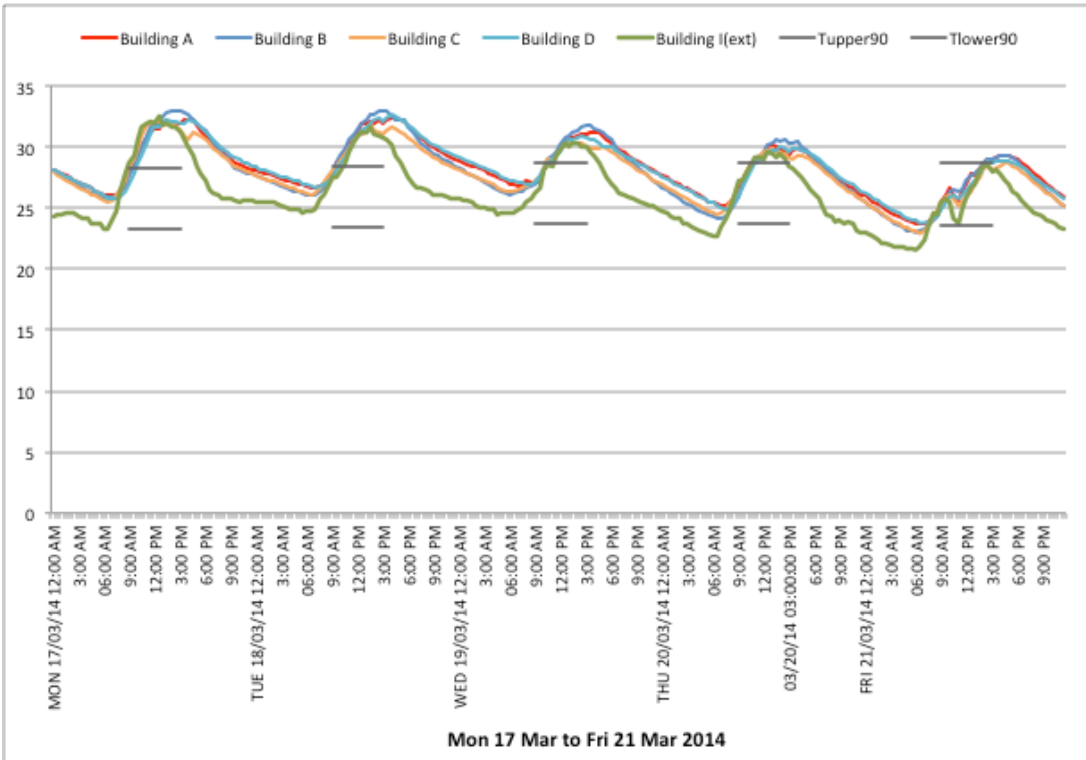


Figure 4.15 Buildings A B C & D, March 17 to 21, 2014

Table 4.10 Brisbane Weather: March 17 to 21, 2014

DATE	17-Mar-14		18-Mar-14		19-Mar-14		20-Mar-14		21-Mar-14	
MIN Temp °C	21.6		24.1		23.8		20.6		19.2	
MAX Temp °C	31.8		32.0		30.6		30.0		29	
RAIN mm	4.6		0.2		0		0.6		0.2	
SUN hours	10.7		8.8		8.7		10.4		8.7	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	28.1	30	27.4	30.2	26.4	28.9	27.4	27.7	25.3	28.7
RH %	61	54	72	58	67	54	56	50	64	51
Cld 8ths	1	1	7	1	7	2	5	5	6	2
Wind Dir	SSE	E	No wind	ENE	E	E	E	E	ESE	ENE
Wind Speed	6	15	0	9	7	15	15	20	9	9

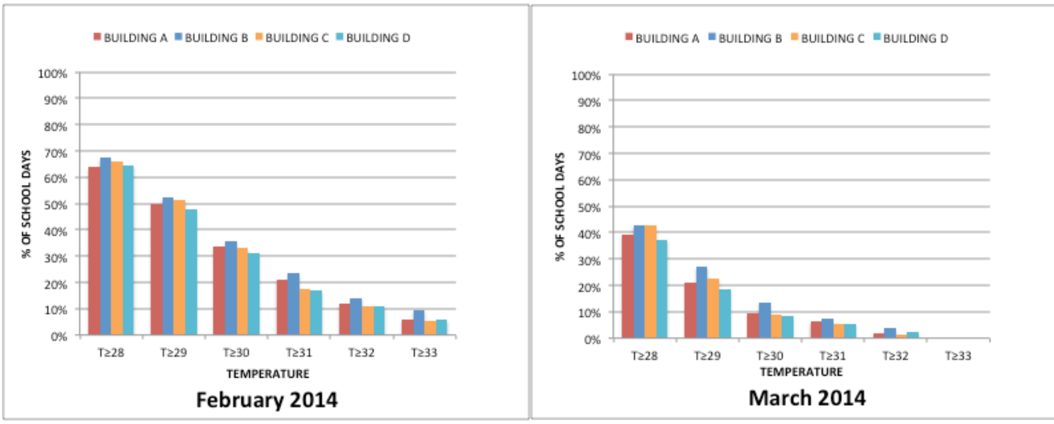


Figure 4.16 Buildings A B C & D, February & March 2014

4.6.3 Binned Classroom Temperatures

In Figure 4.16 February and March shows the four buildings had a similar spread of higher temperatures. In previous charts in Figures 4.6, 4.9, and 4.12 the tallies for each building for each temperature band were more varied. In Figure 4.16 Building B was highest of the tally in February and for ≥29°C in March. It is concerning that in February 2015, the beginning of the school year, that for over 64% of the time classroom temperatures were ≥28°C and that for 5% of the time ≥33°C. March had less time with temperatures ≥28°C in the classrooms (37% to 41% of the time). February and March are months with high rainfall in Brisbane (refer Figure 3.10). When there are days of high temperatures they are also likely to be experienced with high humidity. For example, in Table 4.10 the weather conditions on 18 March were uncomfortable; the temperature is 32°C, the relative humidity is 72%, and there is no breeze outside to provide any relief.

4.7 Intervention 4: Shade Sails and Schoolyard Greening (Stage One)

Intervention 4 consisted of two passive cooling strategies implemented at the same time to the immediate surrounds of classroom buildings. During the July holidays to August 2014 Shade sails were installed to the east and west courtyards and the Front garden stage 1 was constructed to the north of buildings A and C (refer to Figure 3.12). Stage 1 is noted as trees providing a little shade (10% of garden bed area).

4.7.1 $T_{upper90}$ Threshold

In Table 4.11 there are three November periods to compare. November 2012 shows Building D was over $T_{upper90}$ for 71% of the time. In November 2013 after the cool roof intervention this tally dropped to 48% of the time. Then in November 2014 after the Shade sails intervention this tally was up again to 53% of the time. This method does not show any cooling effect of the shade sails to classroom temperature for D. December 2014 is the time showing most frequency of classroom temperatures over $T_{upper90}$ (calculated to be between 27°C and 28°C).

4.7.2 Diurnal Graph

Figure 4.17 a sunny week October showed Building D was coolest on Tue, Wednesday and Friday. Although Wednesday morning had the coolest min for October and all classroom temps were under the $T_{upper90}$ threshold that day and the next. Monday was cooler in Building C. There were N and NNE winds blowing that day and Buildings A and C are more exposed to the north than the other buildings; the wind could have had an effect on classroom temperature. In the next Figure 4.18 a sunny week in November the warmest classroom was Building F. Buildings A and C were coolest on the Monday and Tuesday, then D on Wednesday and Thursday and on Friday A and D were cooler than C, B and F. From this week it appeared that the combination of stack ventilation and shade sails to the north of Building F are not having as much as an effect as stack ventilation, cool roof and shade sails to the north of Building D.

4.7.3 Binned Temperatures

In Figure 4.19 shows Building D consistently had the least of high temperatures of the four buildings in October 2014. In November all buildings had a high tallies of ≥28°C, B the highest at 62%. In November Building B had ≥31°C for 19% of the time and the other buildings D for 10%, C for 9% and A for 6%. Very hard to ascertain from observing these October and November months that the shade sails have a cooling effect in addition to the stack ventilation or cool roof interventions.

Table 4.11 Buildings A B C D & F, Tupper90 Tally Before & After Intervention 4

				Counts exceeding $T_{upper90}$ threshold									
			Half	Counts per building					Percentage of time				
		School	hour										
Year	**Month**	**Days**	**counts**	**A**	**B**	**C**	**D**	**F**	**A**	**B**	**C**	**D**	**F**
2012	NOV	11	143	100	87	95	102	96	70%	61%	66%	71%	67%
	INTERVENTION 2: Cool roof												
2013	OCT	17	221	80	105	94	79		36%	48%	43%	36%	
	NOV	21	273	146	164	147	131		53%	60%	54%	48%	
	DEC	10	130	72	83	86	74		55%	64%	66%	57%	
	INTERVENTION 3: Stack ventilation Part 2												
	INTERVENTION 4: Shade Sails to East and West courtyards/ Front Garden Stage 1												
2014	OCT	16	208	69	75	76	62		33%	36%	37%	30%	
	NOV	20	260	149	153	145	139		57%	59%	56%	53%	
	DEC	10	130	96	94	94	93	101	74%	72%	72%	72%	78%

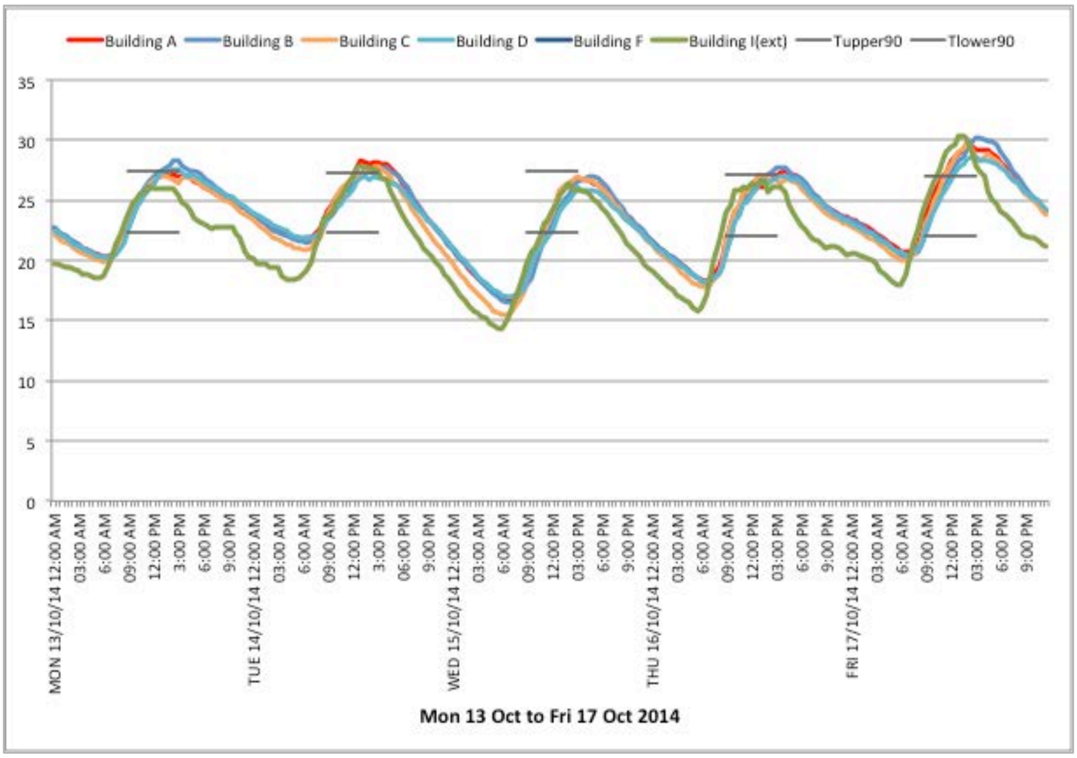


Figure 4.17 Buildings A B C D & F, October 13 to 17, 2014

Table 4.12 Brisbane Weather: October 13 to 17, 2014

DATE	**13-Oct-14**		**14-Oct-14**		**15-Oct-14**		**16-Oct-14**		**17-Oct-14**	
MIN Temp °C	16.2		17.3		13.3		13.2		15.5	
MAX Temp °C	26.9		27.7		26.2		26.7		30.2	
RAIN mm	0		3.2		0		0		0	
SUN hours	10.5		10.9		12.5		12.1		11.9	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	23.2	25.2	23.4	26.8	18.3	25.3	22.8	25.7	23.8	26.7
RH %	57	56	60	26	34	25	45	37	54	38
Cld 8ths	3	3	6	1	0	1	1	1	2	4
Wind Dir	N	NNE	NW	W	W	W	SSW	ENE	S	ENE
Wind Speed	7	13	13	19	13	13	7	11	7	13

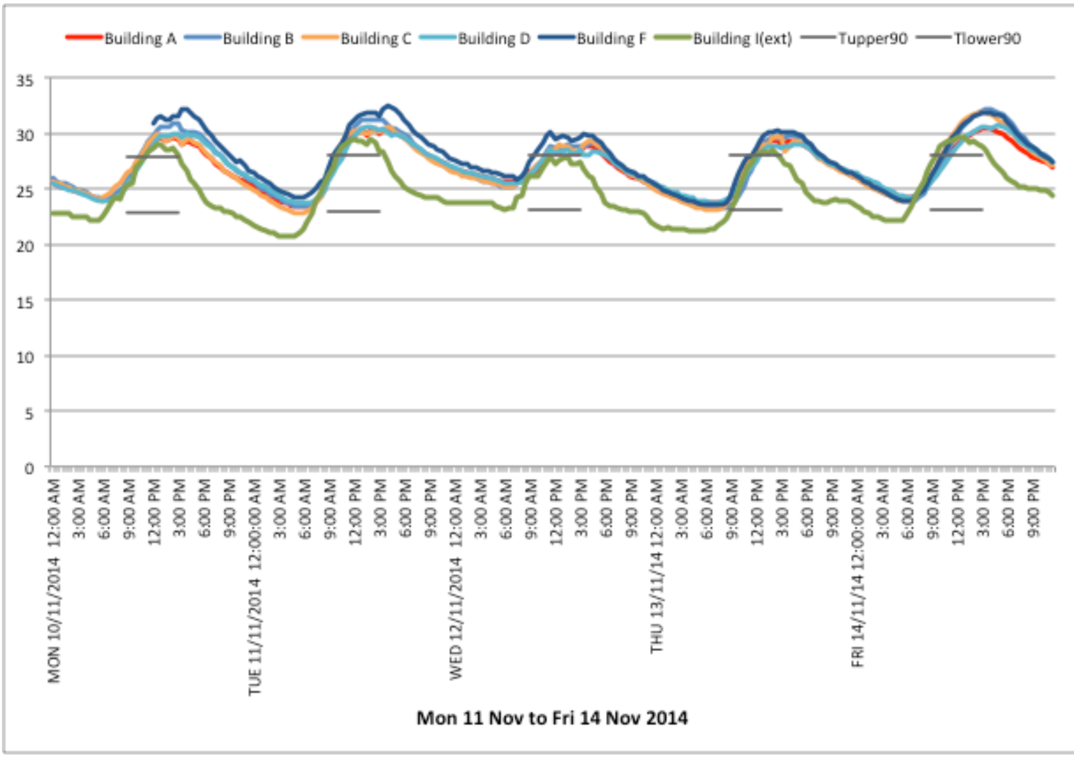
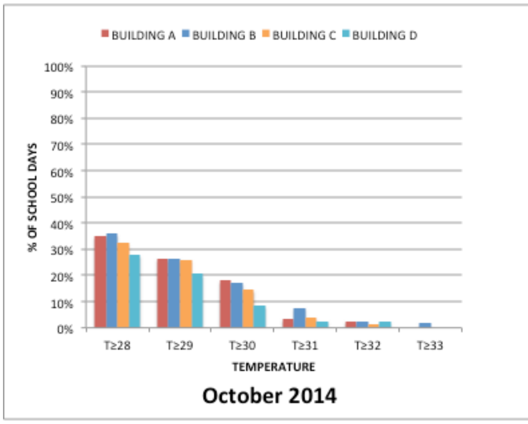


Figure 4.18 Buildings A B C D & F, November 10 to 14, 2014

Table 4.13 Brisbane Weather: November 10 to 14, 2014

DATE	10-Nov-14		11-Nov-14		12-Nov-14		13-Nov-14		14-Nov-14	
MIN Temp °C	19.9		18.8		22.1		20.3		20.9	
MAX Temp °C	29.2		29.9		28.3		28.6		30.0	
RAIN mm	0		0		0		9.2		0.2	
SUN hours	10.6		10.2		8.1		7.6		12.5	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	26.9	26.9	25.9	28.1	25.8	25.7	23.9	26.2	27.9	28.7
RH %	53	50	53	52	61	63	78	61	47	57
Cld 8ths	5	7	1	1	6	5	7	6	1	2
Wind Dir	N	NNE	ENE	ENE	ENE	E	SE	ENE	N	NE
Wind Speed	7	7	6	1	7	5	4	6	7	2



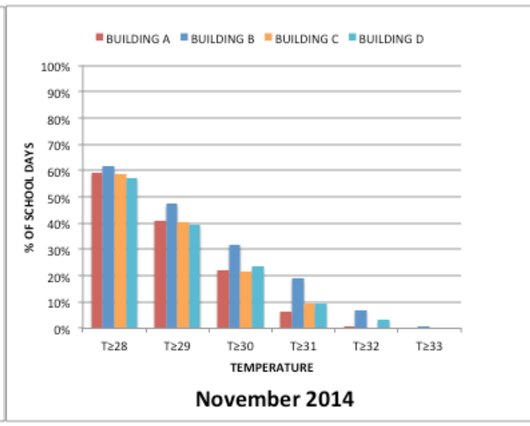


Figure 4.19 Buildings A B C & D, October & November 2014

4.8 Intervention 5: Schoolyard Greening (Stage 2)

Intervention 5 is the second stage of the Front Garden when plants were added to the garden beds in two planting events with the school community during October and November of 2014. These additional plants, together with the Tuckeroo trees spreading their canopy, increased the vegetative cover of the garden beds to approximately 25%.

The summer Term 1, 2015 is regarded as the time to observe any impact of the combination of passive cooling strategies on classroom buildings as shown in Figure 3.15. Term 1, 2015 was the time period of focus for questions asked of teachers in the qualitative phase of the research project.

4.8.1 $T_{upper90}$ Threshold

Table 4.14 shows tallies for February and March across three years and the percentages go down and up for all buildings. For example compare the results for March in Building D. In 2013 the percentage over $T_{upper\ 90}$ was 44%, in 2014 36% and 2015 47%. In March 2015, Buildings A B and C had temperatures over $T_{upper90}$ for 56% of time in twenty school days. There were two heat wave days taken out for the March 2015 tally yet there were two other separate days that were as hot and were included in the count. These extra counts of high temperatures in March 2015 could have skewed temperatures for all buildings to be warmer than the previous March. March 2014 was the wettest month for that year keeping temperatures steady whereas March 2015 was drier with hotter days. When outside temperature I(ext) was above the $T_{upper90}$ threshold on hot days then classroom temperatures were also above (refer to the $T_{upper90}$ lines at 28°C in Figure 4.20 and the $T_{upper90}$ lines at 29°C in Figure 4.21).

4.8.2 Diurnal Graph

In Figure 4.20 classrooms showed less overheating during the day; temperatures were within or even less than the outside I(ext) maximum temperature. In November, 2012, all classroom temperatures were 3 degrees over the outside maximum temperature. In Figure 4.21 in the morning classroom temperatures were less than outside. However in after 12.00pm classroom temperatures became warmer than outside, the warmest in Building F up to two degrees warmer than outside on Monday and Tuesday. For the other buildings, maximum classroom temperatures were all within a degree of the maximum temperature outside. This is a reduction in classroom temperature compared to the trend of overheating observed in November 2012. The passive cooling strategies have reduced the extent of overheating in the classrooms. In Buildings D and A there are days when the classroom temperature was cooler than the outside maximum temperature in the afternoons.

4.8.3 Binned Temperatures

Figure 4.22 showed the extent of classroom temperature for all 22 days (two heatwave days were excluded from Method 1 tally). Building D had the least frequency of high temperatures among the five buildings. In February, D had temperatures ≥28°C for 46% of the time, Building C had the most at 60% of the time. In March Building D had the least percentage of time of temperatures ≥28°C at 60%; Building D had the most at 74%. Building F in March had the highest occurrences of temperature ≥32°C for 15% of time followed closely by Building B with 14%.

Table 4.14 Buildings A B C & D: Tupper90 Tally Before & After Intervention 5

				Counts exceeding $T_{upper90}$ threshold							
			Half	Counts per building				Percentage of time			
		School	hour								
Year	**Month**	**Days**	**counts**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
2013	FEB	18	234	95	80	84	97	41%	34%	36%	41%
	MAR	15	195	62	58	60	86	32%	30%	31%	44%
	INTERVENTION 2: Cool roof										
2014	INTERVENTION 3: Stack ventilation Part 2										
	JAN	4	52	13	14	9	10	25%	27%	17%	19%
	FEB	20	260	158	161	157	152	61%	62%	60%	58%
	MAR	21	273	105	115	112	97	38%	42%	41%	36%
	INTERVENTION 4: Shade Sails to East and West courtyards/ Front Garden Stage 1										
2015	**INTERVENTION 5: Front Garden Stage 2**										
	JAN	4	52	24	25	24	21	46%	48%	46%	40%
	FEB	20	260	120	128	143	103	46%	49%	55%	40%
	MAR	20	260	158	145	149	121	61%	56%	57%	47%

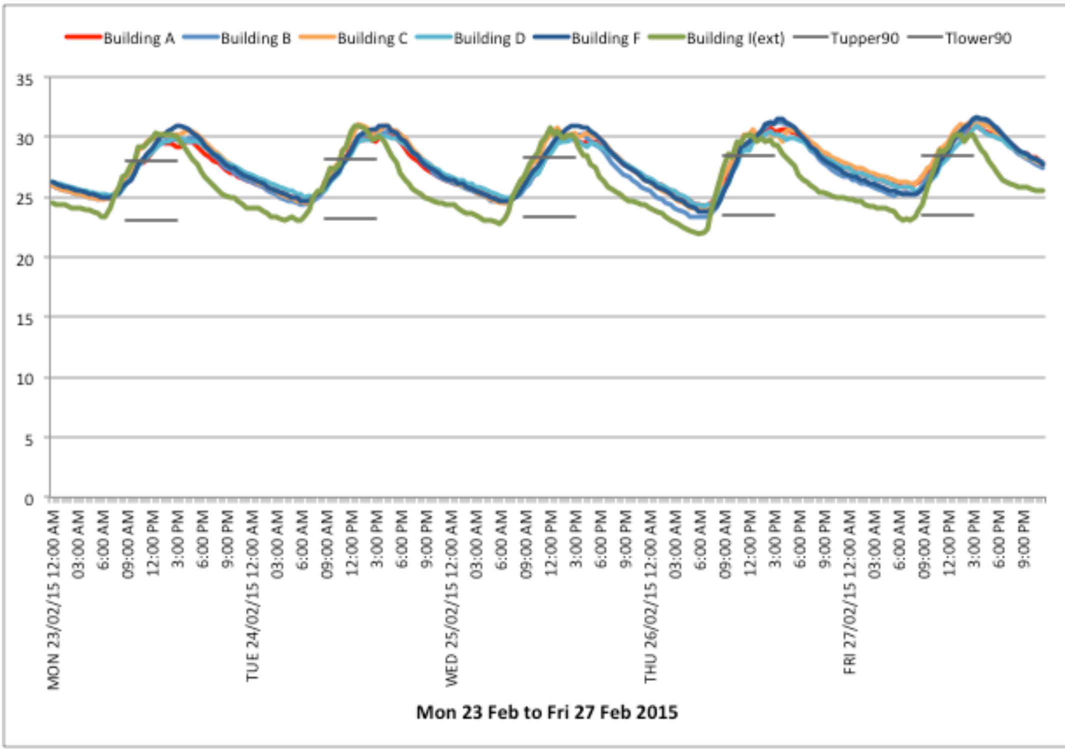


Figure 4.20 Buildings A B C D & F, February 23 to 27, 2015

Table 4.15 Brisbane Weather: February 23 to 27, 2015

DATE	**23-Feb-15**		**24-Feb-15**		**25-Feb-15**		**26-Feb-15**		**27-Feb-15**	
MIN Temp °C	22.6		22.3		21.8		20.5		22.1	
MAX Temp °C	30.6		30.8		29.8		29.8		30.2	
RAIN mm	4.4		0.4		0		0.2		1.8	
SUN hours	10.9		10.5		10.6		9.9		8.4	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	26.6	30.1	25.9	28.8	26.4	28.8	26.4	27.8	24.3	29.5
RH %	72	59	74	60	69	60	62	60	83	56
Cld 8ths	7	2	6	1	7	3	3	3	7	1
Wind Dir	SSE	SE	SE	E	SE	E	SE	E	W	NE
Wind Speed	9	13	11	20	7	15	6	11	6	9

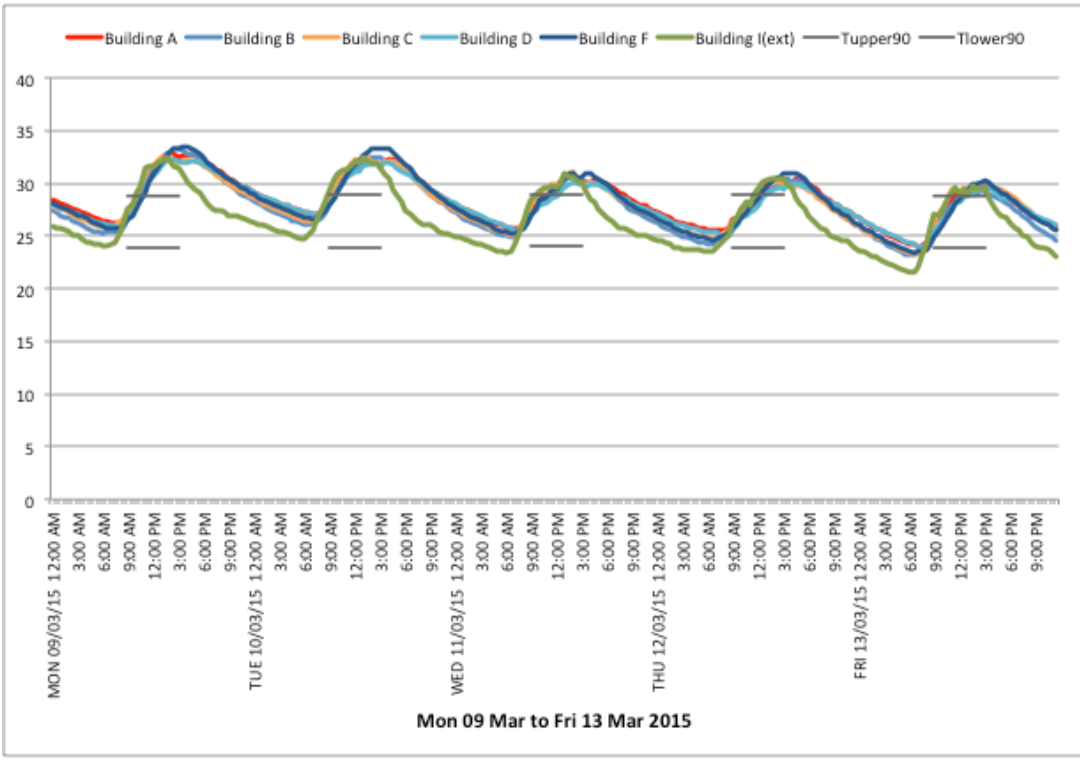


Figure 4.21 Buildings A B C D & F, March 9 to 13, 2015

Table 4.16 Brisbane Weather: March 9 to 13, 2015

DATE	9-Mar-15		10-Mar-15		11-Mar-15		12-Mar-15		13-Mar-15	
MIN Temp °C	22.8		23.6		21.3		20.9		19.9	
MAX Temp °C	31.6		30.6		30.1		29.9		29.5	
RAIN mm	0		0		0		0		0	
SUN hours	10.3		10.8		10.0		10.0		9.0	
	9am	3pm	9am	3pm	9am	3pm	9am	3pm	9am	3pm
Temp °C	27.5	30.1	28.4	29.7	27.7	28.9	26.2	28.5	26.9	28.8
RH %	69	57	66	57	65	57	65	46	60	51
Cld 8ths	5	3	2	1	4	3	7	2	1	2
Wind Dir	SSW	ENE	E	E	ESE	E	SSE	ESE	SE	ESE
Wind Speed	6	9	9	13	9	15	7	13	9	17

Figure 4.22 Buildings A B C D & F: February & March 2015

4.9 Comparison of Buildings A B C D $T_{upper90}$ and $T_{upper80}$ 2012 to 2015

The overheating metric process has been applied to the classroom temperatures in Buildings A B C and D from 2012 to 2015, for upper thresholds $T_{upper90}$ and $T_{upper80}$.

4.9.1 Comparison of Buildings A B C D across 2012 to 2015

Table 4.17 shows all counts of temperature over $T_{upper90}$ in Buildings A B C D from November 2012 to March 2015. This table is an amalgamation of all tables that have already appeared in Method 1 discussions (Tables 5.2, 5.6, 5.9, 5.11, 5.14). Each intervention is listed in the table. Temperature counts for time periods before an intervention are above it and after interventions below. Table 4.18 shows all counts of temperature over $T_{upper80}$ in Building A B C D from November 2012 to March 2015.

It was anticipated that a display of counts would show a decrease in the tally of temperatures over $T_{upper90}$ for summer term 1 2015, compared to terms 1 and 4 in 2014, terms 1 and 4 in 2013 and November 2012. Such a trend could indicate the interventions have had an effect on classroom temperature. However there is no such trend in these tables, nor in the graphs plotted of the percentages in Figures 4.23 and 4.24.

In Table 4.17 the November 2012 percentages are high at 61 to 71% of the time over $T_{upper90}$ indicating overheating in classrooms. But compare these percentages to November 2013 of Buildings A and D, after the cool roof application; percentages dropped from 70% to 50% in A and 60% to 48% in D. From this decrease in overheating it could be inferred that the cool roof had an effect. However in November 2014, after the shade sails were installed to the north of building D and south of building A, percentages rose 57% in building A and 53% in building D. There was no decreasing trend.

In Table 4.18 the number of counts over $T_{upper80}$ were less than for those for $T_{upper90}$, as to be expected because this threshold is one degree higher. However, similar to the $T_{upper90}$ results, there is no trend for a decreasing tally of classroom temperatures after each intervention.

Table 4.17 Buildings A B C & D Tupper90 Tally Before & After All Interventions

Year	Month	School Days	Half hour counts	Counts exceeding $T_{upper90}$ threshold: Counts per building A	B	C	D	Percentage of time A	B	C	D
2012	NOV	11	143	100	87	95	102	70%	61%	66%	71%
	INTERVENTION 1: Stack ventilation Part 1										
2013	FEB	18	234	95	80	84	97	41%	34%	36%	41%
	MAR	15	195	62	58	60	86	32%	30%	31%	44%
	INTERVENTION 2: Cool roof										
	OCT	17	221	80	105	94	79	36%	48%	43%	36%
	NOV	21	273	146	164	147	131	53%	60%	54%	48%
	DEC	10	130	72	83	86	74	55%	64%	66%	57%
2014	INTERVENTION 3: Stack ventilation Part 2										
	JAN	4	52	13	14	9	10	25%	27%	17%	19%
	FEB	20	260	158	161	157	152	61%	62%	60%	58%
	MAR	21	273	105	115	112	97	38%	42%	41%	36%
	INTERVENTION 4: Shade Sails to East and West courtyards/ Front Garden Stage 1										
2014	OCT	16	208	69	75	76	62	33%	36%	37%	30%
	NOV	20	260	149	153	145	139	57%	59%	56%	53%
	DEC	10	130	96	94	94	93	74%	72%	72%	72%
2015	**INTERVENTION 5: Front Garden Stage 2**										
	JAN	4	52	24	25	24	21	46%	48%	46%	40%
	FEB	20	260	120	128	143	103	46%	49%	55%	40%
	MAR	20	260	158	145	149	121	61%	56%	57%	47%

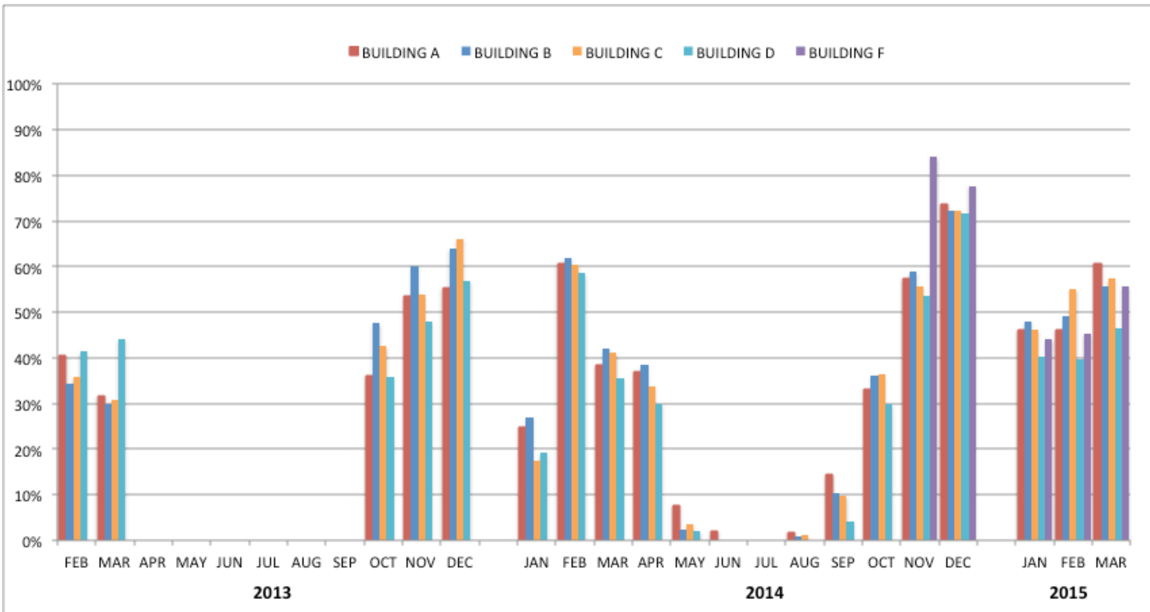


Figure 4.23 Tally of Counts Above $T_{upper90}$ Threshold 2013 to 2015

Table 4.18 Counts of Classroom Temperature Above $T_{upper80}$ Threshold

			Half	Counts exceeding $T_{upper80}$ threshold							
		School	hour	Counts per building				Percentage of time			
Year	**Month**	**Days**	**counts**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
2012	NOV	11	143	82	67	78	90	57%	47%	55%	63%
	INTERVENTION 1: Stack ventilation Part 1										
2013	FEB	18	234	56	42	46	63	24%	18%	20%	27%
	MAR	15	195	28	22	29	42	14%	11%	15%	22%
	INTERVENTION 2: Cool roof										
	OCT	17	221	53	82	63	53	24%	37%	29%	24%
	NOV	21	273	94	118	106	97	34%	43%	39%	36%
	DEC	10	130	37	61	52	48	28%	47%	40%	37%
2014	INTERVENTION 3: Stack ventilation Part 2										
	JAN	4	52	0	4	5	0	0%	8%	10%	0%
	FEB	20	260	112	120	111	101	43%	46%	43%	39%
	MAR	21	273	44	63	41	34	16%	23%	15%	12%
	INTERVENTION 4: Shade Sails to East and West courtyards/ Front Garden Stage 1										
2014	OCT	16	208	45	48	42	32	22%	23%	20%	15%
	NOV	20	260	94	115	95	87	36%	44%	37%	33%
	DEC	10	130	69	81	66	76	53%	62%	51%	58%
2015	**INTERVENTION 5: Front Garden Stage 2**										
	JAN	4	52	12	17	10	11	23%	33%	19%	21%
	FEB	20	260	53	73	78	43	20%	28%	30%	17%
	MAR	20	260	99	100	101	71	38%	38%	39%	27%

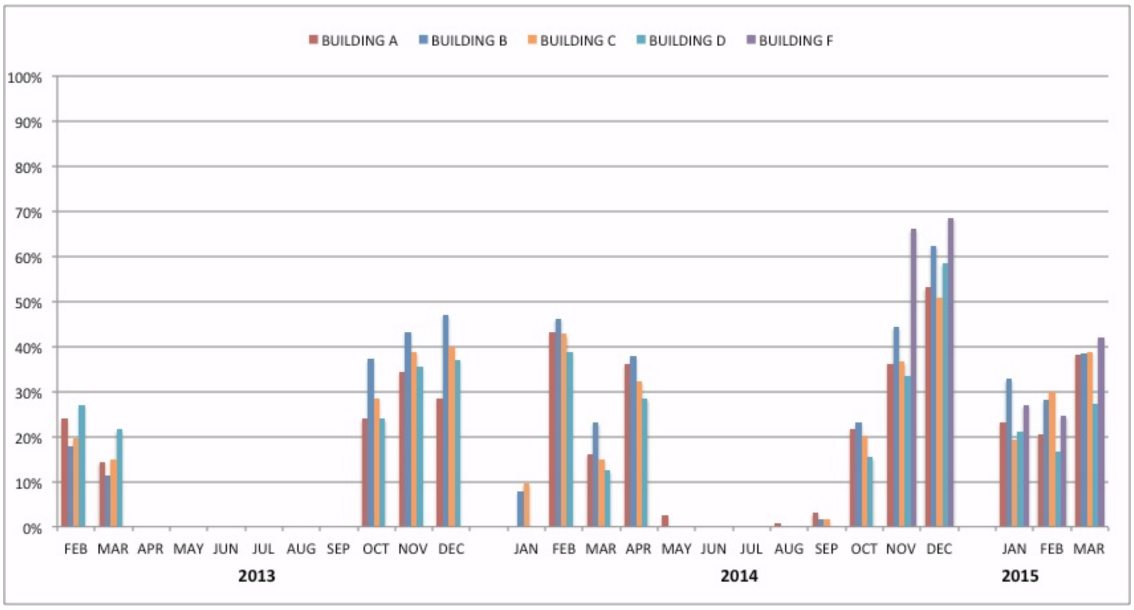


Figure 4.24 Counts Above $T_{upper80}$ 2013 to 2015

This linear comparison of temperature across time periods is not a conclusive way to measure the effect of these strategies, nor a reliable way of understanding overheating in the classroom. Counting the number of times temperature was over a threshold only counts that it is just passed over the threshold; it could have been by half a degree or by three or five degrees. Extent of temperatures has been tallied by the binned method.

What can be inferred from both of these threshold counts over $T_{upper80}$ and $T_{upper90}$, is that months of Term 1 (January, February and March) and Term 4 (October, November, December) are times of the year when high temperatures in the classroom can occur. In these buildings where classroom temperature is influenced by outside temperature, weather variations can affect the classroom temperature.

4.10 Summary of Temperature Analysis

This section summarises the results from the quantitative phase of the research. Structurally, this summary responds to the first two research questions.

The first research question evaluates the impact of the interventions on classroom temperature. The temperature analysis provides key findings to respond to this question. Three methods were used to analyse temperature and it was found:

1) Method 1 counted the number of times classroom temperature went over $T_{upper90}$ in school days for each month. This temperature value in summer months averages 28°C. All results of Method 1 are in Table 4.17. The 'before' period of observation November 2012 showed high percentages of time 61-71% over $T_{upper90}$ for the buildings B C A D. In February 2015 the time was less 40-55% for the buildings D A B C.
2) Method 2 showed classroom temperatures over selected school weeks. The diurnal temperature swings for classrooms were compared with other classrooms and I(ext) and the weather data for Brisbane. In November 2012 overheating in all classrooms was observed (Figure 4.4). In February and March 2015 the classroom temperatures in Buildings A B C D F had reduced in duration of time of overheating in the afternoon (Figures 5.20, 5.21). Classroom temperatures were cooler than outside until midday.
3) Method 3 showed classroom temperatures for school days of each month over one degree intervals from ≥28°C to ≥33°C. In November 2012 there was

greater variability between buildings in each temperature band with Building D and A having the most percentage of temperatures ≥28°C. In February and March 2015 the Building D was the coolest of A B C D F (Figure 4.22).

Impacts of interventions on classroom temperature in each building are noted as

4) Building D temperatures showed reductions in all three methods compared to the other buildings for the same time period. This building had a combination of interventions retrofitted to its building and immediate surrounds: cool roof, stack ventilation and shade sails to its north (Refer 3.21 for interventions per building and other drawings in Chapter 3).
5) Buildings A and D after the cool roof had cooler classroom temperatures compared to buildings C and B and before the interventions, when the building was unoccupied with windows and doors closed. This indicated that heat load through the roof had been reduced.
6) Building B after the Stack Ventilation strategy with night flushing function was observed to cool down at night more quickly than the other buildings, almost matching the minimum temperature outside. However during the day the classroom temperature was warmer than the other buildings.
7) Building C after the Stack Ventilation strategy was observed to have cooler mornings than before. In the afternoon the classroom warmed but not for extensive periods of overheating as before the intervention. Building C was observed to be the coolest at night of the four buildings, attributed to the large eucalypts to its west shading ground surfaces and roof in afternoon.
8) It was difficult to determine if the early stages of the schoolyard greening strategy had a cooling impact on classroom temperature. It is anticipated a cooling effect from the front garden is more likely to occur when the vegetation increases to cover the garden bed completely and the canopy of shade trees increases to shade adjacent asphalt areas. Other perceived impacts of schoolyard greening are discussed in the next chapter.

The second research question asked what is the acceptable comfort zone for the occupants. The temperature analysis referred to the adaptive comfort model as defined by ASHRAE 55, for definitions of upper and lower thresholds of the comfort zone for 90% of the population, $T_{upper90}$ and $T_{lower90}$. Classroom temperatures were observed for when they went over $T_{upper90}$ and when they exceeded outside maximum temperatures; this was regarded as overheating. It was found that in 2015 classroom temperatures were observed to have reduced their extent of overheating; they were no longer over outside temperature for hours, as was the case in 2012. However this fall in temperature was not enough to be within the acceptable comfort zone. It was observed that there were still relatively high percentages of time that the classroom temperature was above the $T_{upper90}$ threshold. Classroom temperatures were influenced by outside weather conditions; when the daily temperature is beyond 28°C the classroom temperature was also most likely to be over this threshold during the afternoon.

This research has applied an overheating metric that was developed for a portfolio of Australian schools (de Dear and Candido 2010). This was Method 1. The $T_{upper90}$ threshold method across the research time period for the Buildings A B C D did not show a trend of less percentages of time over $T_{upper90}$ after each intervention (Figure 4.23). The results in this study compared the same months in different years and showed variations in classroom temperature from year to year, which could be due to a range of site related variables, including weather conditions and the way the buildings are occupied. When comparing Brisbane weather data in the Method 2 diurnal graph, there was not a single week where the variables of temperature, sunlight hours, humidity, wind direction and speed were the same between weeks of comparison.

The concern raised here is that if only one year, or a summer period, is used as a benchmark for assessing whether a school is sufficiently overheated to warrant the use of air conditioning, those weather conditions may not be a consistent indicator of conditions in other years. In two schools in the UK, a difference in weather conditions over two summer periods was observed as a cause for different perceptions in the classroom; one of the summers had a sudden increase in temperatures and this affected the children and teacher’s perception of comfort (Teli et al 2015). In this current study, over the research period some months were wetter or hotter than average conditions for that month in Brisbane. Data was compared to average Brisbane conditions for that month gathered from 15 years of data from the Bureau of Meteorology. Note that March 2015 was hotter than Brisbane's average March. In comparison, classroom temperatures were warmer than the previous years. March 2014 was the wettest month that year, instead January being usually the wettest. If studying a period of time in a school to determine overheating conditions, weather conditions need to be compared with average weather conditions for the location.

Method 2 used in the temperature analysis, the diurnal graph, was the best method to represent the general pattern of classroom temperature swing and compare classroom temperatures with the outside temperature at the school, within similar weather conditions.

There are some limitations about the methods used to evaluate temperature. Other factors that could have influenced the classroom temperature, such as how windows are used from one week to another were not monitored in this study. The questionnaire sought self-reporting behaviours of window use from the teachers however, as the questionnaire was anonymous, these responses could not be matched with specific classroom buildings.

4.11 Conclusion

This chapter presented the results of the quantitative phase of the study. The discussion responded to the first two research questions. Results from the temperature analysis revealed that the interventions indeed had an impact on classroom temperature. After the interventions, the duration of overheating in the classrooms in the afternoons had reduced, compared to the before period observed in November 2012. However the reduction in temperature was not enough to be within the comfort zone described by the adaptive comfort standard in ASHRAE 55.

The next chapter presents and discusses the results of the qualitative phase of the study: the perceptions of the teachers that occupied classrooms with interventions.

Chapter 5 Results - Perception Analysis

5.1 Introduction

The previous chapter contained results and analysis of the quantitative phase of the study, the analysis of the classroom temperature. This chapter contains results and analysis of the qualitative phase of the study, the perceptions of teachers that occupied classrooms during the interventions. This study used methods of a questionnaire and semi-structured interviews to collect perceptions from the participants, teachers and the Principal.

This chapter first discusses the number of participants that responded to the questionnaire. Then responses to each group of questions are presented and discussed. The first group of questions (Q2-Q10) evaluated the passive cooling strategies by asking about perceptions of heat during Term 1 2015, and compared with previous years. The second group of questions (Q11-Q22) explored the current adaptive actions in the school, with specific questions on windows and ceiling fan use. The third group (Q29-Q32) explored current energy conservation practices, reasons why teachers do so and any links between sustainability in the school curriculum and classroom behaviour. The last question (Q36) was an open-ended question, allowing emergent themes to be explored and a greater understanding obtained of the social and cultural context of the school. All questions asked in the Questionnaire and Interviews appear in Appendix I.

The interview responses are discussed next and follow a similar order of themes as the questionnaire but with more insight on the social aspects of cooling classrooms. Key findings from the two collection methods are discussed in the chapter summary. Reflections of the methods used in this phase of the study are discussed before the chapter conclusion.

5.2 The Questionnaire

5.2.1 The Participants

All classroom teachers were invited to participate in the Questionnaire. In 2015 there were 34 classes across Years Prep to Six. There were 42 classroom teachers and 8 classes where two part-time teachers shared the role. There were three specialist subject teachers with classrooms.

For the first three questions of the questionnaire 19 teachers responded. The fourth question, 'Which passive cooling strategies were implemented on their building or surrounds' and 18 teachers responded. However, after this question only 13 teachers continued the questionnaire. Possible reasons why participation decreased are discussed in the chapter.

Demographic questions were asked at the end of the questionnaire, rather than the beginning, to focus on the key questions about perceptions of overheating. The demographic questions provided additional information about teacher's age (Q33), gender (Q34), and age range of children (Q35). For Q33, 11 teachers responded, five were 30-45 years of age, four were 45-60 years and one was under 30. Most teachers were female (10 out of 11). The age range of children was asked because younger children need more instruction for how to behave in the class. For Question 35, there were no responses from teachers of children aged 4 to 6, so it is inferred that no Prep teachers answered the latter part of the questionnaire. Prep classes occupied buildings O and P, and were not in the case study group. There were seven Prep teachers. It could be inferred that 11 of 36 teachers (30%) who occupied the upper part of the school, Buildings A B C D F G L M and R (Figure 3.27), answered the questionnaire to the end.

5.2.2 Evaluating the Passive Cooling Strategies

The first section of the questionnaire evaluated the passive cooling strategies and perceptions of heat inside the classrooms, focussing on Term 1, 2015.

The first questions asked teachers about their classroom environment. The intent of Question 2 was to place each responding teacher into a type of classroom building to enable correlation of teacher responses with the building type. Table 5.1 shows how answer choices were written as building descriptions rather than building names (A, B C etc) to avoid identifying teachers.

Table 5.1 Question 2: Construction of Classroom Buildings

Question 2: Which of the following best describes the construction of your classroom building?		
Response Options	*n*	Researcher Comments
1) One storey, floor above ground, timber construction, mostly open underneath	5	Buildings B C D F G and A. The case study group.
2) Two storey, timber construction, timber floor to upper story, concrete floor to ground storey	6	Building H but wording also describes Building A or G
3) Two storey, concrete floors, concrete block walls to ground storey, fibre cement and metal cladding walls to upper storey, metal screens to outside of windows	6	Building P (Prep) and Building R
4) One storey, concrete floor on ground, some concrete block walls and fibre cement clad walls	2	Building O, the old preschool.
5) One storey, floor above ground, fibre cement and metal clad walls	0	Building M A demountable classroom building.
Total Respondents	19	

LEGEND FOR TABLES Responses to respondents as %	0	< 15%	16-32%	33-49%	50-66%	>66%

Where colour is used in tables, the responses in the tables have been colour toned, based on the percentage of responses over respondents. The highest percentage is the darkest tone.

It became apparent some teachers responded with wrong building descriptions when Question 2 responses were correlated with Question 4 responses. For example, one teacher answered building Type 4) in Question 2, but in then Question 4 responded that they had a cool roof, which could only be building Type 1) or 2). In correlating responses from Questions 2 and 4 with others in the questionnaire, there could possibly be 11 out of 19 respondents in the case study buildings Type 1). However these incorrect responses have invalidated the purpose of Question 2 to correlate reliably between the teacher, building type they occupy, and other questionnaire responses. Instead, respondents have been categorized into occupying naturally ventilated (NV) or air-conditioned (AC) classrooms mainly based on their response to Question 22, which asked if their room was air-conditioned (4 said Yes, 7 said No), and from other responses that accurately described their building type. Table 5.2 shows responses for Question 4 and comments about these responses.

Table 5.2 Responses for Question 4 - Passive Cooling Strategies

Question 4: Which of the following have been installed to your classroom building and/or an outside space next to your classroom?				
Element	Yes	No	Don’t Know	Researcher Comments
1) Insulation in the ceiling	5	3	10	Some teachers were aware of insulation installed in 2012. As insulation is hidden from view expected to have a lot of 'don't know' responses.
2) Solar powered roof fans	0	12	6	Almost all buildings had roof fans installed yet not one teacher said 'yes'. Possible confusion about what this is?
3) Ceiling vents	4	10	4	Ceiling vents were in most classrooms, either existing or new. Could infer from the 10 (out of 18) 'no' responses these elements are unnoticed.
4) Floor wall/door vents	4	10	4	Where there were ceiling vents there were also these, in most classrooms. Same responses as for 3).
5) Cool Roof	2	10	6	Two buildings have Cool Roofs. The 6 'don't know' answers could infer that roof colour is unnoticed among some teachers.
6) Shade sails	3	15	0	Definite 'yes' or 'no' responses. Shade sails were noticed.
7) Front garden	7	11	0	Definite 'yes' or 'no' responses. Front garden was noticed.
Number of respondents			18	

LEGEND FOR TABLES Responses to respondents as %	0	< 15%	16-32%	33-49%	50-66%	>66%

Question 4 aimed to understand teachers’ awareness of passive cooling strategies on their classroom building or adjacent to it. In hindsight including this question was a mistake as five teachers stopped answering questions after this one. It is unclear exactly why teachers stopped responding to the questions. Perhaps the focus on the built environment was not what they were expecting from the questionnaire, or these questions were outside the focus on teaching or they felt providing detail on their environment could have possibly identified them. It was more valuable to the research to find out how they occupied their classroom rather than know their level of awareness of building interventions. Nevertheless the responses did reveal what elements were noticed and unnoticed by teachers, as discussed in comments about responses in Table 5.2.

Question 3 asked how long teachers had occupied their classroom. Eight of the twelve teachers had occupied their classroom from 2012 to 2015; seven had occupied it only during 2015. These responses correlate with Question 8, comparing Term 1 with previous terms.

5.2.3 Perceptions of Heat in the Classroom

Questions 5 to 11 collected responses about teacher's perceptions of when they felt uncomfortably hot in the classroom during Term 1, 2015. Question 5 asked 'How many days' and Question 6 asked 'What time of day'.

Table 5.3 Questions 5 & 6. Days & Time of Day Teachers Felt Hot During Term 1

Question 5: Over Term 1, how many days did it feel uncomfortably hot inside your classroom?		
Response Options	*n*	Researcher Comments
1) Few days (1-4)	3	1 in NV, 2 in AC classrooms
2) Some days (5-14)	1	In AC classroom
3) Less than half the term (15-24)	0	
4) More than half the term (25-34)	4	All 4 in NV classrooms
5) Most days (35-50)	3	All 3 in NV
6) Unsure/don't know	1	In NV
Total	12	

Question 6: Over Term 1, when it felt uncomfortably hot inside your classroom, what time of day did you feel most discomfort?		
Response Options	*n*	Researcher Comments
1) Morning session (8.55-10.45am)	0	
2) Middle session (11.25am-1.05pm)	2	2 in NV classrooms
3) Afternoon session (1.55 - 2.55pm)	7	3 in AC, 4 in NV classrooms
4) All through the day	3	All 3 in NV
5) Unsure/don't know	0	
Total	12	

For Question 5, seven out of nine teachers in naturally ventilated classrooms felt hot for 'more than half the term' or 'most days'. For Question 6, seven out of twelve teachers from both air-conditioned and naturally ventilated classrooms felt most discomfort during the afternoon session. The other five responses were teachers in naturally ventilated classrooms; two felt most discomfort in the middle of the day, and three all through the day.

Table 5.5 shows Questions 8 to Question 10, which compared Term 1, 2015 with Term 1 in the previous three years. These three questions asked teachers to recall their perceptions of their classroom over long periods of time. Three out of twelve respondents had occupied the same classroom for three years in a row.

Table 5.5 Questions 8, 9 & 10: Comparing Term 1 2015 with 2014, 2013 & 2012

Compared with Term 1, 2015 Was your classroom:	**2014**	**2013**	**2012**	Researcher Comments
Less uncomfortably hot than last year	1	1	1	In air con classroom
Same level of discomfort as last year	5	3	2	
More uncomfortably hot than last year	0	0	0	
Don't know / can't recall	1	2	1	
Can't say, in other classroom last year	5	6	8	
Respondents	12	12	12	

If any teachers responded '*less uncomfortably hot'* than previous years, this could have indicated that the passive cooling strategies had reduced the classroom temperature. However, the only teacher who responded this way was in an air-conditioned classroom in 2015, and a naturally ventilated room previous years. The most consistent answer when comparing Term 1, 2015 with Term 1 in previous years was '*same level of discomfort…'* The number of responses for Questions 9 and 10 decreased as the number of teachers who had been in a different classroom the previous year, increased. No teacher answered '*more uncomfortably hot than last year*'. These responses suggest there was no significant change to level of discomfort in the naturally ventilated classrooms compared to previous years. One respondent who answered '*same discomfort'* had answered in Questions 2 and 4 that they occupied a building with a cool roof, roof fans and front garden (Building A), which had shown periods of reduced overheating in the temperature results.

5.2.4 Exploring Adaptive Actions

Current adaptive actions that the teachers practiced to reduce theirs and the children's discomfort from heat were explored through Questions 11 to 21. A survey of all actions was listed in Question 11 (Table 5.6) followed with specific questions about use of windows and ceiling fans in the classrooms, Questions 12 to 21 (Tables 5.7 to 5.11). Question 11 listed fourteen adaptive actions to reduce discomfort from heat in summer. Teachers were asked to rate how successful each action using five descriptions from 'least successful' to 'always successful'.

Table 5.6 Question 11: Current Adaptive Actions

Question 11. Over summer terms do you engage in any of these actions?
If you do please rate how successful the action is?

Action	Least successful	Sometimes	Generally	Mostly	Always successful	*n*
1) Open windows or doors to increase air movement	0	5	4	3	0	12
2) Turn ceiling fans on to increase air movement	1	2	5	2	2	12
3) Turn ceiling fans up to highest setting	1	4	2	3	1	11
4) Encourage children to drink more water	2	2	4	2	3	13
5) Allow children to leave classroom to fill up water bottles	0	4	3	2	3	12
6) Spray children with water mist to cool them	0	4	5	2	0	11
7) Fan children to cool them	5	2	3	1	0	11
8) Ask children to spread apart	0	7	2	1	1	11
9) Allow children to change seats to sit under fan or near windows	3	6	1	0	0	10
10) Allow children to take off socks and shoes	4	4	3	0	0	11
11) Change scheduled learning activity	0	5	3	1	1	11
12) Leave the classroom and move to cooler location	2	6	3	0	0	11
13) Turn on AC upon arriving in classroom in morning	2	0	2	0	4	8
14) Turn on AC when it gets hot during the day	2	0	2	1	2	7

Total	13
Other actions	
15) We also pour water over our heads and have wet face washers	1
16) Leave windows open at night	1
17) Pull down blinds to stop direct sunlight	1
18) Wet towel around teacher's neck.	1

LEGEND FOR TABLES						
Responses to respondents as %	0%	< 15%	16-32%	33-49%	50-66%	>66%

Most of the 13 respondents rated the 14 actions. However, responses for how successful each action was in reducing discomfort from heat varied across the five choices. The action that was 'always successful' was to 'turn on air conditioning upon arriving in morning'. Actions that were 'generally successful' were 'turning ceiling fans on' and 'opening windows and doors to increase air movement' and 'spray children with water mist'. Actions that were 'sometimes successful' were 'turn ceiling fan to highest setting', 'allow children...to fill up water bottles' and 'encourage children to drink more water'. Actions that had the most varied responses involved water, actions 4) 5) 6). Correlating these responses with what type of classrooms respondents occupied helped to explain this; teachers in AC classrooms rated actions 5) and 6) as 'always successful' and teachers in NV classrooms rated these as 'sometimes' successful. In the interviews a teacher in a NV classroom said that 'warm water isn't very satisfying'. Other actions that were 'sometimes' successful were to 'ask children to spread apart', 'children to take off socks and shoes', 'change scheduled activity and 'leave the classroom'.

For other actions, 4 teachers wrote responses listed in Table 5.6 as 15) to 18). Two used wet towels on children's faces or their neck. One teacher said 'leave windows open at night' which is night flushing of the classroom. The action of 'pull down blinds' is unique as only one classroom in Building L has blinds.

There were four teachers who occupied AC classrooms in this questionnaire, however, there were almost double this number of responses to actions about air-conditioning use, actions 13) and 14). These extra responses could possibly be teachers expressing an opinion about air-conditioning classrooms, as there were two 'generally successful' responses as well as two negative responses rating these actions as 'least successful'.

The next questions investigated teachers' use of windows and ceiling fans in their classroom. Table 5.7 shows responses for Questions 12 to 14 about general use of windows and knowledge of breezes.

Table 5.7 Teacher Responses for Use of Windows & Knowledge of Breezes

Question 12. Over Term 1, which of the following best describes your use of windows?	
Response Options	Responses
1) I don't open windows at all	0
2) I open windows on some days	1
3) I regularly open windows in the morning when I arrive and close the same ones when I leave.	8
4) I regularly open windows in the morning, alter them during the day and close all when I leave	1
5) Don't know	0
Total	10

Question 13. Over Term 1, how often did you perceive a breeze through your classroom?	
Response Options	Responses
1) Regularly	1
2) Sometimes	7
3) Not at all	2
4) Don't know	0
Total	10

Question 14 Over Term 1, do you know which direction the best breezes came from? Tick all that apply.	
Response Options	Responses
1) North (from front gate)	0
2) South (from oval)	5
3) East (from Wilbur St side of school)	0
4) West (from Abbotsleigh St side of school)	1
5) Don't know	5
Total	10

A common practice is that the teachers open windows in the morning and close the same ones at the end of the school day. Half of the ten teachers knew which direction the best breezes came from, and the other half did not.

Table 5.8 shows responses for questions 16 and 17. Use of windows for ventilation was explored in Question 16 and other reasons for use in Question 17.

Table 5.8 Teacher Responses for Window Use for Ventilation

Question 16: Over Term 1, which side of the classroom did you open windows and doors at the same time for ventilation?	
Response Options	Responses
1) One side of the classroom	2
2) Opposite sides of the classroom	5
3) Two adjacent sides of the classroom	2
4) Three sides of the classroom	1
5) All four sides of the classroom	0
5) Don't know	0
Total	10
Question 17: Generally over the year, do you open windows and doors for any other reason than ventilation? Tick all that apply.	
Response Options	Responses
1) No, I only open windows for ventilation	9
2) To increase daylight into room	1
3) To have a view of vegetation	1
4) To see and hear other people in the school	1
Total	10
Other reason - *To circulate air / fresh air*	

More than half of the teachers, 8 out of 10, opened windows effectively for cross ventilation; 5 said ‘opposite sides of classroom’, 2 said ‘adjacent sides’ and 1 said ‘three sides’. There were 2 teachers that only opened windows ‘one side of the classroom’ that does not promote cross ventilation. These occupants may not be aware that windows only open on one side are not functioning as intended; to let breezes through. Almost all teachers only ‘open windows for ventilation’. One teacher ticked all other reasons.

Questions 18 and 19 investigated any faults with windows or other barriers to preventing them from being used as shown in Table 5.9.

Table 5.9 Questions 18 & 19: Barriers To Window Use

Question 18: Generally over the year, are there any windows you don't open because of a fault?	
Response Options	Responses
1) No, all the windows can be opened	4
2) Can't reach the window handle	2
3) Window is too stiff to open	3
4) Window doesn't stay open	3
5) Handle is broken so can't open or close the window	1
Respondents	9
Other reasons - *I don't open the oval side windows because of the noise coming from children in R block* - *Have very few windows*! - *The design of some windows hinders breeze.* - *The highest windows in our classroom would be great to open but there are a lot of them and they are very hard to access for reasons stated above. In my first term I was so insanely busy to request work to have them fixed.* - *Window doesn't stay open as lever is broken*	
Question 19: Generally over the year, are there any windows you don't open because of furniture of other physical barriers?	
Response Options	Responses
1) No, there are no physical barriers to opening	7
2) Furniture is in the way of windows so I can't open them	0
3) Children's work is displayed on glass and will blow off it windows are opened	1
4) Paper on desks or elsewhere in room blows around if windows are opened	1
Total	8
- *We have a huge air conditioning tower on one side and a concrete wall on the other, not conducive to breezes*	

For Question 18 there were responses to all the choices; handles out of reach, stiff or broken windows. Another reason given was the design of the window. This was discussed further in interviews as the awning windows. For Question 19, 7 out of 8 teachers said ‘there are no physical barriers to opening windows’. One teacher responded to ‘work displayed on glass’ and ‘paper blows around if windows are opened’ as barriers for not opening them. This use of windows as display surfaces was discussed in interviews.

Question 20 asked about any uncomfortable outside factors that caused teachers to close windows, shown in Table 5.10. For 5 out of 8 teachers the most uncomfortable factor was 'too much outside noise'. Other uncomfortable factors were 'outside heat' and ' glare'

Table 5.10 Question 20: Uncomfortable Factors Outside Windows

Question 20: Generally over the year, do you close windows or not open them because of these uncomfortable outside factors?	
Response Options	Responses
No, I don't experience any uncomfortable outside factors through open window	2
Too much outside heat comes through open window	3
Too much glare from open window	2
Too much outside noise comes from open window	5
Outside view is unpleasant to look at through open window	0
Total	8

Question 15 asked about teacher's use of ceiling fans and Question 21 asked if there was any reason to not use fans, as shown in Table 5.11.

Table 5.11 Questions 15 & 21: Use of Ceiling Fans

Question 15: Over Term 1, which of the following best describes your use of ceiling fans?	
Response Options	Responses
I don't open ceiling fans at all	0
Sometimes I turn on the ceiling fans	3
Turn on ceiling fans in the morning when I arrive and turn off the same ones when I leave	6
Turn on ceiling fans in the morning, alter them during the day and turn them all off when I leave	1
Total	10
Question 21: Generally over the year, do you not use ceiling fans because of any of these reasons?	
Response Options	Responses
No, all the ceiling fans work	0
One fan (or more) doesn't work	3
Fans are too noisy	6
Can't feel the air movement under fans	1
Total	10

Other reasons:

- *Sometimes they don't help*

- *During cutting activities, the fans blow the children's work away. They are only in year one and are not able to contain their work by weighing it down. We turn the fans off until everything is glued. This seems unavoidable.*

- *Too noisy on full power*

For Question 15, 6 out of 10 teachers 'turn on ceiling fans in the morning when I arrive and turn off same ones when I leave'. Question 15 was similar to Question 12 of windows and most teachers responded the same way. This indicates a common practice among teachers to set the room for the school day on arrival and switch off fans and close windows when leaving. For Question 21, 5 out of 9 teachers said 'All ceiling fans work'; 2 teachers don't use fans because they 'are too noisy' another 2 'can't feel the air movement under fans' and one 'one fan or more doesn't work'. Fans in buildings A C D and F are positioned very high; the ceiling they are mounted on is 4.1m from the floor, the blades are 3.0m high from the floor (Figure 5.1). Although another teacher said fans are turned off whilst children cut and paste paper as the "fans blow the children's work away".

Figure 5.1 Ceiling Fans Mounted 4.1m from Floor & Centred in Classroom

5.2.5 Exploring Reasons for Energy Conservation

An exploration of energy conservation practices among teachers at the school was investigated through Questions 29 to 31 as shown in Table 5.12.

Table 5.12 Questions 29, 30 & 31: Energy Conservation Reasons & Practices

Question 29: Do you try to conserve energy use in the classroom?		
Responses	*n*	Researcher Comments
Yes	9	
No	1	
Unsure	1	
Total	11	
Question 30: If you try to conserve energy use, could you give the reasons why?		
Keep the room cooler and save on electricity	1	To save electricity.
Lights off to help save power	1	
Promoting sustainable habits for students AND...	1	Social practice
Good practice - help children be aware	1	Social practice
We have been encouraged to	1	Social practice
Better for the environment	1	Environmental reason
If there is enough daylight, turning on lights seems a waste of resource	1	Environmental reason
…I am very concerned about our environment…	1	Environmental reason
…and the wastage EVIDENT in this particular school!	1	Economic reason
To save the school money	1	Economic reason
So as not to waste the school's money	1	Economic reason
Question 31: If you try to conserve energy use, could you describe your practices?		
Lights off, interactive board off	1	4 teachers said turn off lights and other appliances
Leave lights, computers, fans off when not required	1	
Turn lights and computers off when not in use	1	
Turn off lights, fans, AC, monitor screens and IWB when not using or out of room and at lunchtime. Use windows open as an alternative to AC and fans, decrease paper usage at all costs.	1	This teacher included AC as an appliance to turn off.
Turn off lights when not in the room	1	2 teachers said turn off lights when not in room
Turn lights off if no one is in the room	1	
Turn lights off or leave them off	1	2 teachers said turn lights off (whilst in room?)
Lights off	1	
Using skylights instead of turning on lights	1	Only Building L has skylights, installed in 2014

(Note IWB - Interactive White Board)

For Question 29, 9 out of 11 teachers said they 'conserve energy use'. These teachers answered the next two questions giving reasons why they conserve energy and what their practices were. The reasons why teachers conserved energy could be grouped into three categories; good social practice, for environmental reasons of using less resources and the economic reason of reducing electricity costs for the school. Although two teachers did not fully understand the question 'give reasons why' to conserve energy and replied 'to save electricity'.

All practices of the 9 teachers included 'turn lights off'. One teacher gave a considered response listing all her practices. Actions that involve turning the appliances off when not in the room, or when not in use, are small actions (Moloney and Strengers 2014). These practices are also in keeping with the conserving energy guides distributed by the Department of Education. Except for the compromising practice of turning lights off whilst in the room 'to make the room cooler'. This was explained in the interviews that the lights were perceived as a heat source.

Question 32 explored any links between aspects of sustainability in the curriculum with adaptive behaviours of teachers and the wider school environment as shown in Table 5.12.

Table 5.13 Question 32: Link Between Sustainability in the Curriculum & Environment

Question 32. Do you know about any aspects in the curriculum for sustainability that could be practices in the classroom or wider school environment?	
Responses	*n*
Yes	3
No	3
Unsure	4
Total	10
If yes, please share your ideas about sustainable practices	
1) Leave lights off, separate rubbish etc	1
2) Year 4 geography curriculum looks at reuse, recycling and reduce. This is not practiced. Year 4 also look at worms and compost in science as part of their life and living unit. There are no resources and ability to practice this at this school.	1
3) Term 4 Science Unit 'Save Planet Earth'	1

Not every teacher understood this question, as 4 out of 10 were unsure. The 3 teachers that said ‘yes’ shared their ideas. Two teachers identified science units that cover sustainable topics. Two teachers commented on separating recyclable items from waste. The school does not have recycling bins for children to use, nor a worm farm or compost collection. Recycling items is an everyday practice in Brisbane households, with kerbside bins provided by the local council since the 1990’s.

5.2.6 The Open Question

The last question asked participants to add comments about anything in the questionnaire (Question 36). These responses are listed in Table 5.13.

Table 5.14 Question 36: The Open Question

Question 36. Are there comments you would like to add about anything in this questionnaire?
Responses
1) The inequality of air-conditioning through the school. It is also very hard to ask children to focus at the height of summer when we are just as flustered and tired as them as well as sticking to the tables/papers.
2) I didn't respond to many as they were not relevant given that I use the air conditioning in the hotter months.
3) Was in an air conditioned building last year - student alertness was MUCH HIGHER all day every day / season
4) Rooms need air-conditioning
5) Our classroom is unbearably hot in summer and freezing in winter and in each of these seasons it impacts upon teaching and learning ability. Other classrooms have been modified to combat heat especially, as have staff areas such as the admin building, staff room and HOC room. It strikes me as odd that it's more important to heat and cool adults than it is to heat and cool five year olds. And yes, they use their air conditioners for heating in winter while we weather temperatures between 8 and 14 degrees in winter and almost 40 in summer. It's very uncomfortable and seems a bit unfair.
6) Although I have embraced this project and commend you for your work, I believe the installation of air conditioning units in some classrooms in the school has created a degree of resentment amongst students AND staff. It needs to be one for all - equity is essential. Moving from a classroom where there was no air con to a classroom with air con has clearly demonstrated to me that children work better in air con and work can be sustained throughout the day. As a teacher, I feel that I am able to give 100% in a classroom that is cooler too.
7) It is unfair to air-condition half the school. Teachers in these rooms are less likely to vacate and change rooms. Children get more tired with the heat and their learning is impacted.
Total 7 responses (Each teacher made one response)

Seven teachers responded. All commented about air-conditioning in classrooms. Four out of the seven teachers consider having air-conditioning to some classrooms and not others is an equity issue. Two teachers who had moved from naturally ventilated to air-conditioned classrooms in 2015 said that the children worked better all day in air-conditioned classrooms. One teacher said she felt 'able to give 100% in a classroom that is cooler'.

5.3 The Interviews

Interviews were undertaken with teachers who occupied the classrooms with interventions implemented to them and the acting principal of Term 1 2015..

5.3.1 The Participants

Seven classroom teachers from buildings A B C and D were interviewed. The location of their classrooms is shown in Figure 5.1. Teacher's comments were coded in two ways to avoid being identified. When teachers commented on classroom specific questions they are referred to as occupants of that building e.g. Building A Teacher. When teachers made other comments, for example about social aspects, they are referred to as T1 to T7.

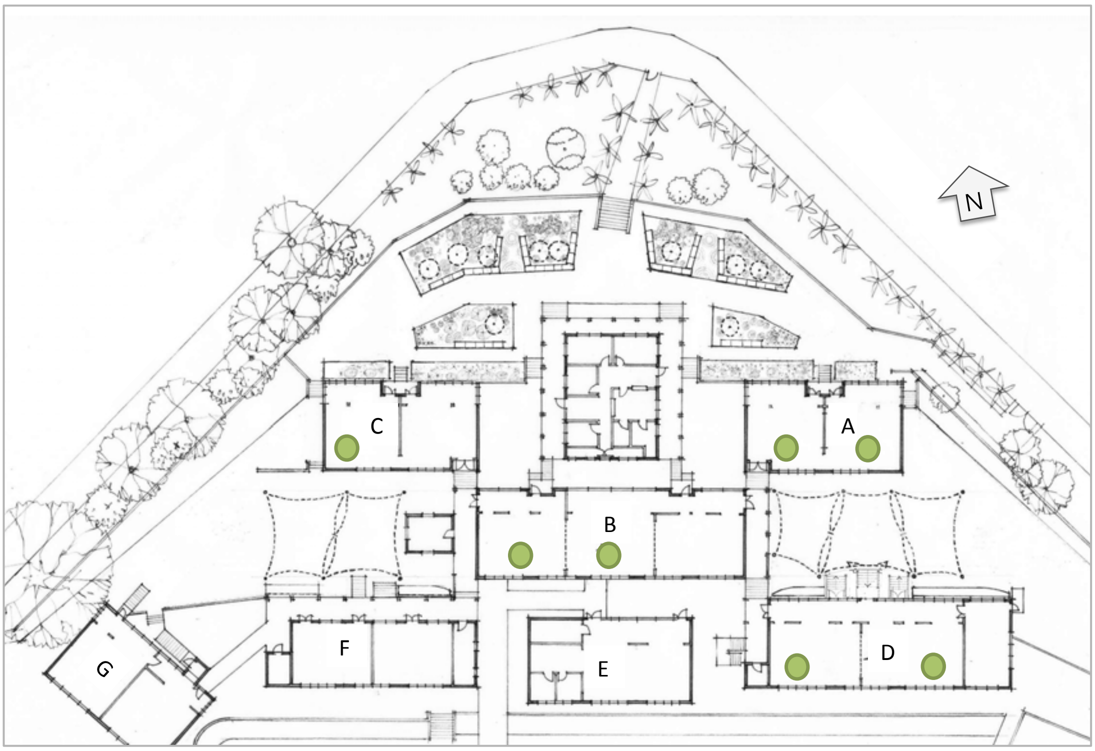


Figure 5.2 Plan Showing Location of Seven Teachers Interviewed

Two pairs of teachers chose to do the interview together. Each pair of teachers had adjacent classes in the same building of the same year level, enabling them to team-teach. This practice involves combining two classes to conduct the same learning activity and one teacher leads the combined class. The other teacher is in a supportive role or free to attend to other tasks.

The acting principal agreed to be interviewed. The school usually functions with the principal sharing aspects of the school leadership role with two deputy principals. The acting principal had been in the role of deputy principal during the time of the implementations, 2012 to 2014. The principal at the time of the interview was unavailable, away from the school for Terms 1, 2 and half of Term 3, 2015. The interview with the acting principal of 2015 was very informative regarding the workings of the school, indicative of an interview with an elite organization (Easterby-Smith, Thorpe, Jackson 2015).

5.3.2 Evaluation of the Passive Cooling Strategies

The interviews investigated impacts of the passive cooling strategies, not just the physical aspect of reducing classroom temperature, but social and cultural impacts.

All interviews started with a request ‘Tell me about any impact the passive cooling strategies have had on the classroom?’ which opened up the interview to discuss foremost in the teacher’s or Principal’s mind anything about the strategies. The Acting Principal started on a positive note stating his view in favour of passive cooling approach for buildings. He has taught in north Queensland schools and experienced how effective casement windows and louvers can be in allowing breezes into the classroom.

> ***Principal:*** *Personally I’ve always been in favour of a passive cooling approach. I’m not a strong advocate for having school buildings that are totally air-conditioned. Personally I would like to be able to have a level of ventilation and cooling and heating that occurred in the classroom that are normally environmentally based but I also acknowledge that fact that we’ve got buildings that have been designed that have created changes in the way*

breezes are caught in the school, so I think there needs to be some level of intervention somewhere down the track with regard to air-conditioning.

The teachers in Building D started with the floor vents.

> ***Building D Teacher 1:*** *Firstly would be the vents in the floor. Sorry, but it may have helped in the assistance with cooling in some small way, but as you can hear at this moment it has just let so much noise back into our rooms. Before and after school care is below we're rarely able to sit with our computer near the air vents with the amount of noise. Holding interviews with parents the noise has increased (in the room). Also I guess after 3.30 the other teacher and I are letting our hair down and summing up our day, we have to watch what is being said because if we can hear what is coming up then they can hear coming down.*

Overall, both teachers in Building D had little positive to say about the strategies.

> ***Building D Teacher 2****: There's very little relief despite the cooling methods that have been put in place when it is hot and humid.*

> ***Building D Teacher 1*****:** *We've got to accept that when we walk into here, with all the things that are being tried, and you walk into a classroom that's air-conditioned, there's just no comparison. There is just none. And I'm sure the work we get from the children reflects that.*

Teachers in Building D observed after the shade sails were installed that less sunlight came into the classroom in winter. They had felt cold, more than in previous winters.

> ***Building D Teacher 2:*** *The other one has been the shade sails. I'm sorry we're sounding so negative but we've never had such a cold classroom in winter. Because we used to have the winter sun all along this veranda; we would work one-on-one with the children along this side. If they didn't have jumpers we'd say you could sit over here. We don't get any of that winter sun.*

That's not to say that we may have had colder days this winter this year too than we have had previously. But yes we certainly noticed at lunchtime we'd sit here with the sun on your back and we could cope with winter. But we've lost all of it. We used to get it from 8 o'clock, onwards, when the sun came through. The room was quite like a little oven.

Teachers in Building A said humidity was an uncomfortable factor in summer. In winter the classroom was cold.

Building A Teacher 1*: It's tricky with the humidity. I find that the vents and things don't make a whole lot of difference with the humidity. The garden at the front, when the trees grow bigger that will be really good. As for the building, when it is really, really hot … I can't notice too much of a difference. Because of our heat…it's really the humidity factor that is really full on. There's not a whole lot of ventilation things really that help with that as far as I'm aware.*

Building A Teacher 2: *It's very cold in winter. Until the sun comes in here, I'm quite cold…. It felt like a long winter for me. As soon as you get here, I'd be in a million layers. I wouldn't peel off those layers until sometime until 2 o'clock, was when I'd start to feel warm ... My body's tense and it's no good for me.*

Another impact for teachers in Building A was glare from the cool roof on Building D. From inside Building A teachers look south across the east courtyard to the roof of D (refer Figure 3.17).

Building A Teacher 2: *The problem with those windows is that when we open them, we get the glare. Children sitting there looking at us as we're teaching and if we've got them open are getting that glare smack in their face. The tinting's good.*

To provide some background context, about tinting on south windows of Building A. One week before the Cool Roof was scheduled to be applied the Principal and Admin staff voiced their concern about glare. They were concerned that Building A teachers would complain about glare from the roof of Building D through their south windows. Before the cool roof coating was applied the Principal wanted a strategy in place to address the concern. An assurance was provided by the Parents and Citizens' Association to fund any glass tinting or shading if required on south windows of Building A to the value of $5000. The Cool Roof application proceeded. The roofs were bright white, enough for the teachers in building A to require window tinting. The tinting softened the brightness of the white roof and subsequent shade sails, making them all look cream through closed windows. However the effect is lost when windows are opened to let breezes in.

To compare this response from Building A Teachers to the responses for Question 4 in the questionnaire: 6 out of 8 teachers gave 'don't know' responses to whether they had white roofs on their building. This response could infer teachers don't recall what roof colour is on their building or that the cool roof is not so bright white for other teachers to notice.

Teachers in Building B and C thought the strategies had little impact on hot days.

> ***Building B Teacher:*** *I think those features would make an impact in maybe second and third term while it is getting warmer. But in the first and fourth term when it is crazy hot, I don't know if they make a great deal of difference on those really hot days, when the children are really sweaty and I don't know if it is enough always for Brisbane on those particularly hot days. I think in between seasons, yes it would make a difference on a day like today (02 September 2015) when they come in hot and the room is like this.*

In the interviews the perception of heat was phrased more generally 'Would you say the classroom temperature has improved (been less hot), stayed the same or become warmer than before the strategies?' Some teachers could recall specifically what it was like in Term 1, whereas others talked more generally about their experiences during summer.

***Building C Teacher**: I think this year there were some hot days. Right at the start of the year is hot and right at the end of the year is hot. I think this year there were a couple of extra hot days in March.*

***Building D Teacher**: I guess we always have it really hot, it's the January and February. December when it's hot, it's the end of the year. Although we work the children very hard to the very end, we do have some down time. Whereas when they come back in the beginning of the year with a new class it is full on getting behaviour management, structure, all of that and also dealing with possibly the hottest days that we'll ever have in the year. It is just tiring.*

When teachers were asked if there was any difference between Term 1 2015 and previous Term 1's, this question was met with some hesitation, perhaps the comparison was too difficult, or there was confusion about the question. Some teachers answered by comparing their warm classrooms with other cooler classrooms in the school that have air conditioning. Most of the answers discussed what summer time is like generally in their classroom.

One Building B teacher said yes it had been 'less hot'. Building B has stack ventilation with night flushing (refer 3.2.3). She started by recalling how hot it was in Term 1.

***Building B teacher**: I remember Term 1 being very hot, very uncomfortably hot for both the children and I. So we did a lot of shoes off, washing our face and hands and stuff to cool ourselves down … I'm sure there were some days that weren't as hot we didn't have to take our shoes off or anything like that but thinking back that far I can remember it being hot.*

***Researcher:** Ok. You've been in this room, has it been more than three years?*

***Building B Teacher**: This is my third year in here and I also think that the situation of this room and the airflow that doesn't happen also makes it a hell of a lot hotter, than say other rooms in the school that have got like four windows and breezes and things and nothing blocking anything.*

Researcher: *The first time you came to this room would have been before the vents and the roof fans. Can you cast your mind back to what it was like then?*

Building B Teacher*: I can definitely say it was a lot hotter then. The vents have definitely helped in those days when it's hot, but not so hot, it's definitely helped in those ones but unfortunately as far as the really hot days goes I can't see much difference.*

Researcher: *When it's sticky and humid it's just so hard to make a difference.*

Building B Teacher*: I can definitely say when it's not super hot outside that it's OK. Whereas before, even a little bit of heat, in here would be just 'ki-kiiik' (gestures finger slashing across throat).*

The teachers in Building A summarised conditions in their classrooms for the year.

Building A teacher 1*: It really feels like six months of the year is hot and three months of the year is freezing!*

Building A teacher 2*: And out of those six months two are humid.*

Researcher: *Which are those – February and March?*

Building A teacher 2*: Even March. Sometimes December.*

Building A teacher 1*: Right up till Easter. Last November, December was awful. November particularly was really hot last year.*

The Principal explained the effects of heat on children and their learning by comparing the experiences of being in an air-conditioned classroom to a classroom that is not. He takes the point of view as a teacher.

Principal*: The other thing I'd like to mention is the issue of efficiency and effectiveness of teaching and learning in the classroom. Teaching in the afternoon from 2 o'clock to 3 o'clock probably the hottest part of the day, from our perspective the productivity is better there on a hot day in those that are air-conditioned than those that aren't. Generally kids are very tired, there's the air issue, kids tend to be more lethargic and it's natural if it's a hot*

> *day that people want to go and have a lie down, a quiet time. That impacts upon learning. If I'm in a classroom where I'm teaching something and I've got air conditioning, then the kids after running around at lunchtime hot and bothered, can come into a classroom that's nice and cool, I can do some work. If I've got kids who are hot and bothered and we all come in hot and bothered into a classroom that's hot in the first place, the tendency is that you can't do high-order thinking activities. The activities will be more geared towards accommodating the feeling that the kids have.*

Four teachers echoed the Principal's comments about effects of heat on children being lethargy (T5, T4, T7, T3) and irritability (T4, T7, T3).

> ***T4**: They're very lethargic, very cranky, for a kid. They don't want to do much they're just so tired and exhausted.*

Generally the afternoon session is experienced as the hottest part of the day. The teachers in naturally ventilated classrooms have a strategy of doing intensive teaching in the morning session as commented by the Principal and teachers.

> ***Principal:** The general approach is that teachers do as much of the teaching and learning that they can in the cooler part of the day, which is the start of the day. Our more intensive work is usually in that first session, that's where you do maths, science and key things that you want to pursue.*

> ***T4**: Because the morning is better, I try to cram a lot into the morning. Then come the afternoon we might do like a bit of rest and reading and just really easy things because it's so hot in here by then. But it's only for those two months or so.*

A Building D teacher has compared the effects of heat on children in their classroom with children in air-conditioned classrooms.

> ***Building D teacher:** … walking in this room in a hot summer's day and walking in a room that has air conditioning there's no comparison … I do non-contact time / supply teaching so I have taught in the other rooms … I'd come*

> *back and I'd be going 'oh my god you should feel that room'. Or the children pal-up with (their) buddies now and again and we've said 'right we're coming to your classroom just for this afternoon.' The big kids read to the little kids (in their air conditioned classroom) just to have a breather… They can't sit on the carpet, they can't relax on the carpet 'cos there's nothing worse on a hot day than to be lying on fibrous carpet or sitting on plastic chairs. They sit up and they've got like a wet spot where they've just sweated into it.*

In very rainy weather children and teachers stay indoors all day. This is particularly undesirable in February when it is hot and humid.

> ***T2****: We have 'wet play' we've got wet clothes and where are we? We're in the classroom. So in the middle of the day with the humidity, the rain and the hottest days of the year, we're in here... We can be in here 9 o'clock till 3 o'clock. They can be long days. That's when it's generally heavy rain. For light showers the kids will sit under B block, that's fine.*

A parent whose child had eczema told a teacher that symptoms were triggered in hot and humid conditions. This parent said air-conditioned rooms are preferred for their child. Although rare, the school does not provide any air-conditioned classrooms from Prep to Year 2 for children with these health concerns.

One teacher told about a child being kept home on hot days because he 'just couldn't cope'.

The Principal and his team have considered the effect of air-conditioned classrooms on children's performance in the National Assessment Program for Literacy and Numeracy tests (NAPLAN). Every year in May Australian school children in Years 3, 5, 7 to 9 are tested in literacy and numeracy. Each school's performance as year cohorts appear on a public website where the school's results can be compared to other schools and past years' results. The Principal refers to the NAPLAN results for improvement in literacy and numeracy in the school from year to year.

> ***Principal**: We were talking about this … if I had kids that were doing the NAPLAN testing, if you had some in air conditioning and some didn't, what changes would occur, what results would we have? We've got some in Year 3 in air conditioning and some who aren't. Although May is not such a significantly hot period…*

One teacher had a different view about classroom environment influencing children's learning, based on her teaching experience in a North Queensland town.

> ***T3**: I don't really believe that it is the be all and end all in achievement outcomes. I think you get very good outcomes with or without air conditioning. I know many people disagree and I know that air conditioning makes it a lot more pleasant. I think that what gets good outcomes is good teaching. And you can do good teaching in the heat. In know it is not as nice, but certainly we got very good outcomes in (town) and it was very hot.*

Four teachers commented on how children have not developed self-awareness to limit their physical activity on hot days. Some children returned to the classroom after spending their break running around in school grounds even in hot weather. When the classroom is warm they were unable to cool down and their overheated state affected their behaviour and ability to learn.

> ***T4:** Particularly after first break they come in and they, of course children don't really have that 'ooh I'm getting a bit hot, I might go and sit down' they don't have that until they've got a headache or something that forces them to stop. Particularly boys. Boys can't stop, until they're really thirsty or they've got a headache, or they feel a bit sick.*

> ***T2:** The kids don't regulate themselves. When it's hot, that doesn't stop them from running around like little twits on the oval, until their blood pressure must be through the roof. So it's a matter of us managing them, saying 'do this do that'… younger children particularly have no idea when they're hot. They don't realise 'if I stop running around, I'll cool down'. I'll never teach them that. Even today (24 September 15) we wore jumpers in the morning, it*

was cool, we went down to the oval and came back ... One was this beetroot wearing a jumper and I said take your jumper off. They think whatever's on them, is what they're wearing.

5.3.3 Exploring Adaptive Actions

The Interviews provided more in depth understanding of the use of windows and fans in the classroom. The adaptive action of leaving the classroom to a cooler place in the school was discussed in detail.

In the interviews a pair of teachers said when there were periods of high humidity in the classroom, ventilation from open windows is not enough. Awning windows were discussed as a type that hinders breezes.

> ***T6**: When there's humidity it doesn't make any difference.*
>
> ***T7**: Yes that's right. I'm quite fine with heat, as long as there isn't humidity. The minute the humidity creeps up it's stifling. These (awning) windows here, they're useless, because they only go so far.*
>
> ***T6**: If they were replaced with louvres maybe we could get more air coming in.*
>
> ***T5:** Our (awning) windows don't open they are quite stiff so they don't open all the way out to get that good flow.*

A teacher in Building A commented on keeping windows shut when it was hot outside.

> ***Building A Teacher:** … when it's that really stifling hot, it's better off just to keep windows shut. To stop the heat coming in off the bitumen and the gardens, don't know how much affect it's had yet, because it hasn't had a chance to grow up. As far as visually, aesthetically, it's nice to look out and have a look at some plants.*

This teacher also said that if they opened their south windows they lost the effect of the tinting on windows to reduce glare from the shade sails and white roof of Building D (Refer to section of Buildings A and D in Figure 3.23).

Other barriers to opening windows were observed whilst conducting interviews in classrooms. Bookshelves placed alongside windows could make it harder for teachers to open windows (Figure 5.3). Almost every available wall surface is used for displaying learning resources and children's work. In addition paper is displayed on window glass and strung across the classroom on wires (Figure 5.4). The amount of paper displayed increases as the year progresses. Questioned in interviews if the displays were a barrier to opening windows, two teachers said 'no it doesn't stop them from opening a window'. Also if the paper display moving in the wind became too much of a distraction it would come down.

Figure 5.3 Shelves Placed Alongside Windows

Figure 5.4 Paper Displays Pasted on Glass & Strung Across Classroom

In the interviews, teachers in rooms with raking ceiling to sides of the classroom commented that the ceiling fans only cover the centre of the classroom as shown in earlier Figure 5.1. One of these teachers had a noisy fan when at higher speed so she only had it at lower speeds to avoid it being a distraction to children.

> ***T6:*** *Something to circulate the air down the end (of the room) where I don't have circulation. We tried fans, parents brought in the pedestal fans, but they weren't strong enough…*
>
> *The only people that felt the fans in that area, was the person sitting right in front.*
>
> ***T7:*** *But again, fans that are any bigger, they're so noisy. Part of our problem is, if you've got an ASD child in your room and you turn on the fans, they're not listening to you. They immediately go to all of that external sensory stuff. We always have ASD kids and it's an issue.*
>
> (Note ASD – Autism Spectrum Disorder)

Teachers were asked specifically about whether they left the classroom and moved to a cooler location when the classroom was hot. The question explored if this adaptive action was regarded as a social norm in the school and if the action is desirable or feasible.

One teacher was flexible to this approach and adapted her class schedule to suit.

> ***Building F*** *Teacher 2014: I used to take the class down to the oval or under a tree for geography once or twice a week.*

Building A teachers took their classes under Building B. Building B and D teachers took their classes to the air conditioned staff room. Four teachers pointed out that there are limitations on what kind of activity can happen when you move the class away from resources in the classroom.

> ***Building A Teacher:*** *Because they need to sit at a desk to write. You can't have them writing on the floor. It's only valuable for those moments when you are reading to them or having a discussion about something. You need to*

bear in mind also the classes above… so you're not to disturb them, because I'm sure they'll have vents …so wooh! Whatever we're saying goes right up…There was one day, in the middle of the day, we took them under B block and they sat on the cold concrete and we read them a story down there.

Building D Teacher: *You can't have a normal lesson. You can't have whiteboards, you can't have them with their pencils and everything. So it's basically sometimes after their first play, we'll go in and just read a book and let them just cool down a little bit before we come in here. But there could be two or three classes trying to do the same thing.*

Building B Teacher*: Sometimes we do take our class into the staff room when it's really hot we turn the air con on and cool down. If they need lots of stuff then I don't make them try and get all down there. Otherwise it's amazing how much they can lose… Whereas when they get older you can say we're leaving now they automatically pick those things up*.

Building B and D teachers also said that in an outside place there are distractions from other children or people passing by and noise from nearby classrooms.

Classes from buildings A and C have used the Front Garden. Even though the trees were still small in 2015 and shady spots to sit were limited the garden was used in autumn, spring and winter months. Summer was too warm.

Building A Teacher*: It's good if it's just a teacher aide and one student. They can find the bit of shade that there is. But there's not enough shade out there yet to make that a good spot (for the whole class).*

Building C Teacher: *Sometimes we do some reading groups out there. We did maths groups out there today (04 September 2015).*

Researcher: *What time of year would you start to comeback in?*

Building C Teacher: *When the sun is getting real hot and it's not pleasant to sit out there anymore… around November…*

A benefit of the Front Garden was noted that it is an environment to learn about nature close to the classroom.

> ***Building C Teacher:*** *So we saw some bees out there yesterday and then had a conversation about the importance of bees for pollinating our food … Because the children were scared of the bee … I picked it up on a leaf … and said 'that they are very important and we need to look after them' and that was a nice little teaching point.*

The courtyards with shade sails are not used by whole classes in adjacent buildings D, A, B or C. The East courtyard has a sloping ground surface unsuitable for chairs. However during breaks times the children use the courtyards for playing, throwing paper planes and handball games. West courtyard with shade sails were used for one-on-one time away from the classroom, by teacher aides with a student or small reading groups of a parent with up to six children. After School Care started using the East courtyard placing rugs down for children to sit and eat afternoon tea. This practice did not occur before shade sails were installed, as the asphalt surface was too hot to sit on.

5.3.4 Exploring energy conserving practices

When discussing with the Principal about possibly changing teachers' opening window behaviours to improve classroom ventilation, he commented how difficult it is for people to change behaviours as it requires conscious thinking.

> ***Principal:*** *Opening a window as opposed to switching on air-conditioning or putting on an extra jumper instead of turning on a heater, are conscious sort of things (thoughts) that have to change … habits are often difficult to change because people take the easy course out, don't they?*

His comments inferred that teachers would lean towards an easier choice (switch on AC) or stay with the way they are accustomed to using windows. He also commented about teachers' expectations compared to environmental issues.

> ***Principal:*** *As a school we've got the staff obviously wanting to improve their personal situation by more actively involving things like air-conditioning … we've got to strike a balance and meet expectations to a degree, but also considering the environmental issues.*

When teachers were asked about their energy conserving practices the first responses were similar to those in Question 31: turn off lights and other electrical appliances that aren't in use and when out of the room. Then the scenario was discussed if they had air-conditioning installed to their classroom.

Some teachers said their use of air-conditioning would be limited.

> ***T7:*** *(I'd use it) for the humidity, definitely ... I'd actually prefer not to be in air con if possible. But when you hit those days you want it bad. I don't like the idea of being in 24/7 with the bugs and not having fresh air ... It dries out skin, you just feel awful. But I think for those few weeks when it's just stifling I think it's important.*

Some teachers in air-conditioned classrooms were perceived by teachers in naturally ventilated classrooms to overuse their air conditioners. Ideas about a limit or protocol to possibly prevent air conditioner overuse by teachers in the school were discussed. A number of teachers welcomed a limit to air conditioner use but mentioned this would have to be across the school. Some teachers included the administration staff in this definition of 'everyone'. One teacher had an idea that electricity for air conditioner use should come from renewable sources. She had solar panels on her own house.

> ***T7:*** *…I think it should be mandated, if temperature is going to get above this, then you put your air con on, and if it's only going to reach this, no one can put it on. Because I know some people put it on and it's like walking into a butcher it's so cold.*

… if it is going to reach 36 degrees just turn it on at 7.30am, get the cleaners to turn it on so it gets to the ideal temperature quicker, rather than trying to turn it on later, and still switching it off at a certain time.

T3: *There needs to be some type of central switch because they seem to have them on all the time…*

T4*: I think that we should have solar powered air conditioning … people use it and it costs a lot of money and they use it too much and they rely on it and they get used to it. But I think … if it gets to a certain temperature then they all go on, then once we're out of solar energy, they all go off and we resort back to fans and opening windows and things like that. Just when it's those really hot, hot-hot-hot days… if it gets above say 31 degrees then we're all able to turn it on. But as soon as we've got no solar energy or wind energy or whatever energy left, or it gets back down to like 25°C there should be a magic switch that turns everyone off.*

5.3.5 Social Aspects of Cooling Classrooms

Social aspects of cooling classrooms emerged from the Interviews. The most dominant aspect was the situation in the school of some teachers with air-conditioning to their classrooms and those without. The situation was described as an equity issue.

In the interviews teachers in the naturally ventilated classrooms perceived themselves as the 'have nots'. The Acting Principal gave his view:

Principal: *I think the air-conditioning issue … that has come of late … is more a cultural issue. I think it resonates mainly because some classes have got it … and the same boiling hot day the kids next door don't have air-conditioning. So they're putting up with the heat and this other classroom is not…*

He explains how equity in students' learning is important and this rationale extends to teachers in their teaching.

> ***Principal:*** *We're always talking about equity of the programmes that we run… for students and 'option, ease and access' to facilities … that I guess it's just a normal extension to go from having that at the student level to the adult level.*

Teachers have requested the Principal consider moving classes from non air conditioned classrooms to an air conditioned classroom the next year so teachers in their time at the school have a turn of being in an air conditioned classroom. The Principal explains that movement of classes is not systematically desirable:

> ***Principal:*** *From an administrative perspective … how can we manage the staffing arrangements in the school and the classroom allocations to make it equitable for everybody to take time in there? It just doesn't work that way. We try to have areas … designated for P class or Year 1,2 class … to make it more manageable to operate the school in a successful way.*

Teachers in naturally ventilated classrooms feel it is unfair that they and the children suffer in hot classrooms when neighbouring classes are in air-conditioned comfort. One of the teachers describes the situation at the school.

> **T1**: *It can really segregate staff. Who gets it? Some get it and you think we've got 25 children that we're supposed to be educating, why haven't we got it? But I believe the Principal is very much looking at it. Cos it's not equitable.*

The notion expressed by both Principal and teachers is that all teachers should have the same controls available in classrooms for teachers and children's comfort.

Another social aspect that emerged was that some teachers in the naturally ventilated classrooms compare their role to other professional workplaces. The social norm is that professional workplaces are air-conditioned. One teacher recalled how surprised other people were to learn that not all teachers are working in air-conditioned classrooms.

> ***T1:*** *People are really surprised that in our climate in Brisbane that we work in un-air conditioned buildings. At a previous school I worked in … often my*

husband would pick me up soon after 3 just to go back and do paperwork in his office which was air conditioned for a couple of hours because it would be more comfortable than sitting in an un air conditioned classroom. I'd go to his office to shower and freshen up … to then go out, having worked in a place without air conditioning and being on playground duty.

Researcher: *So the people in the office were surprised to see you there, just to be in air conditioning?*

T1: *That's right.*

A pair of teachers commented that air-conditioned classrooms are becoming more common in schools.

T1*: A colleague in another school mentioned her P&C raised money for air conditioning.*

T2: *The principal of the next school said how his school was completely air-conditioned and one parent had even donated fifty thousand dollars for it.*

T2: *Our friends, other teachers, can't believe we don't have air conditioning … a lot of these (other public schools) are air conditioned now … love the school, don't want to go … but I think it still goes back to fairness if one school can have it why can't others. The other side of the school can have it why can't the other?*

This teacher compared the role of teachers, people that do good in society, to those who have done wrong.

T2: *We even look at prisoners, they get air-conditioned buildings and they've done the wrong thing. We're trying to do the right thing! They've got to have cooler air than what we're working in. I guess they're the bitter twisted attitudes that we have after years of just sweating it out. Other people are in air-conditioned comfort and we're stuck.*

The idea of air-conditioning being prevalent in home and workplace environments emerged in interviews. One teacher noted how their classrooms are different to the social norm of air-conditioned environments in everyday life.

> ***T1:*** *Look at our school environment, when the kids come to school in air conditioned cars, we, a lot of us have air conditioning at home now, most homes would have air conditioning, and then we work all day in an un-air conditioned environment.*

This teacher shared her view that all new workplace buildings are constructed with air conditioning.

> ***T1:*** *… my husband works in the building industry. They wouldn't build any government building or re-fit any office without air conditioning, not at all.*

To support T1's comment T2 gives the example of the newest building at the school.

> ***T2:*** *Even the new building that was built here, R Block. It was built with air conditioning in mind.*
>
> ***Researcher:*** *What makes you think that?*
>
> ***T2****: Because they have no open windows… they've no big windows to open they've just got these little awning or sliding windows. So air conditioning went in. It's like well, if the government is approving buildings that are designed for air conditioning then are they saying that classrooms should be air-conditioned? So, can we catch up with that? Or build them so they don't need air conditioning. Like the Prep building is beautiful. With the Besser brick (concrete block) there, it's so cool.*

One other theme that emerged from interviews is that clothing choice is limited when working in hot conditions. One adaptive action for occupants in hot conditions is to wear light clothing. However, dressing for hot classrooms and appearing professional requires consideration of what clothing is appropriate. For men the social norm of wearing a tie is abandoned in hot weather.

__AP:__ … you have to view yourself as a teacher and … you have to be professional in your appearance. This year I've been wearing a tie more often due to the fact that this room is air-conditioned.

__T1:__ I look for something sleeveless in our tropical climate, a nice cowl neckline, a cool dress that's long, obviously to my knee. Something that's smart that doesn't look like my housedress or a big maxidress.

One teacher added if children are wearing sun safe clothing all the time then so should teachers. Teachers have the option of wearing sleeveless clothes. The children's uniform has short sleeves covering their shoulders in both shirts for boys and dress or blouse and skirt for girls. The garment insulation levels for the children's uniforms, including socks and shoes but not hats, was for boys 0.33 clo and for girls 0.36-0.38 clo (ASHRAE 2013).

5.4 Summary of Perception Analysis

This section summarises the results from the qualitative phase of the research. Structurally, this summary responds to the three research questions.

The first research question aimed to evaluate the impacts of the interventions on classroom temperature. The second research question aimed to understand what is an acceptable comfort zone for the occupants of the classrooms, the teachers and children. In this study perceptions were gathered from teachers. It was found that

1) The passive cooling strategies alone are not enough to provide comfort for teachers on hot days in summer terms. High humidity in summer was perceived as an uncomfortable factor that could not be reduced by increasing air movement using ceiling fans or opening windows.
2) Most teachers in naturally ventilated classrooms felt uncomfortably hot for more than half of Term 1. The time of day that teachers in both NV and AC classrooms felt discomfort was in the afternoon, 1.55-2.55pm.
3) In the interviews, Teachers in Building B perceived less discomfort from heat in term 1 compared to previous years. Teachers in B and D commented that in shoulder seasons the classrooms were comfortable.

4) Teachers observed the effect of heat on children as being lethargic and irritable which impacted on their learning. Teachers observed some children not being able to regulate themselves in hot weather; when returning to warm classrooms after breaks they were overheated and unable to cool down.
5) Some teachers perceived negative impacts on classrooms from the passive cooling strategies. Floor vents let in noise from underneath. Cool roof was a source of glare for teachers in the adjacent building. Shade sails reduced winter sunlight into classrooms. Teachers in A and D with the cool roof were cold in winter in the mornings

The third research question aimed to understand the range of current adaptive actions of teachers to reduce their discomfort from heat. This investigation was an important aspect of the qualitative phase of the study. Responses were gathered from Questions 11 to 22 in the questionnaire and elaborated in further detail in interviews.

6) Most teachers responded to all of the 14 adaptive actions listed in question 11, indicating that they had practiced these at some time. Although how successful each action was in reducing discomfort from heat varied. The adaptive action that was always successful was to turn the air-conditioner upon arriving in the morning. Generally successful actions were to increase air movement by using ceiling fans and opening windows. Encouraging children to drink water or spraying them with mist had varying responses of success.
7) Most teachers would open windows and/or switch on ceiling fans in the morning and close or switch off the same when leaving the classroom at the end of the school day.
8) More than half the teachers used windows effectively for cross ventilation. Half the teachers knew which direction the best breezes came from.
9) Increasing air movement by ceiling fans was limited due to existing fans being too high or noisy. Fans turned on high were disruptive to children doing cutting and pasting paper activities in the classroom.

10) Increasing air movement by using windows was limited by type of window (awning windows), having a fault or being broken, or letting in too much outside noise or heat.
11) The adaptive action of retreating to a cooler location was practiced by teachers and was sometimes successful in reducing discomfort from heat. However this action was problematic for a whole class, as children require writing surfaces and materials, and teaching resources for learning activities are kept in the classroom. One-on-one time between a student and teacher aide, or small groups of children with an adult reading books, were practiced in outdoor locations near the classroom.

To provide a greater understanding of the social and cultural context of the school the study explored the reasons and practices of energy conservation in the classroom and invited teachers to provide any other comments about the topic of cooling classrooms. The responses to the open question at the end of the Questionnaire and the discussion in the semi-structured interviews revealed important social and cultural factors to cooling classrooms and maintaining thermal comfort.

1) It is an equity issue that some classrooms are air-conditioned in the school and others are not. Being expected to perform the role of teacher in a warm uncomfortable classroom alongside other teachers in comfortable classrooms that were air-conditioned was perceived as unfair. Teachers felt that classrooms should have the same controls available for providing comfort from hot and cold weather conditions.
2) Teachers perceive air-conditioned environments to be the social norm for professional workplaces in Brisbane. Naturally ventilated classrooms are perceived as different other workplaces. Air-conditioned classrooms are increasing in other schools.
3) The expected professional appearance of teachers is limited in clothing choice when teaching in warm conditions.
4) Current energy conservation practices included turning off lights and appliances when not in use.

5) Some teachers suggested that energy saving practices that limit air-conditioner use should be the same for everyone in the school, teachers and administration staff.

5.5 Reflections on the Qualitative Phase of the Study

It is worth noting a few reflections on the methods used in the qualitative phase of the research project. Understanding the limitations and side effects of methods used, can only improve future attempts at collecting data using these methods.

An observed effect in the interviews was when two teachers paired up. By choosing to do the interview together they shifted the one-on-one approach (teacher and researcher) to two-to-one giving more power to their voices. In these interviews it was observed that each teacher was more forthright about undesirable aspects of the passive cooling strategies and they constantly supported each other's views. At the end of both paired interviews one teacher left and the interview continued with one teacher. The teacher's tone changed as comments were made in a kinder, and more positive manner. In the interview with teachers in Building D, one teacher continued talking whilst closing windows for the day and said about the classroom "Other than February and March, it's nice." In future situations where two interviewees are attending the one interview, some additional time to interview each interviewee again separately may be required.

The situation in the school where some classes were air-conditioned and others not came through in the interviews as a pervading feeling of unfairness. This seemed to impact on the teacher's evaluation of the passive cooling strategies on their naturally ventilated classrooms. Undesirable aspects of the strategies were explained in longer detail and desirable aspects seem to be shorter comments, mere recognition of some change. Some teachers appeared keen to record numerous undesirable aspects of the passive cooling strategies to support their argument that their classrooms should be air-conditioned. This may have stemmed from the participant information sheet, which said that comments received would be given to the Principal for consideration.

Recalling the previous summer term's heat and what it was like compared to previous Term 1s was not easy for many teachers. This may have been because timing of the interviews was not ideal, just after winter. Or there may have been some reluctance to provide information in the interview in case it strengthened the argument for passive cooling and adaptive actions to remain as the only means of providing thermal comfort for their classrooms. This was not seen as a desirable outcome for the teachers in naturally ventilated classrooms who believed their situation was unfair and wanted air conditioning in their classrooms, like the classrooms in the neighbouring building.

After the interviews, in October 2015, the Principal, his deputies, and the Parents and Citizens' Association (P&C) decided that all classrooms would have air conditioners installed to them, funded by the P&C. It was considered important for the work to be done 'in one go' to result in similar working conditions for all teachers sooner. Explained by the Principal at the October P&C meeting, not only had air conditioning of some classrooms become an equity issue among the teachers, it had extended to parents of the school that questioned why their child was being educated in a non air conditioned classroom. The decision that all classrooms be air-conditioned was based on the social factor of equity, not the physical factor of which classrooms were warmer than others and needed it. There was one building in the school, according to the Principal and at least one teacher interviewed for this research that didn't need air conditioning, the Prep Building.

5.6 Conclusion

This chapter presented and discussed the results of the qualitative phase of the study. A summary listed key findings. The chapter included reflections on the qualitative phase of the study. The next chapter will converge the results gathered in 2014 from the quantitative and qualitative phases of the project.

Chapter 6 Discussion

6.1 Introduction

The previous two chapters presented results from the quantitative phase of the study and the qualitative phase of the study. In this chapter results from these phases are converged to discuss findings of the study in relation to the research questions:

1 How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

2 What is perceived to be an acceptable comfort zone for classroom occupants?

3 What adaptive actions do teachers currently practise to reduce discomfort from overheating in their classrooms?

This chapter combines the temperature results with the perception results from Chapter 5, in a side-by-side display (Dickinson, Chapter 19 in Tashakkori and Teddlie 2010). The range of comfort temperatures in the four buildings, A B C and D for 2014, after the installation of cool roofs, stack ventilation, night flushing (Building B), shade sails and schoolyard greening, are displayed alongside comments from teachers about their perceptions of classrooms in these buildings during school terms of 2014. These combined results form the basis of a proposed list of actions for low energy occupation of the classrooms for each school term in the case study school.

The chapter continues to interpret and discuss the findings of the temperature and perception results, responding to the three research questions. Implications of the study are discussed next. As the case study is of a typical timber classroom building type with the common combination of surrounding asphalt areas the transferability to other schools in the same climate region of south east Queensland are discussed. Lessons learnt from the implementation and impact of the passive cooling strategies on classroom temperature and the teachers' perceptions are listed. The study explored a range of adaptive actions currently practiced in the classrooms and by making these explicit the ability of this knowledge to increase low carbon occupation of classrooms is proposed.

This chapter finishes by recommending key understandings and actions that combined together could inform a pathway of low carbon occupation of existing classroom buildings. This discussion leads into the final thesis chapter, the Conclusion chapter.

6.2 Convergence of Results

This chapter begins by converging the temperature and perception results of 2014.

6.2.1 Comfort Range Between $T_{upper90}$ and $T_{lower90}$ Thresholds for 2014

A full year of classroom temperatures for 2014 was collected for buildings A B C and D and the thresholds of $T_{lower90}$ and $T_{upper90}$ were calculated using Method 1 in the temperature analysis. The temperature range between these thresholds is regarded as comfortable for 90% of the population (ASHRAE 2013). The following figures indicate months of the year when classroom temperature is within the comfort range and when there are periods of discomfort, either too warm (above $T_{upper90}$) or too cold (below $T_{lower90}$) in the buildings. In the interviews, teachers who occupied the classrooms in 2014 provided comments on comfort conditions in their classrooms during summer and winter months. Figures 6.1, 6.2, 6.3, and 6.4 provide, for each building, a side-by-side display of the monthly comfort zone temperature analysis during 2014. Each figure presents a graphic representation of the 2014 calendar year with school terms as blocks, and comments from the teacher interviews regarding their perceptions of comfort in their classroom.

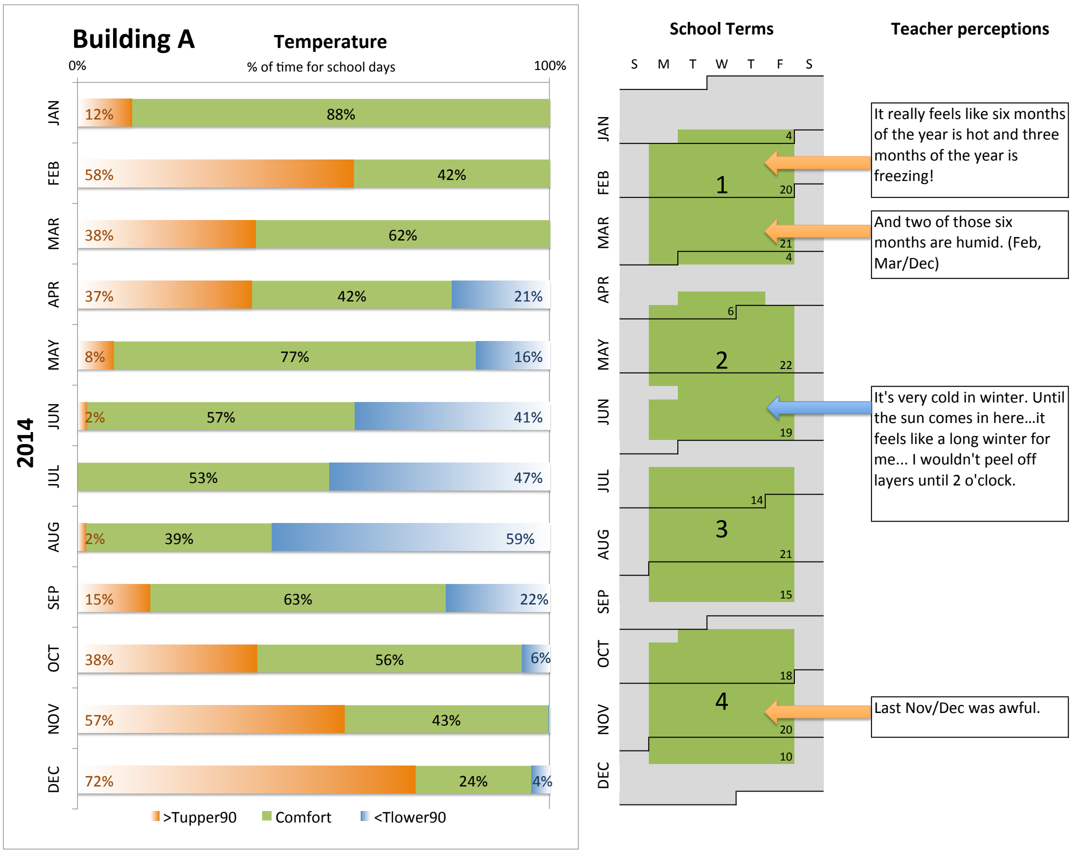


Figure 6.1 Building A: Comfort Temperatures & Perceptions

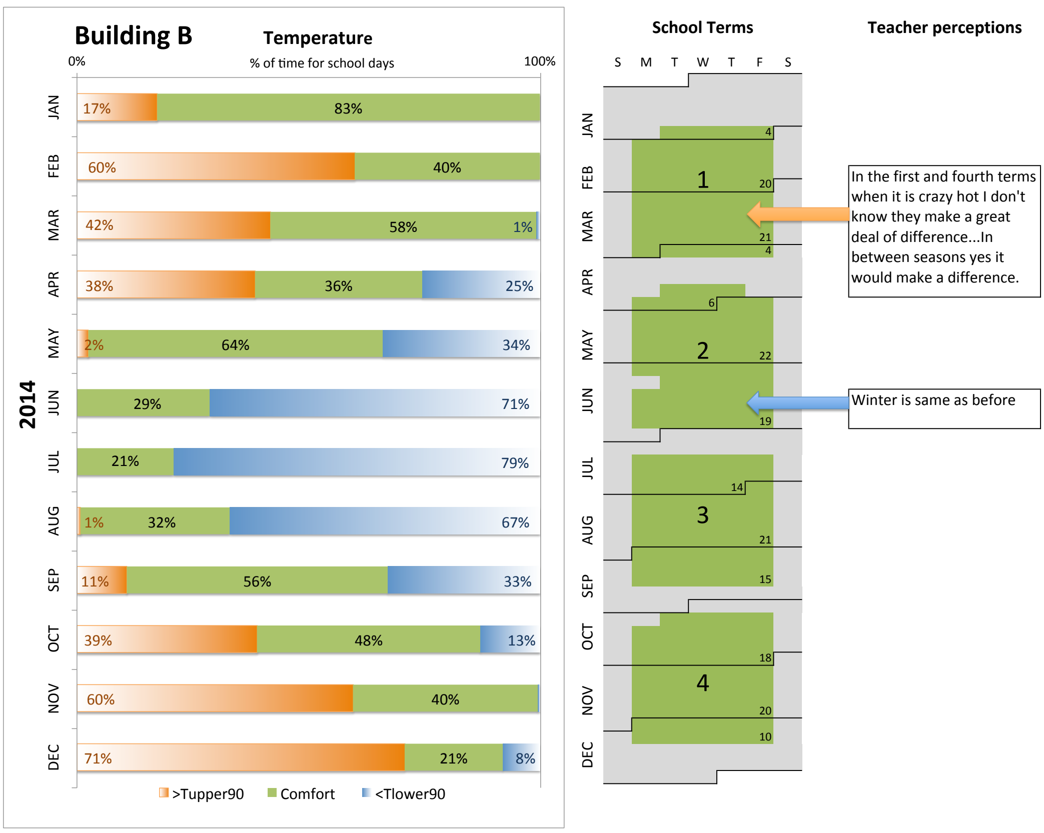


Figure 6.2 Building B: Comfort Temperatures & Perceptions

Figure 6.3 Building C: Comfort Temperatures & Perceptions

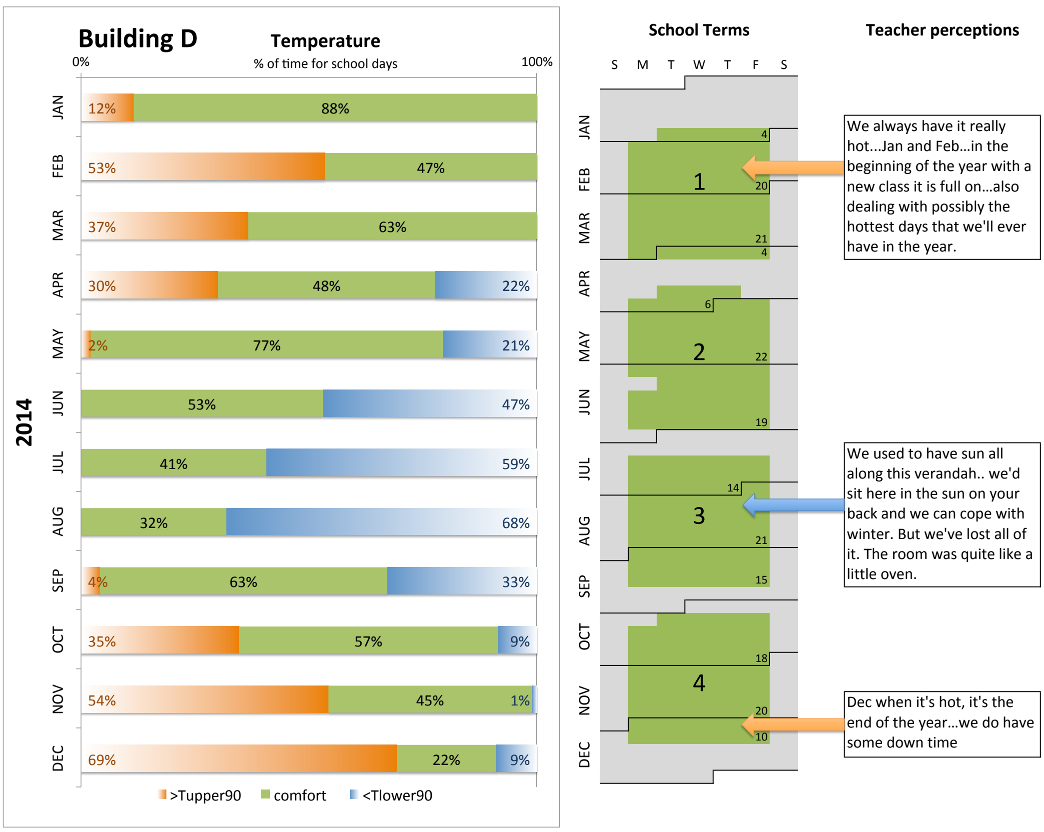


Figure 6.4 Building D: Comfort Temperatures & Perceptions

General trends across all these charts show classroom temperatures were above $T_{upper90}$ in February, November and December for more than half the school days. Classroom temperatures were under $T_{lower90}$ in June, July and August for approximately half the time, and the classrooms had periods of comfortable temperatures in May, September, March and October. All four buildings showed the greatest percentage of time within the comfort zone in May (Building A at 77%, Building B at 64%, Building C at 80% and Building D at 77%). January shows the largest percentage of comfort time, but this was an anomaly as there were only four school days in January, and the maximum outside temperatures on those days were below the average maximum temperature for January 2014.

From the perception results, it was found that teachers felt most discomfort in summer months in the afternoon. In winter, teachers felt most discomfort in the mornings and for some individuals this extended until 2.00pm.

It is worth comparing the perceptions of teachers from buildings A and D with the perceptions of a teacher from building B. Teachers from buildings A and D commented on how cold their classrooms were in winter. Yet building B actually had more time below $T_{lower90}$ in June, July and August, than buildings A and D, shown in Figure 6.2. In the interview, teachers from building D said they noticed less sunlight in their classroom in winter, due to the shade sails. These teachers had become accustomed to warm sunlight coming in through their northern windows on winter mornings and noticed the difference when it was less. One teacher in A felt the cold in winter more than the other teacher and said it took until 2.00pm for her to feel warm. Both Buildings A and D had cool roofs applied to them, intended to block the thermal radiation from sunlight, reducing heat transfer through the roof. Yet the amount of time that temperatures were below $T_{lower90}$ was greater in building B than in buildings A and D. The two teachers interviewed in building B did not mention cold mornings as an issue; one B teacher said winter was the same as before. This comparison suggests that people can become accustomed to certain thermal environments and their perceptions may be influenced by past thermal experiences.

6.2.2 'Actions to improve': a List of Low Energy Behaviours for the School

Figures 6.1 to 6.4 showed school terms between the temperature charts and the teacher's comments, allowing a correlation between months of warm or cold classroom temperatures and terms of the school year. Each display indicates times in school terms that need additional cooling or heating from air-conditioning. Based on this information Figure 6.5 lists actions by school term for controlling the temperature in classrooms, an adaptive approach.

Air conditioning could be used for cooling during Terms 1 and Term 4 as the temperature in the classrooms shows they are over $T_{upper90}$ and the perception analysis suggests it is most needed is in the afternoon. At the end of Term 2 and the beginning of Term 3 air conditioning could be used for heating, particularly in the mornings, according to comments made by teachers in buildings D and A. The beginning of Term 2 and end of Term 3 are times when natural ventilation can be used effectively, opening windows with no air-conditioning. The structure of the school year in Queensland, in four terms, presents a simple way to assist teachers to shift cooling modes, from air conditioner use to a naturally ventilated mode.

This list of low energy behaviours can be regarded as a list of 'actions to improve' as derived from the learning cycle offered by Soft Systems Methodology (Checkland and Poulter 2006).

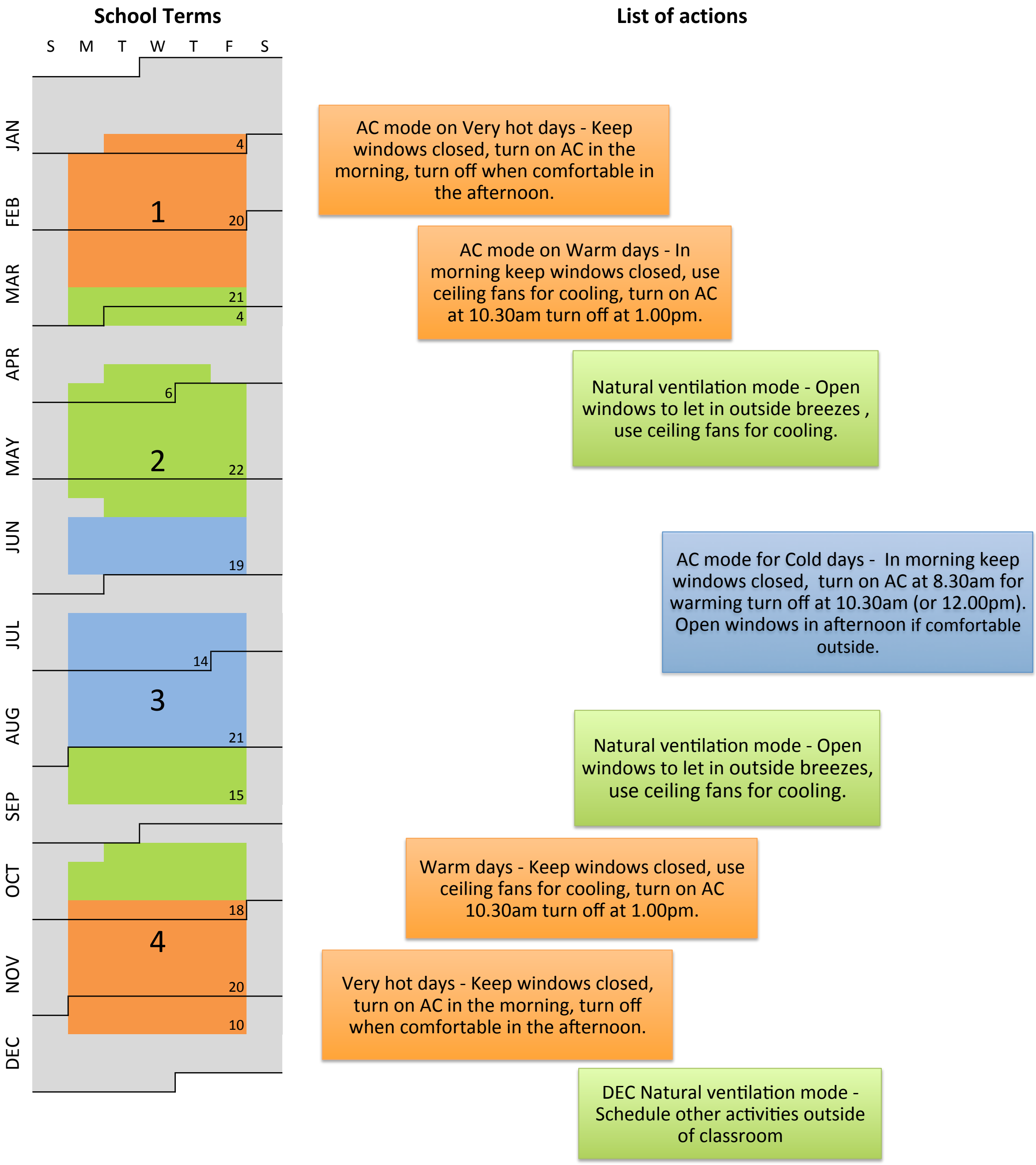


Figure 6.5 Low Energy Actions Appropriate for Each School Term

6.3 Findings from this Research

In this section findings of the research are discussed responding directly to the research questions. The next section discusses the implications of this research, primarily the transferability of these findings to other schools.

6.3.1 Findings Related to Research Question 1.

The first research question asks, "How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?"

The quantitative analysis of classroom temperature showed that classrooms were overheated in the afternoons of Term 1, 2015 for less time compared with before the interventions. Method 2, the diurnal graph method of the analysis, showed the reduction in duration of high temperatures. Repeated here are graphs from November 2012, prior to the interventions (Figure 6.6) and March 2015, after the interventions (Figure 6.7).

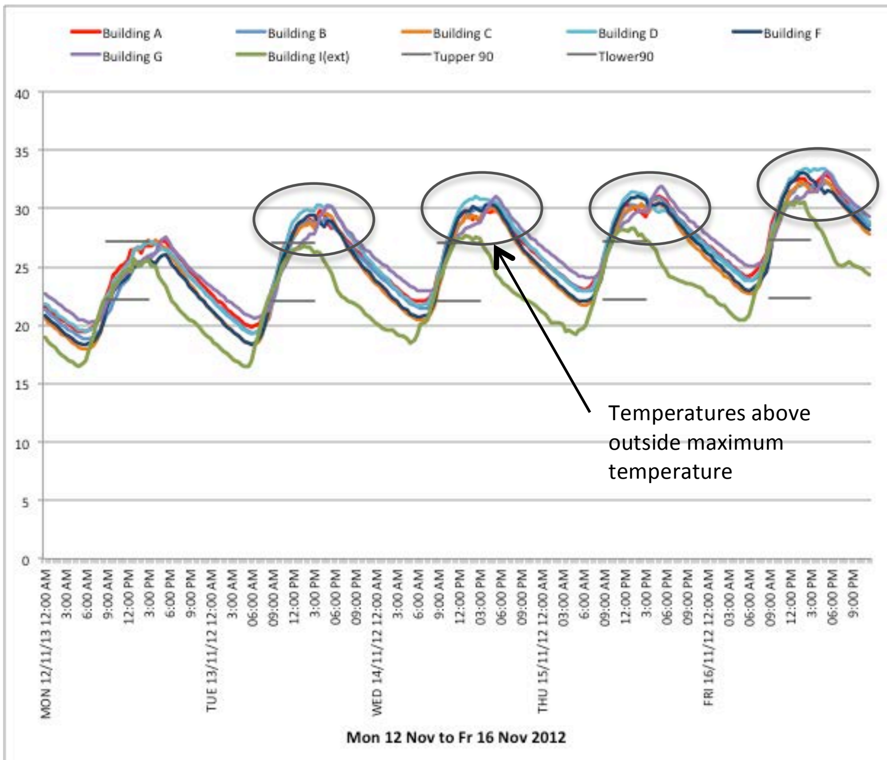


Figure 6.6 Diurnal Graph Before the Interventions

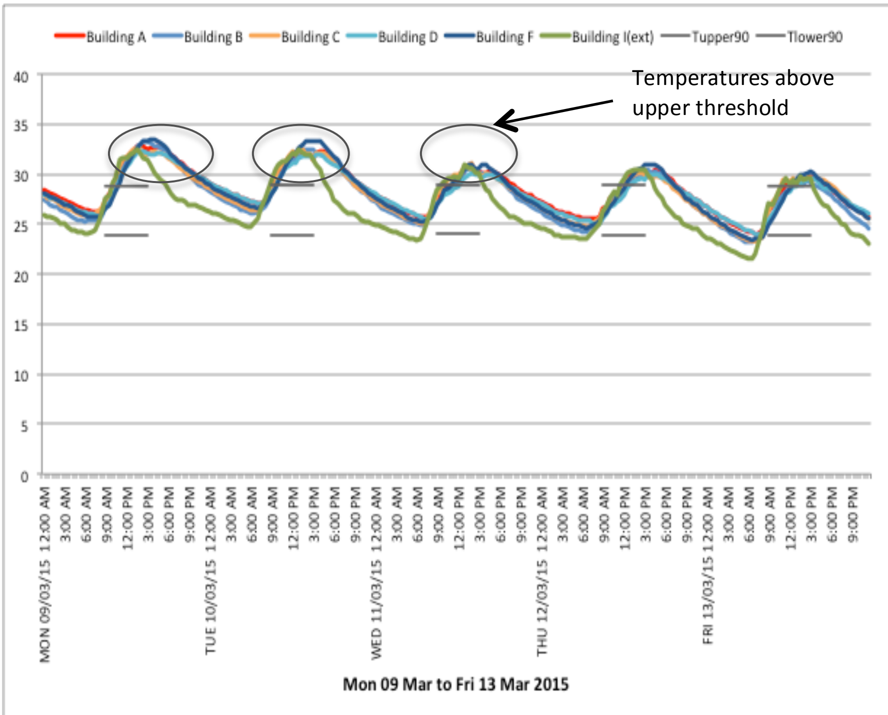


Figure 6.7 Diurnal Graph After the Interventions

In November 2012, the classroom temperature was warmer than the outside temperature by 3°C, for the entire afternoon. In March 2015, the classroom temperatures are much closer to the outside temperature, even lower during the school day for buildings D and C. The classrooms had fewer periods of over-heating in the afternoons in 2015, compared with 2012.

Classroom temperatures inside these buildings were influenced by outside temperature; when it was warm outside in the morning it was cooler inside, but not for very long, as can be seen in Figure 6.6. Inside buildings B and C the temperatures dropped overnight to be within 1-2°C of the outside minimum temperatures. During the day when doors and windows are opened for ventilation the cooler air is lost and the classrooms warmed up with outside air. Also, the low thermal resistance in the roof, walls and floor allowed heat to transfer from outside to inside. As a result classroom temperatures experienced a similar range of outside temperatures.

Classroom temperatures in the time period before any of the interventions November 2012 were compared to March 2015. The impact on classroom temperatures was observed as a reduced duration of time classrooms were overheated. Before the interventions the classrooms were all overheated for the entire afternoon. After, the duration was much less, varying from an hour to three. The most noticeable difference to temperature was in the classroom building that had three interventions; building D had implemented to it cool roof, stack ventilation and shade sails to the asphalt area to the north of the building.

As the aim of interventions was to reduce classroom temperature, knowing what the classroom temperature needed to be for occupants to be comfortable was investigated. The second research question explored the definition of acceptable comfort zone.

6.3.2 Findings Related to Research Question 2.

The second research question asks “What is perceived to be an acceptable comfort zone for classroom occupants?”

A mixed methods approach was required to answer the second research question. The quantitative analysis provided a measure of how warm the classrooms were in the summer months of the school year. The qualitative analysis provided the teacher’s perceptions of their level of discomfort from heat in the summer months. Classroom temperatures were not acceptable to the teachers during hot and humid times of the year, mostly in February but also for days in November, December, and March as observed in the quantitative temperature analysis and perceived by the teachers.

The question around the perception of classroom temperature compared with the temperature during the previous Term 1, received the response ‘same level of discomfort’ (refer Table 5.5). The temperature results showed a reduction of overheating in classroom temperature. The teacher felt hot at similar times as the year before, but not necessarily for as long as the duration of time previously.

During the interviews the comparison of naturally ventilated classrooms with air-conditioned classrooms was always present in discussions. With this in mind, it was difficult to have a conversation for how long a teacher felt hot in their naturally ventilated classroom during summer. These teachers desired the same conditions as their neighbouring teachers, air conditioned classrooms. Social and cultural factors were very influential regarding what teachers experienced as acceptable thermal comfort.

From Building B came positive responses that the interventions of stack ventilation and night flushing had made a difference. The teacher's recall of the previous term was that it was less hot than previous summers.

As classroom conditions are strongly linked to outside conditions, when the weather was hot and humid, these conditions were present in the classroom. In humid climates increasing ventilation is a key way to providing a cooling effect for occupants (Allard and Santamouris 1998). Yet in the school there were barriers to the use of windows and ceiling fans in classrooms, identified in the current adaptive actions. To use the adaptive action of turning on ceiling fans for cooling, it is important that they are not too high from the occupants, are not noisy at high speeds and have a range of adjustable speeds to suit the occupants.

The Adaptive Comfort Model provides a definition of comfort by suggesting that a comfortable temperature for 90% of the population is between temperature thresholds of $T_{upper90}$ and $T_{lower90}$ (ASHRAE 2013). In the summer months the value of $T_{upper90}$ averages 28°C to 29°C, shown as the horizontal lines on Figure 6.6, but the classroom temperatures were greater than $T_{upper90.}$ So, although classroom temperatures reduced in their duration of overheating, classrooms have not become cool enough to be within the defined comfort zone. However, some studies have shown that occupants can find temperatures outside the ASHRAE comfort zone to be acceptable. Daniel et al (2015) demonstrated that individuals living in houses in Darwin regarded temperatures above the comfort zone as acceptable due to environmental values influencing their occupation of their houses. Thermal comfort studies showed Japanese school children in naturally ventilated environments were satisfied with conditions well outside the ASHRAE comfort zone, although the children did prefer being cooler (Kwok and Chun 2003).

Previous thermal comfort studies of school children have suggested that an Adaptive Comfort Model for children needs to be different from that for adults (Teli et al

2012; de dear et al 2015). Most conditions for using the Adaptive Comfort Model are met in this case study school. However, there are two conditions that have not been met in this school. They are a) that the windows should be easy to operate and b) the metabolic level of the occupants should be sedentary. The interviews revealed that inoperable windows were barriers to teachers wanting to adjust the classroom environment to improve their comfort. Also in this school, teachers observed children to be very active on hot days, running around on the oval during their breaks, elevating their metabolic rate to 3.0-4.0 MET. Back in their classrooms they sat at their desks or on the floor, and time needed to pass before MET levels were lower and near a sedentary activity of 1.2. The MET level of some fidgeting children remained high. Warm children possibly need more effort to cool down than sedentary children or adults. So, although some adults may be able to find higher temperatures acceptable, children with high activity levels may prefer cooler classroom conditions than that defined by ASHRAE. In their study of school children in NSW schools, de Dear et al found children preferred an acceptable summertime temperature range of 19.5°C to 26.6°C, lower than that suggested by the Adaptive Comfort Model (de Dear et al 2015). The teachers in the case study school have observed why children may need cooler classrooms; that their metabolic rates are much higher due to higher activity levels This observation corresponds with the findings of the study of UK school children by Teli et al. where they found a number of factors need to be considered in providing thermally comfortable classrooms for children; that children have a higher metabolic rate per kilogram body weight, that they have limited adaptive opportunities in classrooms, such as opening windows themselves, that children do not always adapt their clothing, such as removing their jumper, and children spend a lot of time outdoors playing, unlike adult occupants in offices who are more sedentary and stay inside for most of the day (Teli et al. 2015).

It is evident from this case study that there are more factors to consider in defining thermal comfort than the physical and personal factors measured in the heat-balance model of thermal comfort. Conventional thermal comfort studies measure physical parameters of an indoor environment (ambient temperature, humidity, radiant temperature, wind velocity) and personal factors of occupants (clothing level, metabolic rate) together with levels of sensation and the preference of occupants in the building at a single point in time, or repeated over a period of time (de Dear et al. 2013). This study referred primarily to the adaptive thermal comfort model (Nicol, Humphreys and Roaf 2012) and recent thermal comfort studies in Australian schools (de Dear et al 2015) to shift the focus onto the social and cultural factors of thermal comfort.

Another form of evaluation of that includes assessing thermal comfort of occupants is the Post Occupancy Evaluations (POEs). POEs are used to assess the performance of new sustainable buildings to seek out how satisfied occupants are of the building environment in terms of thermal comfort, noise, lighting factors and overall. Such studies then inform other sustainable building design (Baird 2010). But POEs are limited in their capacity to understand subjective points of view of occupants. This study differs to POEs in that teachers were asked to retrospectively recall and describe their perceptions of classrooms, current adaptive behaviours of teachers were investigated together with an exploration of conserving energy practices. Through a questionnaire and interviews the social and cultural context of the teachers in the school in regards to cooling classrooms and maintaining thermal comfort was better understood. The subjective viewpoints of teachers were analysed using the framework offered by Soft Systems Methodology (Checkland and Poulter 2006).

6.3.3 Findings Related to Research Question 3.

The third research question asks "What adaptive actions do teachers currently practise to reduce discomfort from overheating in their classrooms?"

This case study provides an understanding of the social practices among teachers in regards to thermal comfort (Moloney and Strengers 2014) and the cultural context of the school. This study has identified the adaptive practices teachers in this school engage in, to reduce their discomfort from heat. A survey of adaptive actions was undertaken in the questionnaire including more specific questions about window and ceiling fans. As the teachers have responded to most of the fourteen adaptive actions listed in Table 5.6, it can be inferred that the teachers have tried most actions over time. Where classrooms had air-conditioning, this action was regarded as the most successful in reducing discomfort from heat. The teachers in naturally ventilated classrooms used open windows and ceiling fans to increase air movement, encouraging children to drink more water and occasionally left the classroom for a cooler location in the school. In the interviews the teachers discussed using a strategy of doing intensive teaching in the morning session, when it was cooler. However, as there were other classrooms with air-conditioning in the school, having to schedule intensive teaching in the morning was seen by the Principal and some other teachers as a limitation. Having some classrooms air-conditioned and others not was perceived as an inequitable work environment. This finding was important to the study, as any suite of energy saving behaviours recommended to the school would need to include the use of air-conditioners. (The decision to install air-conditioners to all classrooms occurred at the end of the research period in 2015).

To investigate possible ways of reducing the use of energy intensive air-conditioners, reasons why teachers conserved energy in the occupation of their classrooms was investigated in the study. Stoknes suggests that research on social groups to better understand their behaviours around energy use can help resolve the ‘disconnect’ between behaviour and belief (Stoknes 2014). The main reasons for why teachers want to reduce energy use are for a) the financial reason that spending less money on utilities provides more money to spend on teaching resources, b) environmental reasons for using fewer resources and c) demonstrating good social practices of low carbon behaviour. Teachers as role models in front of children demonstrating low carbon behaviours has been suggested by Bernardi and Kowaltoski as a way of increasing low carbon behaviours in society (2006). As a result of understanding the behaviours of teachers in naturally ventilated classrooms, this study has prepared recommendations to this group of teachers, the list of ‘actions to improve’.

6.4 Implications of this Study

Firstly, this study increases understanding of what passive cooling strategies can be retrofitted to existing, older, timber classroom buildings in schools in South East Queensland. The passive cooling strategies (cool roofs, stack ventilation, shade sails and gardens) were developed for the conditions in the case study school. They were then implemented, and observed, for their impact. As some of the physical conditions are present in other schools in South East Queensland, it is possible the passive cooling strategies used here are transferable to other schools. A current trend in schools is to install air conditioners in some classrooms, and results from this project may be useful for schools wanting to implement an adaptive approach to comfort, for particular times of the year.

Secondly, this study provided insight into the current adaptive actions of teachers during times of overheating in the classroom to reduce theirs and children's discomfort. Knowledge from this study could inform a suite of actions for schools that choose to occupy their classrooms in low carbon manner.

Thirdly, this study reflected on the methods used for evaluating the impacts of the passive cooling strategies: for the quantitative (temperature) analysis and for the qualitative (perceptions) analysis. The reflections on methods used are at the end of each of the results chapters and serve the purpose of improving the methods for future studies.

6.4.1 Transferability of Passive Cooling Strategies to Other Schools

This case study allows some generalizations to be made about the passive cooling strategies that could transfer to other similar school situations.

1) Cool roofs are generally applicable to other school buildings with unpainted or previously painted roofs. Roofs that are unpainted galvanised steel are good candidates for applying the cool roof coating, as the surface requires only cleaning compared to previously painted surfaces that may require stripping off of the previous coating. However, in application of the cool roof there needs to be awareness of the potential for glare. Particularly from classrooms that look down or across at a building with a cool roof. In this school, occupants of building A looked southwards, and down, at building D. Looking southwards at a roof is not as glary compared with looking northwards at a roof with the sun above it. Measures to reduce glare from adjacent buildings may need to accompany the

application of a cool roof. Tinting the windows, or having curtains or blinds at occupants' eye level can reduce indirect glare. Upper level windows in clear glass are recommended to allow daylight to reflect across the ceiling of a classroom. A room that is too much darker than outside can increase the contrast between the wall and the window, increasing the effect of glare. Direct glare through windows may need to be controlled using external adjustable louvre screens.

2) The cool roof was observed to have an effect on reducing classroom temperature when windows and doors were closed to the surrounding air. This has a useful implication for air-conditioned classrooms, as less heat in the ceiling space due to a cool roof means an air-conditioner will have less of a cooling load in order to provide the desired classroom temperature.
3) Stack ventilation is most applicable to buildings with unoccupied open space underneath them, as floor vents allow noise from underneath directly into the classroom. Shaded space beneath the floor, which is cooler than the outside air temperature, can assist in the reducing the temperature. The solar panel on the roof is at maximum power when in direct sunlight, and reduces to half power during overcast conditions. The best orientation for a solar panel may be to face the direction of the sun between 3.00pm and 6.00pm, so the solar panel continues powering the fan until sunset. When a classroom is using an air conditioner, the floor and ceiling vents need to be closed, to avoid leakage of cool air.
4) Night flushing is effective in reducing the night temperature of classrooms to close to that of the outside, dawn temperature. The roof fan switches to mains electricity after the solar panel stops supplying power. A thermostat can be set at a temperature that will switch it off in cooler months. During summer, set the thermostat at 20 degrees, or lower, to ensure it stays on all night.
5) Shade sails over asphalted areas reduce the surface temperature of asphalt. These areas become more useable by children during the day, as the shade sails protect their skin from ultraviolet radiation and. In the case study school children could sit on courtyard ground surface in the afternoons whereas previously the surface was too hot. However, shade sails placed too close to the northern side

of buildings can shade their interiors from the winter sun, a welcome source of radiant heat.

6) Schoolyard greening can possibly reduce the heat from surrounding asphalt areas to classroom buildings. Schoolyard greening improves the aesthetics of the school environment. It can also give children opportunities to learn about nature, and provide them with outdoor places adjacent to classroom buildings for reading groups or on-on-one teaching.

During the research project the trend for schools to have air conditioning installed to classrooms occurred at the case study school. Implementing passive cooling strategies on classroom buildings and their surrounds can reduce electricity use for air-conditioning in two ways:

1) The passive cooling strategies reduce the duration of overheating in classrooms during the afternoon in summer months and increased the period of time for milder times of the year, autumn and spring. The increased time periods of milder conditions enable occupants to occupy the classrooms for longer without the need for turning the air conditioner on. A range of adaptive actions could be practiced by teachers in these milder times of warm weather.
2) In times when air-conditioning is used, the passive cooling strategies have reduced the cooling load for the air-conditioner to maintain the desired comfort temperature in the classroom. The most effective interventions to assist in reducing cooling load are those that aimed to reduce heat entering the classrooms cool roof, shade sails and school yard greening (when well established). The stack ventilation strategy has elements of floor vents and ceiling vents that ideally need to be closed when a room is air conditioned to seal the room. Roof fans are effective on an air-conditioned building as they reduce heat load on the ceiling of the room by extracting hot attic space air out. In these buildings air intake is from the soffit or gable vents of the roof. (At the case study school Building H had air-conditioned classrooms and had roof fans sized for the attic space volume refer Appendix B).

6.4.2 Transferability of Adaptive Actions to Other Schools

The range of adaptive actions discussed in Chapter 5 could be transferable to other similar schools that have similar physical, social and cultural contexts to the case study school. An 'actions to improve' is discussed earlier in this chapter, section 6.2.2. There is the possibility that the adaptive actions discussed in Chapter 5, could be considered as alternative behaviours to using air-conditioning, especially if the desire to occupy classrooms in a low carbon manner is bolstered by the belief that a school should be a sustainable place. This possibility is discussed further in the next section.

6.5 Pathway towards low carbon occupation for SEQ schools

This study found that retrofitting passive cooling strategies to one school resulted in an impact on classroom temperature. The study also explored the current adaptive actions of teachers at the school. A question to emerge from this research is

4. How can schools in south-east Queensland improve their thermal comfort levels in existing classrooms using low-energy strategies?'

This study found that other factors significantly influenced teachers of the school to what is regarded as a comfortable temperature range. The equity issue of whether the teacher in the next classroom or the next school has air conditioning affected their consideration of thermal comfort. By interviewing the Principal and teachers in the school, it was found as important that teachers have the same controls available to them in each classroom, to maintain theirs and the children's thermal comfort. This means any further consideration of energy saving behaviours within the school would include the use of air conditioners as one of a suite of actions available to all teachers throughout the year.

Another way of viewing the idea of seeing teachers as a social group with the same actions available to all, is that if the group followed a belief that low carbon behaviour is important, then all would be acting together as a collective effort rather than relying on individual effort (Kania and Kramer 2011).

If a group of school teachers valued sustainable occupation of their classrooms highly, they may set limits to their air conditioning use and use more adaptive actions to occupy their classroom. Daniel et al (2014) showed that individuals in houses with high sustainability values accepted higher temperatures that the comfort zone. However, in a school environment the challenge to overcome is that individuals hold different levels of adherence to low energy behaviours and their acceptance of comfort (de Dear and Brager 1998). A principal would have a leading and coordinating role in this action. If it was left up to the individual there could be some teachers putting more effort into saving energy, but others not giving it a second thought and following a habit of cooling classrooms all day, every day in summer with air conditioning. Observing the latter behaviours could be discouraging to those teachers trying to conserve energy (Ockwell et al 2009).

For teachers trying to conserve energy, having a suite of low carbon behaviours to choose from to occupy the classroom comfortably in milder times of the year would support this aim. Leading by example teachers that practiced low carbon behaviours in the classroom would increase the opportunity for children to learn everyday practices of low energy use (Bernardi and Kowaltoski 2006).

This case study, set in South East Queensland, provides an understanding of current adaptive actions and times of the year when classroom temperatures are within an acceptable comfort zone. Being aware of when the weather conditions are within a comfortable range outside can assist in reducing air conditioner use. This awareness of times when air conditioning can be switched off can lead to more effective policies around air conditioner use, instead of the usual habit of not thinking about it and leaving it running every day. If low carbon occupation were to increase in schools the positive implications for schools are enormous, financially and environmentally.

If energy consumption increases in schools across Queensland due to overuse of air conditioning, electricity costs over time will increase the electricity costs paid by the Department of Education and Training and place pressure on the remainder of the state budget for schools. For this reason encouraging schools to reduce their energy use and spend less on electricity is in the interests of the Department of Education and Training. The Department could actively encourage schools to occupy their classrooms in low energy ways by providing information about passive cooling strategies that reduce classrooms from overheating (reducing the need for air conditioner use) and other adaptive actions that teachers can engage in during warm days. This case study provides such information.

This research has studied one case study school with passive cooling strategies developed for its existing timber buildings in the site context of asphalt covered surroundings. This case study has demonstrated that there are three important factors to understand for occupying existing buildings in a low energy manner whilst maintaining thermal comfort.

1) Understand climate. There are times of the year when outside conditions are comfortable enough to use natural ventilation and adaptive practices in the school. Then there are other times of the year that are uncomfortably hot and humid, when occupants will prefer to use air conditioning for cooling. In winter there are cool mornings when occupants use air-conditioning for heating.
2) Understand the thermal performance of the existing building and aim to improve it through retrofitting passive cooling strategies. A lightweight building with little or no insulation offers little resistance to hot or cool conditions outside. Heat loads can come from surrounding areas adjacent to the buildings, not just through solar gain through the roof or unshaded windows.
3) Understand the social and cultural factors in the school. A significant finding in this study was that an equity issue was created when some classrooms had air-conditioning and others did not have it. Teachers strongly believed that teachers in all classrooms should have the same control over their environment.

6.6 Conclusion

This chapter started with converging results of the preceding chapters, the temperature and perception analysis. Results from temperature observations of 2014 were presented in a side-by-side display with teacher's comments of their recalled perceptions of the classroom during the year. Times when classroom temperatures of Buildings A B C and D were inside or outside the adaptive comfort zone for each month were aligned with comments from Terms 1 to 4. From this understanding a list of 'actions to improve' to occupy the classrooms in a low carbon manner was presented. Then, findings of the study were discussed in relation to the three research questions. In discussing the implications of this research and the transferability of the findings to other schools, a fourth research question emerged 'How can schools in south-east Queensland improve their thermal comfort levels in existing classrooms using low-energy strategies?' This study informs a pathway for low carbon occupation of schools in South East Queensland. Future research directions are suggested in the Conclusion chapter.

Chapter 7 Conclusion

This case study research project aimed to tackle the wicked problem of how to maintain thermal comfort in an existing school building type and lessen building emissions to reduce impact on climate change (Roaf, Nicol and de Dear 2013). A common solution to providing comfort to occupants who experience overheating in existing classrooms in south East Queensland is to install energy intensive air conditioning. The case study is of a school with four interventions implemented to a group of six classroom buildings and their immediate surrounds. The interventions were based on passive cooling design strategies and aimed to reduce the heat load to classrooms and the occurrence of overheating experienced by occupants during warmer months. The classroom building type studied was the Sectional School, built in Queensland schools between 1920 and 1950, was constructed mostly from timber with metal sheet roofs, and elevated from the ground surrounded by asphalt covered surfaces. The type is prevalent in schools of South East Queensland.

The study aimed to firstly evaluate the impact on classroom temperature of retrofitted passive cooling strategies of stack ventilation, cool roof, shade sails over courtyards, and schoolyard greening. Secondly the study aimed to understand the current range of adaptive actions that teachers currently practice to reduce discomfort form overheating in classrooms. Of interest was that the potential findings of the study are transferable to other schools, increasing knowledge of low energy occupation of existing classrooms.

This study addressed the need to retrofit existing building stock to reduce carbon emissions (Swan and Brown 2013). Swan and Brown suggested approaching the problem of retrofitting existing buildings by framing it as socio-technical in nature (2013). However studies that investigate adaptive behaviours of occupants in existing buildings together with low energy retrofits are rare (Chiu et al. 2014).

The literature review linked relevant fields of research and positioned the study in the field of adaptive comfort research. The literature review informed the research questions, research design and methods. The methodology for this research was single case study using a mixed method approach to collecting and analysing data (Creswell and Plano Clark 2011). This study combined quantitative temperature analysis with qualitative perception analysis to firstly evaluate the impact of interventions on classroom temperature. This study had three research questions:

1. How do passive cooling strategies retrofitted to existing classroom buildings and their immediate surrounds impact upon classroom temperature?

2. What is perceived to be an acceptable comfort zone for classroom occupants?

3. What adaptive actions do teachers currently practice to reduce discomfort from overheating in their classrooms?

It was found that after the interventions classroom temperatures reduced in their duration of overheating, especially in the afternoon. However classrooms had not become cool enough to be within the defined comfort zone. Secondly the current adaptive practices of teachers in the school to reduce discomfort from heat were articulated. The qualitative phase of the study revealed insights about the problematic situation not evident at the beginning of the research project. A significant finding was that air-conditioning to some classrooms and not others was seen as an equity issue. In addition the study obtained an enhanced understanding of retrofitted, passive cooling strategies and transferability to other schools.

A fourth research question that has emerged from this study is

4. How can schools in southeast Queensland improve their thermal comfort levels in existing classrooms using low-energy strategies?

A pathway towards low carbon occupation for southeast Queensland schools could be formed combining a number of key elements. Firstly, schools can be improved by implementing retrofits to buildings and surrounds to reduce heat load based on passive cooling principles. Secondly, the occupation of the classrooms can be improved by increasing adaptive actions that teachers can engage in during more comfortable times of the year and day in South East Queensland climate. Finally the belief that a school should be a sustainable place needs to be linked to the way occupants occupy their classrooms. Teachers could demonstrate everyday practices of occupying classrooms in low carbon manner, including the use of electrical appliances in an energy efficient manner especially the most energy intensive of these, air conditioners.

Finally, this single case study could inspire further research into other schools. Future research directions should:

1) Use the findings from this research to encourage the case study school to support its teachers in maintaining thermal comfort using low energy strategies in their classrooms (Checkland and Poulter 2006). Another learning cycle at this school could begin and this project could transform into action research (Sankaran, Tay and Orr 2009; Checkland and Poulter 2006; Flood 2010).
2) Conduct further case studies in Brisbane schools that have different building types to learn more about cooling a range of school buildings using low energy strategies. Investigate how heat load to classrooms can be reduced by retrofitting passive cooling strategies to other buildings and surrounds, together with a range of low energy practices, developed from this case study.
3) Investigate Brisbane schools that have a renewable energy source and monitor their energy use. Encourage schools to become sustainable, and assist them to further create a situation beyond being carbon neutral, where they generate more energy than they use. Explore the idea of a *regenerative* school using retrofitting (Hes and Pleussis 2015; Mang and Reed 2012).
4) Further investigate the impact of schoolyard greening in south east Queensland schools by observing the impact of cooling on classrooms, exploring opportunities for learning in outdoor places and increasing children's well being and connection with nature.

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Appendix A – Classroom Comfort Project Drawings

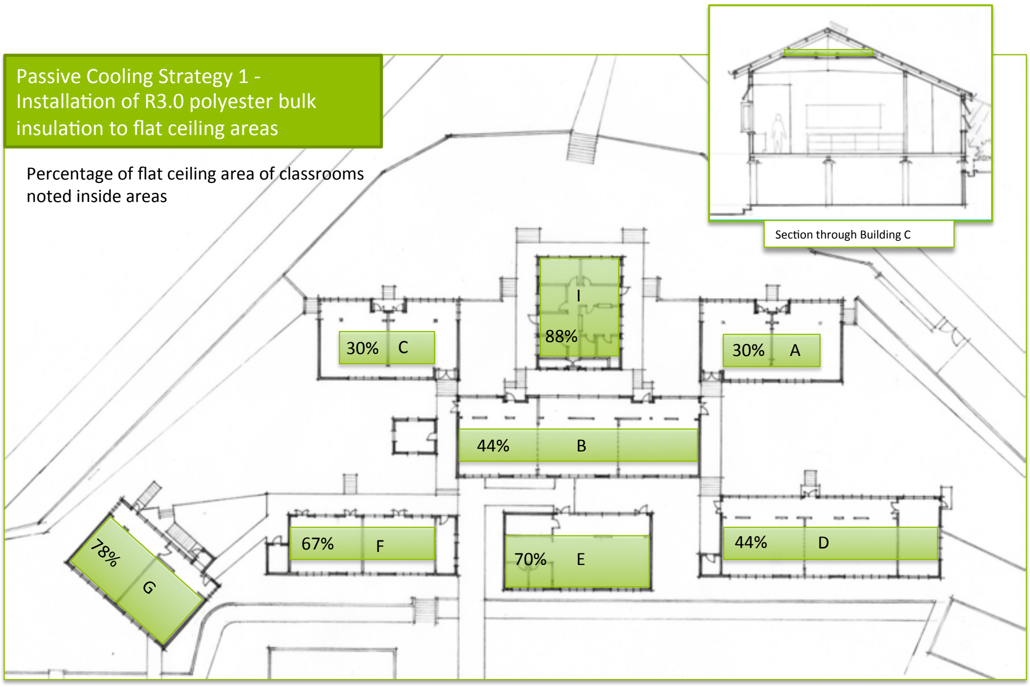

Figure A.1 Classroom Insulated Ceiling Areas (Presentation to School March 25, 2013)

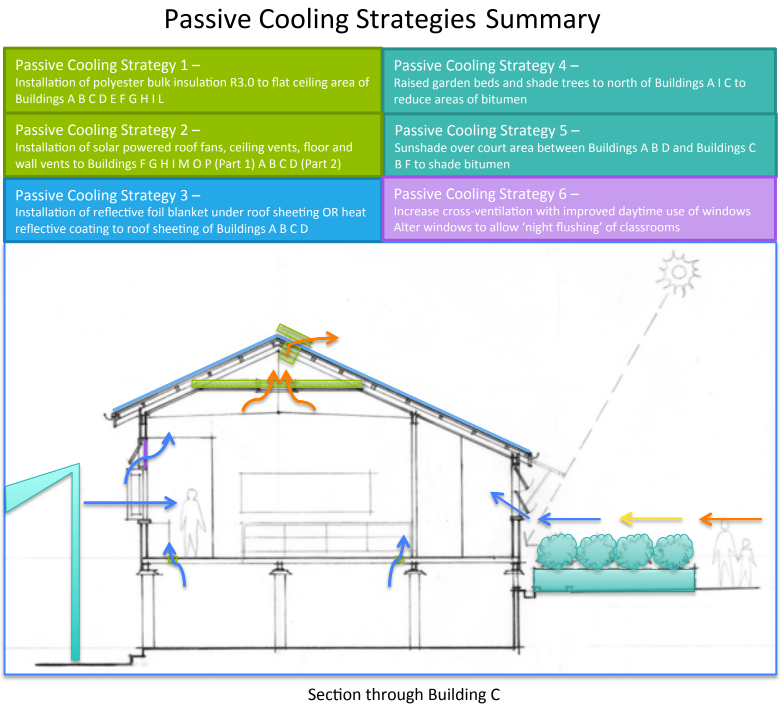

Figure A.2 Summary of Building Section with Passive Cooling Strategies (25 March 2013)

Appendix B - Summary of Passive Cooling Strategy Costs

Table B.1 Passive Cooling Strategy Costs

STRATEGY	DESCRIPTION	COST	BUILDINGS THAT BENEFIT	DATE	Comments on Intervention	FUNDING SOURCE
Strategy 1 **Ceiling Insulation**	Supply & install bulk Insulation (Tontine Polyester R3.0) to flat ceiling areas	$16,270.00	A (30% of ceiling area), B (44%), B4 (100%), C (30%), D (44%), E (70 %), G (78%), H (77%), I (88%), L (100%)	Jan/Feb 2012	EQ site approval not required (no change to building) which sped up quotation/delivery process. Installed by *Outback Insulation*.	P&C Building Maintenance budget 2011/2012
Strategy 2 **Stack Ventilation Part 1**	Roof Fans, Ceiling Vents, Floor vents	$18,579.00	F G H I L M O P	Dec 2012 – Jan 2013	Documentation and quotes June/Sept 2012 EQ site approval Oct 2012 *Bright N Cool* took six days to do this work over Dec/Jan holidays.	P&C funds of 2011 (Fete year)
Strategy 2 **Stack Ventilation Part 2**	Roof Fans, Ceiling Vents, Floor & Wall vents	$19,600.00 $890.00	A B C D	Dec 2013 – Jan 2014	Documentation Feb/Mar 2013 DETE Site Approval 01/11/13 Fans powder-coating to match roof colour. Thermostat and 'night packs' to fans of Building B extra cost	P&C funds of 2011 (Fete year)
Strategy 3 **Cool Roof**	Cool Roof coating to Buildings A D	$13,300.00 $704.00	A D	Oct 2013	Holland Park included in trial as naturally ventilated buildings Windows of Building A tinted to reduce glare from roof of D	DETE funded Cool Roof Trial administered by SmartGrid HPSS P&C funded tinting
Strategy 4 **Schoolyard greening (Increase Vegetation)**	Install garden beds and shade trees to reduce heat from asphalt, north of buildings A, C, I	$51,500.00 Free $2250.00 Donated Free	A C I	Jul - Aug 2014 14-16 Oct 22-23 Nov 3-4 Aug 2015 23-30 Oct 2015	Major works over 3 weeks by landscape contractor *Oasis* Year Ones Arbor Day Planting 2014 P&C Working Bee P&C working bee Year Ones, Preps & Year Six Arbor Day planting 2015	Through DET, National Solar Schools Program for 2013/2014 BCC supplied 162 free plants P&C funded $2000 plants Parents $250 fruit trees & donated plants Donated pavers BCC supplied 80 free plants
Strategy 5 **Shade Sails over courts**	Five Shade sails to East and West courts at ends of Building B	$44,000.00	A B D - East court C B F - West court	Jul - Aug 2014	Posts installed over 4 days Shade sails 2 weeks later in 5 hours. By *Advanced Shade Systems*	GCBF Grant received in July 2013 of $35,000.00 P&C funded remainder of $9,000.00
TOTAL		**$167,093.00**				

Appendix C - Roof Fan Calculation Table

Table C.1 Table of Roof Fan Calculations

BUILDING	ROOM NAME	AREA m^2	HEIGHT m	VOL m^3	ATTIC VOLUME m^3	TOTAL VOLUME m^3	FANS	ACH[1]	COMMENTS
A	A1	70	2.4 - 4.1[3]	212	11	223	1 [2]	13.5	Rooms are separated by concertina door
	A2	68	2.4 - 4.1	204	11	215	1	14.0	
C	C1	68	2.4 - 4.1	204	11	215	1	14.0	Wall between rooms open at one end
	C2	71	2.4 - 4.1	212	11	223	1	13.5	
B	B1	82	2.4 - 3.0	206	-	258	1	11.6	These fans are ducted and on thermostat for night flushing
	B2	81	2.4 - 3.0	206	-	258	1	11.6	
	B3	82	2.4 - 3.0	206	-	258	1	11.6	
	Attic	156	1.2	-	187	774	2	6.2	When ceiling vents open includes classroom volume
					187	-		32[4]	When ceiling vents closed
D	D1	42	2.05 - 3.36	150	10	160	1	18.8	Photocopy room
	D2	95	2.4 - 4.1	341	21	362	3	13.0	Rooms are separated by concertina door which is kept open most of the time.
	D3	86	2.4 - 4.1	308	19	327			
F	F1	55	3.4 - 4.1	214	17	231	1	13.0	
	F2	60	3.4 - 4.1	214	17	231	1	13.0	
	F3	16	2.1 - 3.4	48		48	1 small fan	29	Teacher aide room
G	G1	72	2.4 - 3.3	227	42		2	11.1	
	G2	69	2.4 - 3.3	220	42			11.5	
	Attic only				84			29.0	When ceiling vents closed
H	H1	52	2.6 - 3.0	153	51	204	2	4.5	This building had existing AC units to each classroom. Roof fans aimed to assist in keeping attic space cooler.
	H2	63	2.6 - 3.0	183	51	234			
	H3	63	2.6 - 3.0	183	51	234			
	H4	63	2.6 - 3.0	183	51	234			
	H5	63	2.6 - 3.0	183	51	234			
	Attic	256	0.7	-		1320			When ceiling vents open includes classroom volume
					179	-		33.5	When ceiling vents closed. Building has another room to classrooms.
I	Admin offices	118	2.7	354	152	506	1	5.9	When ceiling vents open
	Attic only				152	-		19.7	When ceiling vents closed
P	P1	80	2.7	215	135	391	2	7.7	When ceiling vents open
	Staff	11	2.7	29					
	P2	80	2.7	215	135	391		7.7	When ceiling vents open
	Kitchen	11	2.7	29					
	Attic space and kitchen				299	-		20	Ceiling vents closed
O	O1	179	2.4 - 2.7	470	64	534	1	5.6	
	Attic only				86			34	Ceiling vents closed. Building has other rooms to classroom.
M	M1	63	2.6	165	15	180	1	8.3	
	M2	63	2.6	165	15	180			
	Attic only				30	-		100	Ceiling vents closed

Notes:

1. ACH stands for Air Changes per Hour
2. Fan type is Solarwhiz 3000 which has maximum air change capacity of 3000L per hour. This will be reduced to half when there is cloud cover.
3. Ceiling height varies when there are sections of raking ceiling and flat. Building sections have been referred to for calculating volumes.
4. Calculation is given for when ceiling vents are closed to consider air change rate of the attic space. This is when classrooms are in air conditioning mode.

Appendix D - Front Garden Drawings

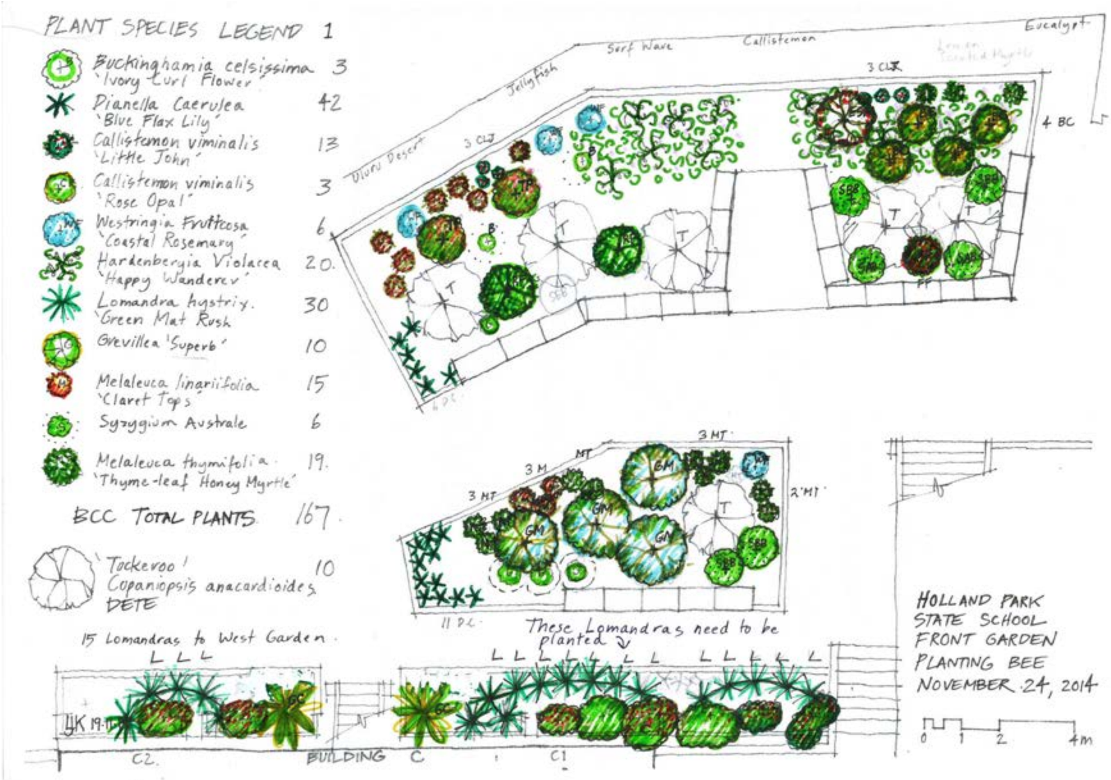

Figure D.1 Planting Scheme for the Western Side of the Front Garden

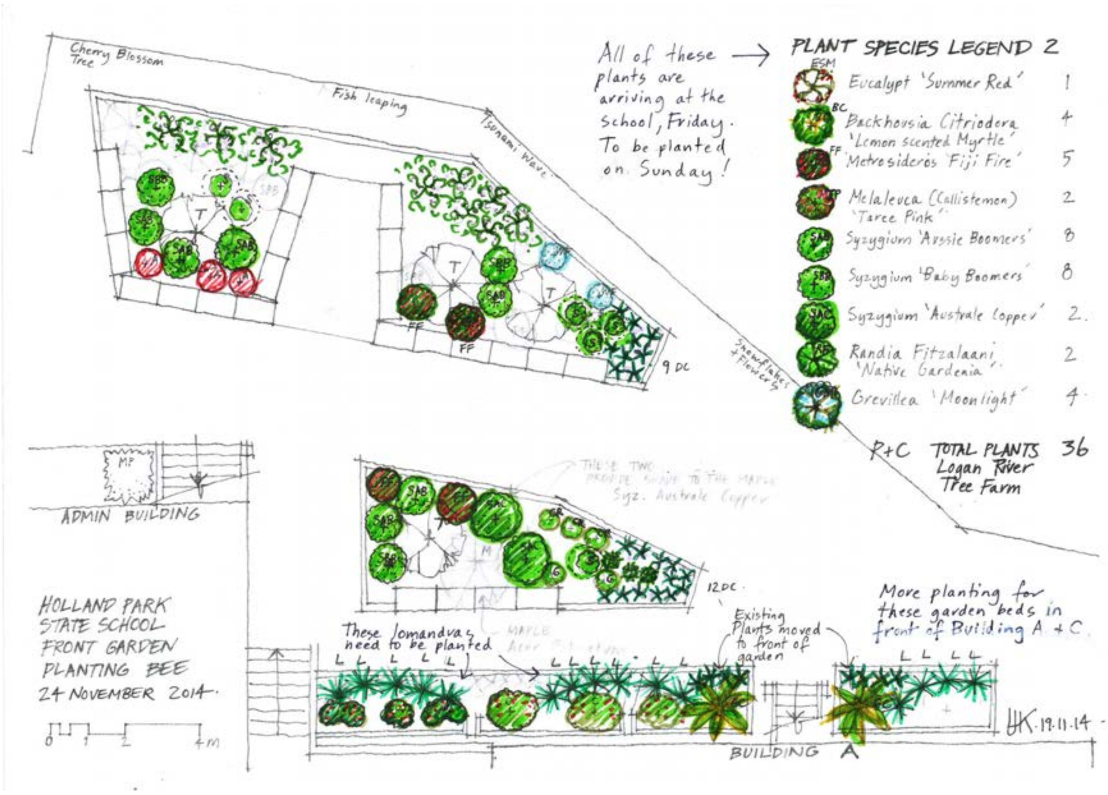

Figure D.2 Planting Scheme for the Eastern Side of the Front Garden

Appendix E - Participant Information Sheet for Interviews

Ms Lisa Kuiri
BDesSt, BArch
Registered Architect
MPhil Candidate
School of Architecture

CRICOS PROVIDER NUMBER 00025B

Participant Information Sheet – Interviews

Project Title:	Retrofitting of passive cooling strategies to timber classroom buildings and their surrounds in a typical South East Queensland school.
Project Investigator:	Ms Lisa Kuiri, MPhil Candidate, The University of Queensland
Supervisors:	Dr Chris Landorf, Senior Lecturer, The University of Queensland
	Dr Wendy Miller, Senior Research Fellow, Queensland University of Technology
Version:	Updated 11 June 2015

What is the purpose of the project?

This project investigates the effect of retrofitting passive cooling strategies to a group of timber classroom buildings and their surrounds in Holland Park State School. These buildings are the oldest in the school and are typical among other Queensland schools. Since January 2013 four strategies have been implemented to the buildings and their immediate surrounds with the aim to reduce heat entering the classroom.

The two main sources of data for this investigation are *temperatures* recorded by data loggers inside classrooms and *perceptions* of Teachers who occupy the classrooms. The effect on classroom temperature is investigated by comparing time periods before and after implementations. The effect perceived by Teachers will be investigated by two methods: an anonymous voluntary online *Questionnaire* and *Interviews* with particular Teachers and the Principal.

A fifth strategy considered in this project is to improve the range of actions taken by occupants to reduce feeling discomfort from heat. This project regards the Teacher as the main occupant that controls the classroom environment, to make adjustments to the room, to open windows or switch on fans. Hence this project seeks to understand current behaviours of Teachers in their classrooms across the school in warmer times of the year. In both the Questionnaire and Interviews the questions draw out the range of actions teachers engage in when experiencing discomfort from heat inside the classroom. In addition, energy saving behaviours in the classroom and school environment will be explored.

Who is being invited to participate in interviews and why?

I am seeking the participation of Teachers that currently occupy the classrooms that have had passive cooling strategies implemented to them. Of particular interest are Teachers that have been in the same classroom for the past three consecutive years. These Teachers are in a unique position to comment on the current condition of the classroom after strategies were implemented and reflect back on previous summers. Also, what these Teachers do to reduce feeling discomfort from heat for themselves and children in the classrooms of typical timber Queensland school buildings is of value to this research.

I am seeking the participation of the School Principal to discuss any effect of the implementations in the social and cultural context of the school; any current strategies of dealing with heat in school grounds and within classrooms; the importance of energy conservation in the school.

What choice do you have about participating and withdrawing?

Participating in an Interview is entirely voluntary. Your decision will not disadvantage you in any way or affect your Employee-Employer relationship with the Principal. Only those who give their informed consent will be included in the project. If you do decide to participate, you can withdraw from the project without giving a

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reason within 3 weeks of the return of the edited interviews for review. Any data collected from you will not be used in the project.

What will you be asked to do?

If you agree to participate, you will be asked to take part in an audio-recorded 30-minute semi-structured interview facilitated by the Project Investigator at your workplace and at a time to suit you. The core interview questions are attached. You will subsequently be given the opportunity to:

- review the transcribed recording of the interview and to edit and/or approve your contribution, and
- approve the subsequent use of any data arising from the interview

What are the risks and benefits associated with the project?

There are no perceived risks attached to participating in the project research beyond those of normal every-day living. There are no direct benefits from your participation: your comments will increase understanding of what it is like to occupy the classrooms in warmer times of the year.

How will your privacy be protected?

Hardcopy material (interview consent forms and notes taken in the interview) will be stored in a locked cabinet and electronic material (audio recordings) on a password-protected computer in the Project Investigator's workplace at UQ. In transcribing the Interview each Teacher's name will be replaced with number e.g. T1. Interview participants will be given opportunity to review the transcription and edit and/or approve their contribution, or withdraw from the process. Hardcopy material and back-up electronic data will be kept for 5 years in a locked filing cabinet after research project is completed. After this time the data will be destroyed.

Another data collection method includes taking notes and photographs of classroom environment occupied by Teachers being interviewed. Prior to taking photographs I will ask the Teacher if it is ok to do so. Photographs will not include the Teacher or children occupying the classroom. Care will be taken to not include identifiable items in the photographs such as class name, names or photographs of Teacher or children. The Teacher will be given the option to view photographs that could be used in the research.

How will the collected information be used?

The Interviews will be used for this research project. In addition, it is intended some aggregated information from Interviews will appear in a presentation back to the participants. Data may also be used in subsequent presentations and publications about the research project. There is potential for this research project to inform future sustainability initiatives or support from DET to reduce energy consumption in schools.

Complaints about the project

This study adheres to the Guidelines of the ethical review process of The University of Queensland (Project Number 20150601). Whilst you are free to discuss your participation in this study with the Investigator (contactable on 0437 772 636), if you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Coordinator on 07 3365 3924.

What do you need to do to participate?

Please read this Participant Information Sheet. Be sure you understand the contents before you make your final decision about participating. If there is anything you do not understand, or if you have any questions, please ask the Project Investigator using the details included at in this document. If you would like to participate, please read and sign the Consent Form and we will commence with the Interview.

Thank you for considering this invitation to participate in the research project.

Lisa Kuiri

Lisa Kuiri
Project Investigator

Appendix F - Question Schedules for Interviews

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Ms Lisa Kuiri
BDesSt, BArch
Registered Architect
MPhil Candidate
School of Architecture

CRICOS PROVIDER NUMBER 00025B

Question Schedule – Interview with Principal

Project Title:	Retrofitting of passive cooling strategies to timber classroom buildings and their surrounds in a typical South East Queensland school.
Project Investigator:	Ms Lisa Kuiri, MPhil Candidate, The University of Queensland
Supervisors:	Dr Chris Landorf, Senior Lecturer, The University of Queensland
	Dr Wendy Miller, Senior Research Fellow, Queensland University of Technology
Version:	Updated 28 May 2015

1) **Passive Cooling Strategies** – Tell me about any perceived impact the implementation of passive cooling strategies have had on the school, not only in the physical sense but social and cultural sense?
2) **Feedback from teachers** – Has there been any feedback from teachers about any changes they may have detected in classrooms of buildings with strategies implemented?
3) **Range of actions to reduce heat experienced by teachers and children** – As Principal how do you facilitate the range of actions that teachers engage in to reduce discomfort from heat in classrooms?
4) **Current strategies for dealing with heat** – Does the school have any strategies for dealing with heat in the school?
5) **Flexibility of teachers to move classes within school** – What extent of flexibility do teachers have to move their class to cooler parts of the school?
6) **Energy Conservation in classrooms** – Is it important for the school to reduce electricity use and if so, why and how?
7) **Link between classroom and sustainability in the curriculum –** Are there any opportunities to link aspects of sustainability already in the curriculum to the physical classroom environment or behaviours of occupants of classrooms? What about in external areas of the school or the wider school environment?
8) **Other** – Is there anything else you'd like to tell me about in relation to reducing heat in classrooms?

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CRICOS PROVIDER NUMBER 00025B

Question Schedule – Teacher Interviews

Project Title:	Retrofitting of passive cooling strategies to timber classroom buildings and their surrounds in a typical South East Queensland school.
Project Investigator:	Ms Lisa Kuiri, MPhil Candidate, The University of Queensland
Supervisors:	Dr Chris Landorf, Senior Lecturer, The University of Queensland
	Dr Wendy Miller, Senior Research Fellow, Queensland University of Technology
Version:	Updated 28 May 2015

1) **Passive Cooling Strategies** – Tell me about any perceived impact the passive cooling strategies have had on your classroom?
2) **Perception of heat in classroom** –Would you say the classroom temperature has improved (been less hot), stayed the same, or become warmer than before the implementations?
3) **Use of windows, doors and ceiling fans** - How do you use the windows, doors and ceiling fans in this classroom?
    a) During this last summer term, Term 1 2015?
    b) Are using these successful in providing a cooling effect?
    c) Do you find these effective in hot and humid weather?
    d) Are there any barriers to the use of these items?
4) **Other actions to reduce heat in classroom** –
    a) What actions do you engage in to reduce discomfort on hot days?
    b) Which actions are most successful?
5) **Effects of heat on children** – What effects do you notice on children on hot days?
6) **Energy conservation in classrooms** – Would you say you try to conserve electricity use in the classroom?
7) **Extension of classroom to outside** –
    a) Does your class use the Front Garden, if so how?
    b) Do you use the Courtyards more now that they are shaded?
8) **Other** – Is there anything else you'd like to tell me about in relation to reducing heat in the classroom?

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Appendix G – Questions in Questionnaire and Interviews

TEACHER QUESTIONNAIRE	TEACHER INTERVIEW	PRINCIPAL INTERVIEW
Evaluation of passive cooling strategies		
Q2 Which of the following best describes the construction of your classroom building? Q3 How long have you occupied this classroom? Q4 Which of the following have been installed to your classroom building and/or an outside space next to your classroom?	1) **Passive cooling strategies** Tell me about any perceived impact the passive cooling strategies have had on your classroom?	1) **Passive cooling strategies** Tell me about any perceived impact the passive cooling strategies have had on the school, not only in the physical sense but social and cultural sense?'
Q5 Over Term 1, how many **days** did it feel uncomfortably hot inside your classroom? Q6 Over Term 1, on days when it felt uncomfortably hot inside the classroom, what **time of day** did you feel most discomfort? Q7 In Term 1 there have been some days when the max temp >32°C (5, 19, 20 March). Can you recall what it was like in your classroom during those days? Q8 Compare Term 1 to last year's Term 1 2014. Was your classroom Q8 Compare Term1 to two years ago… Q10 Compare Term1 to three years ago…	2) **Perception of heat in classroom** Would you say the classroom temperature has improved (been less hot), stayed the same, or become warmer than before the strategies? 5) **Effects of heat on children** What effects do you notice on children on hot days?	2) **Feedback from teachers** Has there been any feedback from teachers about any changes they may have detected in classrooms with strategies implemented?
Exploration of current adaptive actions in the school		
Q11 Over summer terms do you engage in any of these actions? If you do please rate how successful the action is?	4) **Other actions to reduce heat in classroom?** a) What actions do you engage in to reduce discomfort on hot days? b) Which actions are most successful? 7) **Extension of classroom to outside** a) Does your class use the front garden, if so how? b) Do you use the Courtyards more now that they are shaded?	3) **Range of actions to reduce heat experienced by teachers and children** As Principal how do you facilitate the range of actions that teachers engage in to reduce disomfort from heat? 4) **Current strategies for dealing with heat** Does the school have any strategies for dealing with heat in the school? 5) **Flexibility of teachers to move classes within the school** What extent of flexibility do teachers have to move their class to cooler parts of the school?
Q12 Over Term 1 which of the following best describes your **use of windows**? Q13 Over Term 1, how often did you perceive breezethrough your classroom? Q14 Over Term 1, do you know which direction the best breezes came from? Q16 Over Term 1, which side of classroom did you open windows and doors at the same time for ventilation? Q17 Generally over the year, do you open windows or doors for another reason than ventilation? Q18 Generally, are there any windows you don't open because of a fault? Q19 Generally, are there any windows you don't open because of furniture or other physical barriers? Q20 Generally, do you close windows or not open them because of these uncomfortable outside factors? Q15 Over Term 1 which of the following best describes your **use of ceiling fans**? Q21 Generally, do you not use fans because of any of these reasons? Q22 Is your classroom air-conditioned?	3) **Use of windows doors, and ceiling fans in this classroom?** a) During last summer Term 1 b) Are using these successful in providing a cooling effect? c) Do you find these effective in hot and humid weather? d) Are there any barriers to the use of these items?	
Exploration of energy conservation practices		
Q29 Do you try to conserve energy use in the classroom? Q30 If you try to conserve energy use, could you give the reasons **why**? Q31 If you try to conserve energy use, could you describe your **practices**?	6) **Energy conservation in classroom** Would you say you try to conserve electricity use in the classroom?	6) **Energy conservation in classrooms.** Is it important for the school to reduce electricity use and if so, why and how?
Q32 Do you know about any aspects in the curriculum for sustainability, that could be practiced in the classroom or wider school environment?		7) **Link between classroom and sustainability in the curriculum** Are there opportunities to link aspects of sustainbility in the curriculum to the classroom environment or occupant behaviours? What about in external areas of the school?
Q33 What is your age? Q34 What is your gender? Q35 What is the age range of children in your class?		
Emergent themes		
Q36 Are there comments you would like to add about anything in this questionnaire?	8) **Other** Anything else you'd like to tell me about in relation to reducing heat in the classroom?	8) **Other** Is there anything else you'd like to tell me about in relation to reducing heat in classrooms?

Appendix H – Reponses from Questionnaire and Interviews

	TEACHER QUESTIONNAIRE	TEACHER INTERVIEW	PRINCIPAL INTERVIEW
	Evaluation of passive cooling strategies		
Q2	Unreliable responses	1) **Passive cooling strategies**	1) **Passive cooling strategies**
		D - Noise from floor vents	In favour of PC strategies approach however some AC needed in school
Q4	1) Insulation on ceiling 5-Y 3-N 10-DN	D - Shade sails reduce winter sun	
	2) Roof fans 0-Y 12-N 6-DN unnoticed	A D - doesn't help the humidity	School buildings design not best for PC
	4) Floor vents 4-Y 10-N 4-DN unnoticed	A - glare from open South window	
	5) Cool Roof 2-Y 10-N 6-DN unnoticed	B - not on very hot days but between seasons (Sept) ok	
	6) Shade sails 3-Y 15-N 0-DN visible		Can effective learning be increased across school if more rooms AC?
	7) Front garden 7-Y 11-N 0-DN visible	D - no comparison to AC rooms	
Q5	7/11 teachers in NV classrooms felt hot more than half the term 3/11 felt hot most days	2) **Perception of heat**	2) **Feedback from teachers**
		C- Start and the end of the year is hot	Degrees of acceptance by staff
		A - When it's hot outside it's still hot	A - felt cold in winter needs heaters in 2016
Q6	T1 7/12 teachers felt hot in afternoon and 3/12 felt hot all day	D - Really hot in Jan Feb when setting up class. Dec hot but class has down time	
Q7	7/12 teachers felt unberably hot +32°C March days	B - Hot in Term 1 but not as hot as 2 years ago. Has	
Q8	T1 2015 to 2014 5/12 same discomfort	5) **Effects of heat on children**	
Q8	T1 2015 to 2013 3/12 same discomfort	T5 T4 T7 T3 said lethargy, irritability.	AP said lethargy and irritability
Q10	T1 2015 to 2012 2/12 same discomfort	T4 Use morning for effective learning	
		D - Nowhere for kids to relax in non AC room, sweaty	
		B - Good teachers good learning even when hot	
		T4 T2 T1 T7 Kids don't regulate themselves in hot weather	
		T7 Absent child due to hot days	
	Exploration of current adaptive actions in the school		
Q11	13) Turn on AC in morning 4/8 AS(5)	4) **Other actions to reduce heat in classroom?**	3) **Range of actions to reduce heat experienced by**
	2) Increase air movement with fans 5/13		Teachers have autonomy how they run their class
	1) Increase air movement with windows 5/13	7) **Extension of classroom to outside**	4) **Current strategies for dealing with heat**
	6) spray children with water mist 5/11	A B D - Leaving class has limitations need stuff	Windows are kept open, children drink enough water, class kept in coolest place possible.
	8) childrenspread apart 7/11	D B retreat to AC staff room	
	9) children to sit under fan or near windows 6/10	A C use garden for T-aide and child, reading groups	Hot days play reduced to 20m children stay under buildings don't go on ovals
	11) change learning activitiy 5/11	F took class under tree twice week for Geography	
	12) Leave classroom move to cooler location 6/11		Wet play children and teachers stay indoors or under buildings
Q12	8/10 teachers open same windows in the morning and close when leave	3) **Use of windows doors, and ceiling fans in this classroom?**	
Q13	7/10 perceive breezes in classroom	T6 T7 in humid weather windows open doesn't make a difference	
Q14	5/10 say breezes come from South		
Q16	5/10 open opposite windows, 2/10 adjacent sides, 1/10 three sides, 2/10 one side (no cross ventilation)	T1 T2 use fans all the time	
		T1 T2 open windows in winter for fresh air	
Q17	9/10 only open windows for ventilation	T6 replace awning windows with louvres could let more air in	
Q18	5/9 don't open windows because of fault	T7 awning windows too stiff to open	
Q19	7/10 no barriers to opening windows		
Q20	5/9 say outside noise causes them to close windows	T6 T7 fans only in centre of classroom	
Q15	6/10 turn fans on in morning and turn off when leave	T7 bigger fans are too noisy and distract ASD child	
Q21	6/10 don't use fans because too noisy		
Q22	4/11 AC classrooms 7/11 not AC		
	Exploration of energy conservation practices		
Q29	9/11 teachers try to conserve energyuse in the classroom	6) **Energy conservation in classroom**	6) **Energy conservation in classrooms.**
		2/7 teachers turn lights off when in classroom	Electricity is a utility cost within an alllocated budget. No savings back to school if from reduced electricity use
Q30	**Energy conserving reasons**		
	2/9 economic, 3/9 environmental, 3/9 good social practice		
Q31	**Energy conserving practices**		
	3/9 teachers turn off lights and 1 or 2 other elec appliances when not in use	T7 T3 T4 limit on AC use ideas: temp setting, really hot days only, morning use only, outside air temp 25°C turn off, central switch turn all off, solar powered only	Conscious thinking required to change a habit. 'Easy way out' often first choice behaviour.
	2/9 teachers turn off lights when not in room 2/9 when in room		
	1 - used skylights not elec lights		
	1- turn off lights, fans, AC, IWB and monitor screens when out of room and not using, open window as allternative AC and fans, decrease paper use.		
Q32	3/11 teachers know aspects in the curriculum for sustainablity that could be practiced in the classroom	Question not asked in interviews.	7) **Link between classroom and sustainability in the curriculum**
	1 - leave lights off, separate rubbish		Season changes, Tree life cycles, experiments of how plants grow in different locations (dark/light, no water), how humans adjust to hot and cold environments
	1 - Y4 geography: Reuse, recycling, reduce. Y4 life and living: Worms and compost		
	1- Y4 science: save planet earth		
	Emergent themes		
Q36	7/7 teachers mention AC for classrooms	8) **Other**	8) **Other**
	4/7 teachers consider AC to some classrooms and not others equity issue	Equity issue - some classrooms in the school are AC and some are not	Equity issue - some classrooms in the school are AC and some are not
	2 teachers who had move from NV to AC classrooms said children work better all day	social norm- role of teacher compared to other professional roles their workplaces are AC	Culture is that everyone should have same benefits
		social norm - children live in AC houses, travel in AC cars, NV classroom is different	To move teachers each year to have time in AC classrooms not desirable as year level classes kept together
		social norm - all new workplaces are built with AC	
		social norm - clothing choices are limited when working in hot classrooms	social norm - men abandon neck ties in NV office but can wear in AC

Appendix I – An SSM View of the Interventions

Soft Systems Methodology provides a framework for viewing an intervention of a system as a purposeful activity. Analysis 1 is the analysis of the intervention (Checkland and Poulter 2006). Firstly a root definition of the purposeful activity is done through considering the elements of the activity (Figures K.1 and K.2). Then a purposeful activity model of the interventions implementation process at the school is shown in Figure K.3.

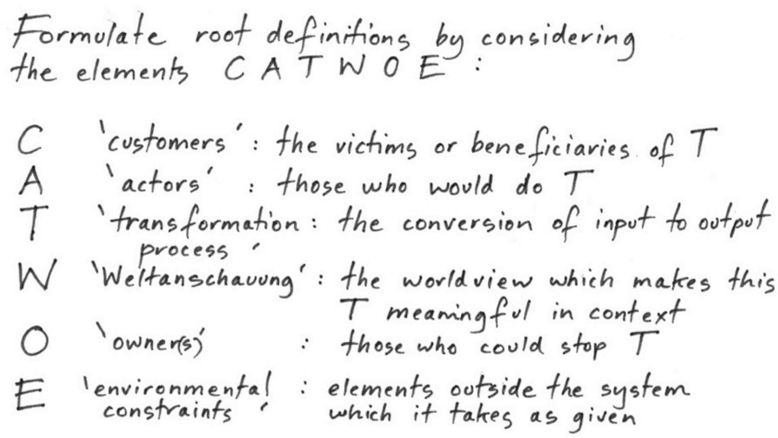


Figure I.1 The CATWOE Tool for Defining Elements of the Purposeful Activity

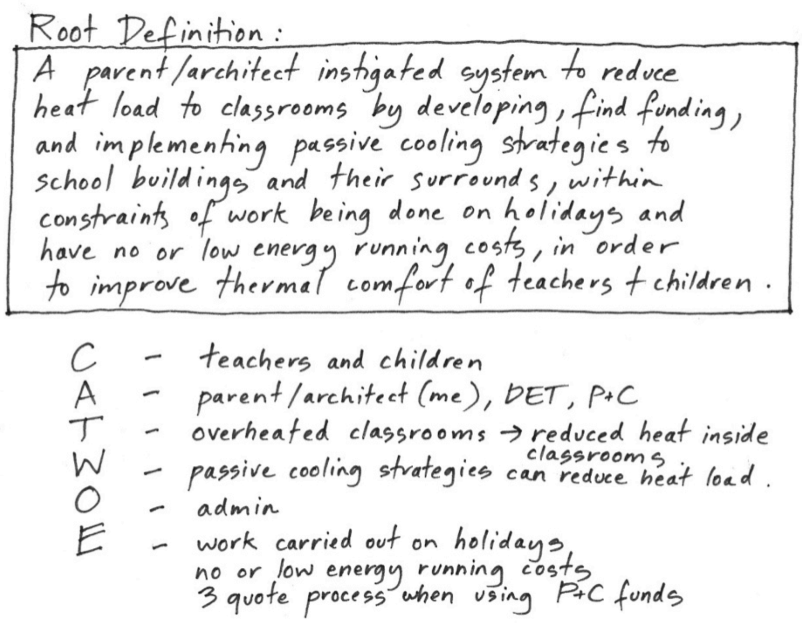


Figure I.2 Root Definition of the Intervention's Implementation Process

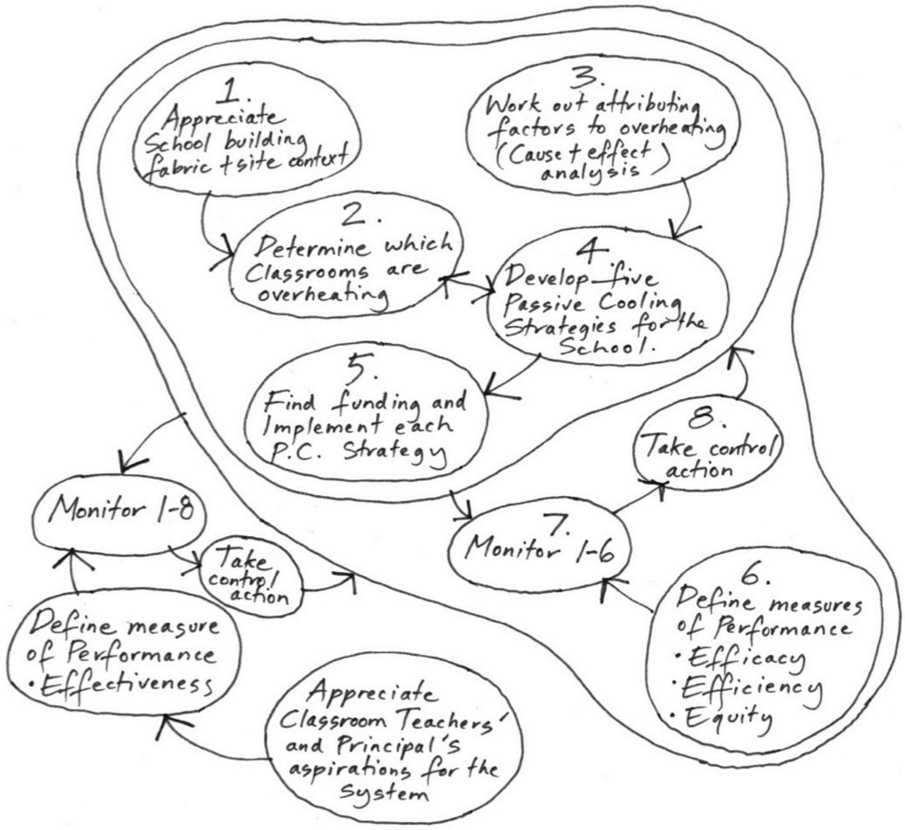
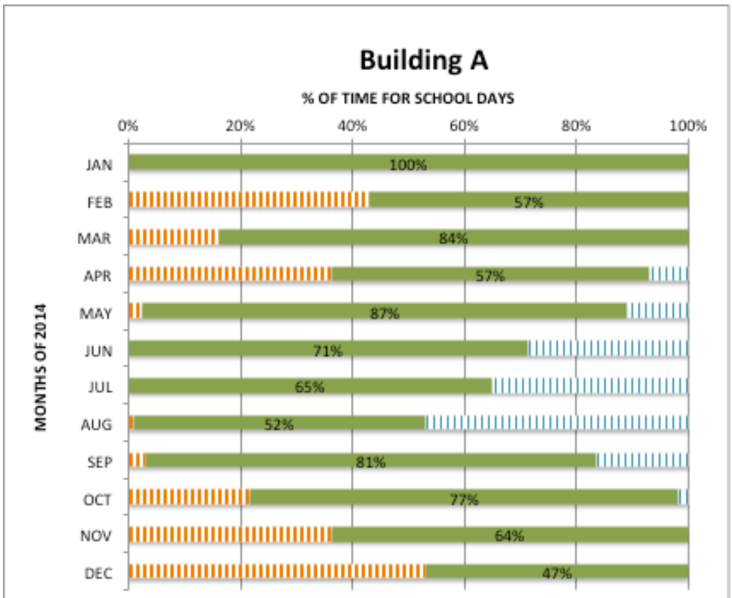


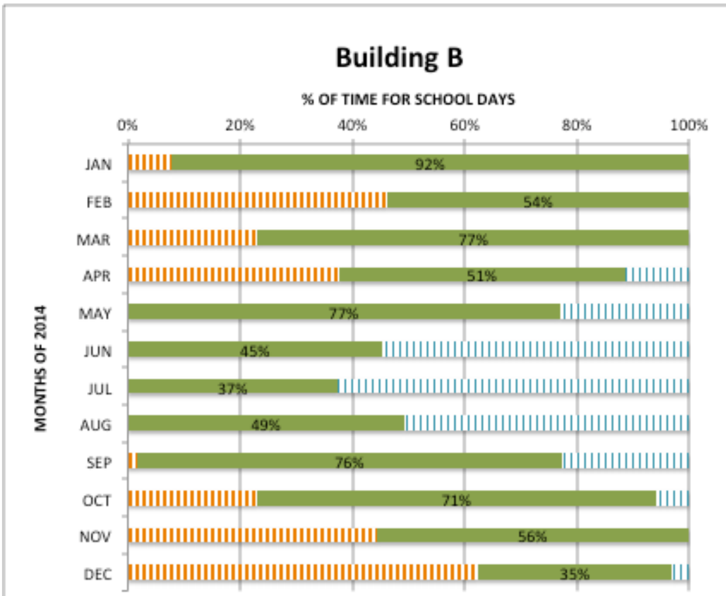
Figure I.3 Interventions Implementation as a Purposeful Activity Model

Appendix J - $T_{upper80}$ and $T_{lower80}$ Charts for Buildings A B C & D During 2014



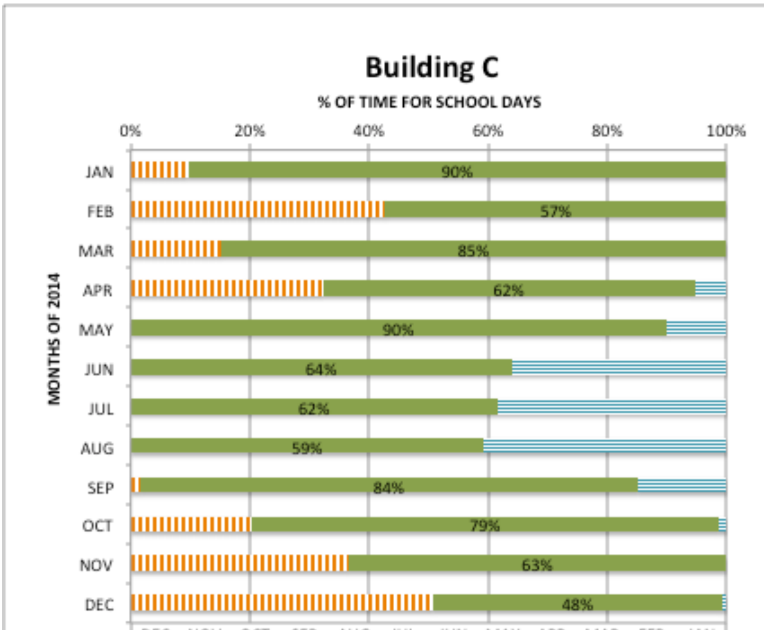
	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN
>Tupper80	53%	36%	22%	3%	1%	0%	0%	2%	36%	16%	43%	0%
Comfort	47%	64%	77%	81%	52%	65%	71%	87%	57%	84%	57%	100%
<Tlower80	0%	0%	2%	16%	47%	35%	29%	11%	7%	0%	0%	0%

Figure J.1 Building A Percentage of Time of Comfort within T80 Thresholds



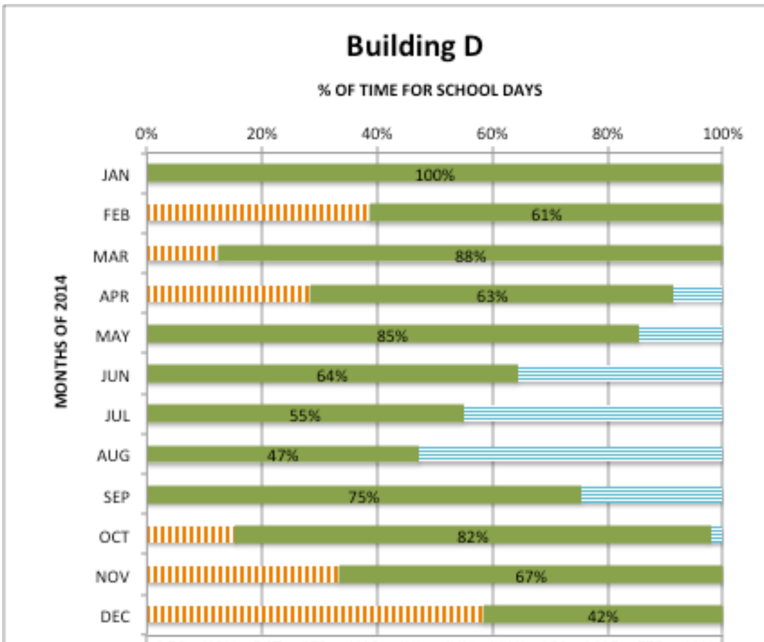
	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN
>Tupper80	62%	44%	23%	2%	0%	0%	0%	0%	38%	23%	46%	8%
Comfort	35%	56%	71%	76%	49%	37%	45%	77%	51%	77%	54%	92%
<Tlower80	3%	0%	6%	23%	51%	63%	55%	23%	12%	0%	0%	0%

Figure J.2 Building B Percentage of Time of Comfort within T80 Thresholds



	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN
>Tupper80	51%	37%	20%	2%	0%	0%	0%	0%	32%	15%	43%	10%
Comfort	48%	63%	79%	84%	59%	62%	64%	90%	62%	85%	57%	90%
<Tlower80	1%	0%	1%	15%	41%	38%	36%	10%	5%	0%	0%	0%

Figure J.3 Building C Percentage of Time of Comfort within T80 Thresholds



	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN
>Tupper80	58%	33%	15%	0%	0%	0%	0%	0%	28%	12%	39%	0%
Comfort	42%	67%	82%	75%	47%	55%	64%	85%	63%	88%	61%	100%
<Tlower80	0%	0%	2%	25%	53%	45%	36%	15%	8%	0%	0%	0%

Figure J.4 Building D Percentage of Time of Comfort within T80 Thresholds