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The physical and social aspects of retrofitting passive cooling strategies to timber school buildings and their surrounds in South East Queensland

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Abstract: Overheating is a problem in existing timber classroom buildings in South East Queensland. In a case study school passive cooling strategies were retrofitted to six classroom buildings and their immediate surrounds between 2012 to 2014: *stack ventilation*, *cool roof*, *shade sails* over courtyards and *schoolyard greening*. This research project investigates how effective the strategies are in reducing heat inside the classroom by analysing quantitative data (classroom temperature) and qualitative data (perceptions of Teachers and Principal). This paper reports how the research project began and the results of applying an overheating analysis metric to the classroom temperature across summer terms, with inconclusive results. Uncontrolled variables such as climatic factors and building use are discussed. Another strategy being investigated is the range of *adaptive actions* Teachers engage in to reduce thermal discomfort from heat. The Teacher is regarded as the main occupant with control of the classroom environment. Understanding the current range of adaptive actions teachers engage in, especially in naturally ventilated classrooms, could provide an understanding of low energy *social practices* in the school. This research aims to synthesize quantitative data with qualitative data to assess the effectiveness of the passive cooling strategies and create informed recommendations to increase adaptive actions within classrooms towards a low-carbon occupation of existing classrooms.

Keywords: Overheated classrooms; passive cooling; thermal discomfort; adaptive actions.

1. Introduction

Overheating is a problem in existing timber classroom buildings in South East Queensland (SEQ). Over a sunny week in November 2012 in a case study school in Brisbane, classrooms in six buildings were observed to be 3°C warmer than the maximum daily temperature for the entire afternoon. A common twentieth century solution to achieving thermal comfort for overheated houses, offices or schools in Australia, is by installing air-conditioning (Roaf et al 2010). Currently in Queensland, schools in the north and west of the State are air-conditioned in accordance with the Department of Education and Training's (DET) policy. For schools in SEQ (defined here as the area from Noosa in the north to the New

South Wales border in the south and west to Toowoomba) the decision to install air-conditioners is at the School Principal's discretion and funded by the school budget and/or funds raised by the school's Parents and Citizens Association (P&C). In the case study school, the school community decided *not* to install air-conditioning to the school, preferring to first fund other strategies to reduce heat to classrooms. The older timber buildings in the school are a good example of the *Sectional School* type, the dominant type built in Queensland between 1920 and 1950 (Burmester, Pullar, Kennedy 1996). The author is an architect experienced with designing buildings for the sub-tropics and tropics and developed a number of passive cooling strategies for the school in consultation with the P&C and the School Principal.

The author recognised a unique research opportunity in the school as a case study. The research project describes the design and implementation of passive cooling strategies in the school and considers the social and organizational context within which this has taken place. All strategies needed to be of low capital cost, have little or no running costs, suitable for retrofitting into timber buildings and cause minimal disruption to normal operations within the school. Fitting within these criteria the strategies, if effective, have potential to be rolled out to similar schools.

DET is interested in the research as it could contribute to reducing energy use in schools. An increasing amount of air-conditioners installed in schools in recent years have had an adverse impact on the overall state government budget for schools. Up until recently this school had all naturally ventilated classrooms, in 2010 and 2014 there have been air-conditioners installed to some classrooms. As the Principal has commented, there is increasing pressure from some teachers that their classrooms should be like other workplaces; all air-conditioned. Also some parents, as represented by the Queensland P&C Association, consider that the state government should fund 'basic infrastructure' such as air conditioning for classrooms in state schools (ABC 2014). This social context increases the complexity of the problem of finding other ways to reduce heat in classrooms than using air-conditioners, considered in the wider global need to transition to a low-carbon society (Shove et al 2008)(Swan and Brown 2013).

Between 2012 and 2014, four passive cooling strategies were developed and implemented to the case study school: *Stack Ventilation*; *Cool Roof*; *Shade Sails* over courtyards and *Schoolyard Greening* (or increasing vegetation to surrounds). Another strategy being investigated is the role of occupants in *adapting* their classroom environment to reduce heat perceived by them (Nicol *et al* 2012). The research takes the viewpoint that the teacher is the main occupant with control over the classroom environment. Previous thermal comfort studies that have investigated adaptive actions of school children resulted in low participation by the children to adjust their environment to suit their comfort; this was attributed to either having restricted spontaneous movement in the classroom to due to discipline codes (Bernardi 2006) or teachers' preferences (De Guili *et al* 2012). Understanding the current range of actions that teachers engage in to reduce their thermal discomfort, especially in naturally ventilated classrooms, could lead to a better understanding of *social practices* in the school (Moloney and Strengers 2014). This research project aims to synthesize classroom temperature (quantitative data) with perceptions of occupants (qualitative data) to assess the effectiveness of the passive cooling strategies, to inform recommendations that increase adaptive opportunities and behaviours within classrooms, and reduce the use of air-conditioning (Kim et al 2013) (de Dear et al 2014).

2. The case study school

2.1. Brisbane location and climate

The case study school is located 6km from Brisbane City in a suburban environment. Brisbane (Latitude 27.4° S Longitude 153.1°E) has a subtropical climate with warm humid summers and mild dry winters (*Cfa* under Köppen climate classification). Maximum and minimum temperatures logged at the school on outside logger I(ext) are plotted in Figure 1. Extreme weather events that occur in Brisbane are tropical thunderstorms and heat waves. Occupants regard summer thermal discomfort as a greater concern than winter coolness, which can be adapted to with extra layers of clothing.

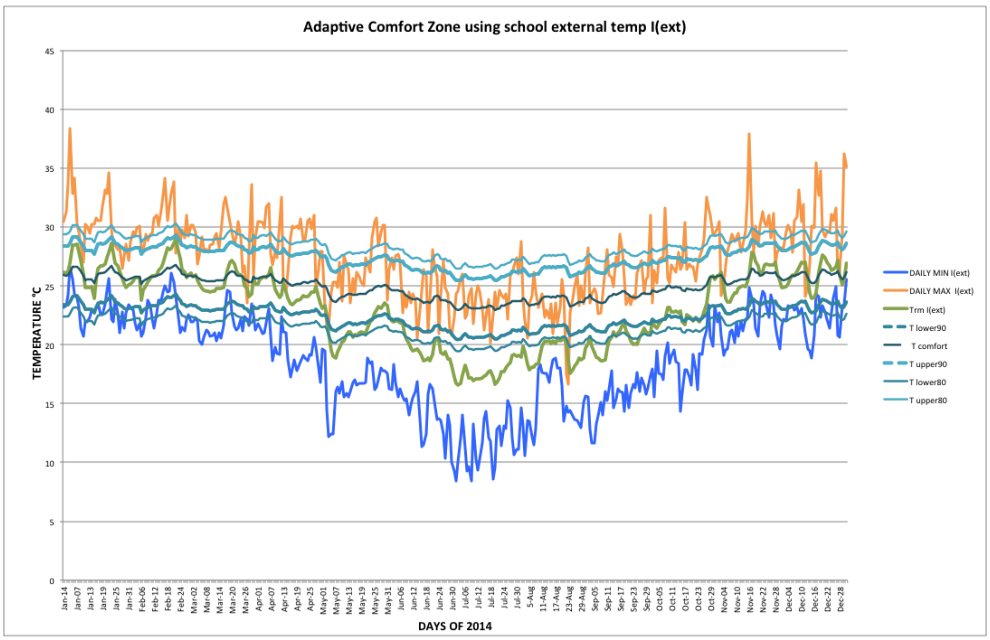

Figure 1: Adaptive comfort zone, daily max and min outdoor temps at the school 2014.

2.2. Description of school occupancy

The school is a state primary school (Prep to Year 6) with a population of 850 children in 34 classes. Classrooms of the case study buildings are occupied by 37% of the children at the school. These classrooms were anecdotally reported as being the warmest in the school and measured to be 3°C warmer than outside over a sunny week in November. During 2014 Building R, Admin and Staff Buildings I and E had air-conditioners installed. Building H had air-conditioners installed to upper classrooms in 2010 due to construction noise and dust of Building R requiring closed windows (Figure 2)

The Queensland school year has four terms, ten weeks each. Summer terms are Term 1 (late Jan to early Apr) and Term 4 (mid-Oct to mid-Dec). In 2014 there were 197 days, Monday to Friday starting 5 minutes before 9.00am to 3.00pm. During the day children move in and out of their classroom to outside, for two breaks and to attend specialist subjects in other locations in the school.

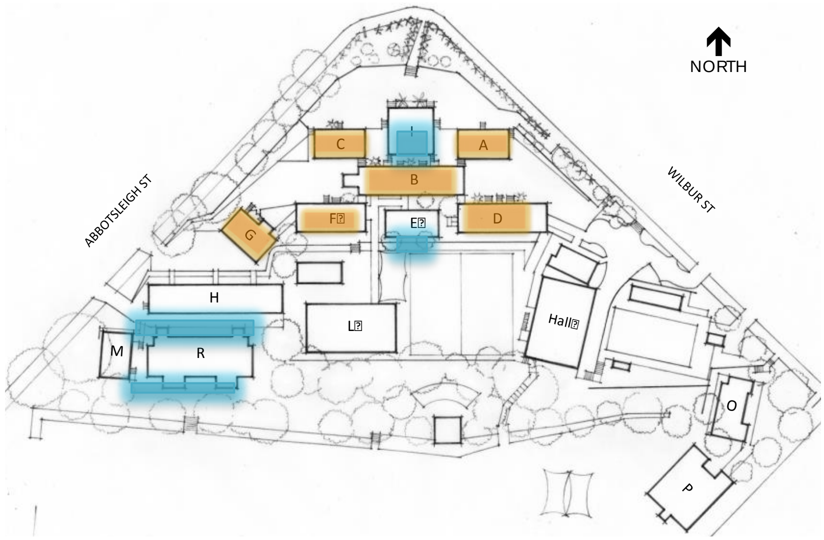

Figure 2: Case study buildings and air-conditioned buildings in the school (Author, 2015).

2.3. Sectional school type

The older timber buildings in the school are a good example of the *Sectional School* type, the dominant classroom type built in Queensland between 1920 and 1950. The first building (B) was built in 1929 and subsequent buildings added over the next decade (A, C, D, F) in a radial layout connected by verandahs. In a 1996 conservation study of Queensland Schools out of 2000 schools, only under fifty of them had brick buildings (Burmester, Pullar, Kennedy 1996). Among the 1327 state schools currently open in Queensland there are 754 schools established from 1871 to 1950 (DETE 2013). Between 1920 and 1950 the 160 Sectional Schools were established. Classroom buildings up to 1960 were all typically constructed of timber elevated off the ground with space underneath. Orientation of the Sectional School building type is optimal for the sub-tropics with long sides facing north and south with large windows for natural light and cross-ventilation. Building F remains the only intact example of the type with an open north verandah. In the mid 90's the other buildings A B C D had their verandahs enclosed to increase classroom size; awning windows were installed and the roof overhang reduced.

These older timber buildings form part of the school's identity and are likely to remain in use for years to come. They are of local cultural significance and are on the Brisbane City Council's Heritage Register (BCC 2012). Addressing this volume of existing building stock within schools is an important inclusion in the transition to a low carbon society (Swan and Browne 2013).

2.4. Attributing factors to heat

The author identified a number of attributing factors that could be the root causes of overheated classrooms before developing cooling strategies. The first of these is the building envelope. Little or no insulation in the roofs, walls or floors offer little resistance to the transfer of heat into the interior. These buildings are constructed of materials similar to the Queenslander vernacular: corrugated iron roof sheeting, hardwood timber frame, timber weatherboard wall cladding, timber tongue and groove floor boards and ceilings, elevated on posts above the ground. In January 2012 bulk insulation was installed to accessible flat ceiling areas of classrooms. Raked ceiling areas remained un-insulated.

A second factor is that spaces between and surrounding these lightweight timber buildings have ground surfaces covered with 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 of an Urban Heat Island (UHI); Inner city urban environments are warmer than the surrounding rural areas (Akbari *et al* 2010). The field of UHI mitigation research has provided three passive cooling strategies: heat reflective roof paint *Cool Roof* (Santamouris 2012); shading the asphalt by installing *Shade Sails* and decreasing asphalt areas of the school by *Schoolyard Greening* (Block et al 2013). These strategies aim to reduce heat outside before it passes through the building envelope, open windows and doors to the classroom.

A third attributing factor is direct solar gain passing through glass of north, east and west windows. Buildings A, B, C and D have inadequate roof overhangs (300mm width) to shade north facing windows from sun. West facing windows of Buildings A, C, D are exposed to low-angle hot afternoon sun. Building G differs in orientation to the other buildings and has large southwest facing window. As a strategy, shading windows was not considered by the P&C as the preference was for strategies that could be applied across the largest number of classrooms such as roof fans, or be shared between buildings such as shade sails. Costs to install window shading elements to a few buildings was regarded as relatively high and in the realm of the DET to fund.

The next attributing factors observed relate to the low amount of cross ventilation in classrooms. Increasing cross ventilation is an important way for occupants to feel cooler. 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 the amount of breezes to classrooms; Building I blocks southeast and northeast breezes to Building B. 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, if opened enough to do so. Some windows are not opened at all due to handles broken or out of reach. Improving the use of windows is being considered in this research. Prior to developing an *adaptive actions* strategy a thorough understanding of how windows are currently used and other adaptive actions is being sought through the qualitative data collection stage. 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 inside. In a house an occupant can ‘flush out’ warm air by opening windows in the late afternoon and night.

3. Passive cooling strategies

3.1. Implemented strategies

In order of implementation the strategies are *Stack Ventilation (Part 1), Cool Roof Strategy*, *Stack Ventilation (Part 2), Shade Sail Strategy* and *Schoolyard Greening* (Figure 3). Timing of strategy implementations was ad-hoc as funding became available from various sources.

- Stack ventilation strategy. Installation of solar-powered roof fans, ceiling vents and floor/wall vents to encourage stack ventilation. Hot air in the attic space exhausted by a roof fan creates a current that draws warm classroom ceiling air through ceiling vents. Floor vents let cooler air from underneath the building into classrooms. Part 1 implemented to Buildings F I G Jan 2013. Part 2 implemented to Buildings A B C D Jan 2014. Funded by P&C.

- Cool roof strategy. Application of heat reflective paint 'Cool roof' coating to two buildings. The bright white coating reflects the full spectrum of solar radiation, visible and thermal ranges, reducing the transfer of heat through the roof (total solar reflectance value of 98%). Applied to Buildings A and D October 2013. DET. Funded by DET Cool Roof School Trial.
- Shade sail strategy. Installation of shade sails over courtyards to reduce the heat from the asphalt surface. Shade sail fabric is a light cream colour to reflect solar radiation. Sail forms are allow breezes through and provide shade mostly from afternoon summer sun. Installed to East courtyard (between Buildings A B and D) and West courtyard (between Buildings C B and F) July and August 2014. Funded by Gambling Community Benefit Fund Grant and P&C.
- **Schoolyard greening (Landscaping) strategy**. Reduction of the 800 m^2 asphalt area north of classroom Buildings A C and I by installation of partially raised garden beds with shade trees covering 300m^2. Increasing vegetation provides cooling effects in a number of ways; plants absorb solar radiation, plants cool air by evapotranspiration, trees shade asphalt surface reducing solar radiation being absorbed that would otherwise be released into the air later at night. Garden beds constructed and ten shade trees planted July-August 2014. Further planting of 200 plants over two school community events: Year Ones' Arbor Day planting 15-17/10/14 and P&C working bee on 22-23/11/14. Funded by National Solar Schools Program, Brisbane City Council Arbor Day planting program, P&C and parent donations.

Figure 3: Summary of passive cooling strategies at the school (Source: nearmap).

4. Methodology

4.1. Case study

The research methodology is an embedded *single case study* (Yin 2014) allowing a rich in-depth understanding to be sought of the strategies implemented to the school environment together with the social and cultural context of the school. To analyse the effectiveness of the passive cooling strategies the research uses quantitative, data classroom temperature collected by data loggers in the school over 2012-2015 and qualitative data, perceptions gathered from Teachers and the School Principal through an online Questionnaire and Interviews being conducted this year.

4.2. Temperature analysis

The effect on classroom temperature of the passive cooling strategies is being analysed by two methods. The first method measures the amount of overheating occurring in the classrooms from the 'before' period of November 2012 through all summer terms to Term 1 2015. A method used to evaluate overheating in a portfolio of education buildings in Australia, an Adaptive Comfort Overheating Policy, has been applied to the temperature data here (de Dear and Candido 2012). As explained by de Dear 'the basic concept of adaptive comfort is that the comfort zone or range of acceptable indoor temperatures, drifts upwards in warm weather and downwards in cool weather, particularly in environments where occupants have a variety of adaptive opportunities at their disposal.' This upward and downward trend is visible in the Adaptive Comfort Zone using I(ext) plotted in Figure 1.

The concept behind this Adaptive Comfort Overheating Policy is to develop an overheating metric based on ASHRAE's Adaptive Comfort Standard 55-2010 for occupied hours. The metric tallies the frequency classroom temperature is greater than upper 90% and upper 80% thresholds of acceptability. The results for the overheating of classrooms in Buildings A B C D using the 90% threshold are in Table 1. Steps that have been followed in this method are:

- *Step 0: Identification of local threshold temperatures for heat-wave criteria.* Heat-wave days are excluded, as it is unreasonable to expect the passive design of a building to maintain a level of comfort during extreme events. The heat-wave definition is deemed to be two consecutive days with the daily maxima exceeding the third percentile of daily maxima on record and the daily minima exceeding the third percentile of daily minima on record, for that month using data from nearest weather station Brisbane 040913. Heat-wave days were removed from the occupied days (27-28 Oct 2014 and 9-10 March 2015).
- *Step 1: Monitoring indoor (classroom) temperatures in Buildings A B C D F.* Data loggers (HOBO U10 Temp/RH) were located in each building. Loggers monitor temperature and humidity at half hourly intervals. Logger placement was guided by practical reasons; away from radiant heat of windows (2m); within the height of a standing adult (1500mm from floor) and on the back wall of classroom out of sight of children.
- *Step 2: Monitoring outdoor weather* A data logger at the school I(ext) provides the outdoor temperature for the temperature analysis. This differs from de Dear and Candido's method, which uses data from the nearest weather station. Maximum and minimum temperatures and daily mean for I(ext) have been plotted in Figure 1. A similar plot was made of temperatures from weather station Brisbane City 040913 for 2014. Comparing these two graphs, the microclimate of the school differs slightly from Brisbane city in that it has warmer minimum temperatures, of at least 1 degree throughout the year. Outside logger I(ext) is behind the building opening plaque on the shaded north verandah of Building I.
- *Step 3: Tallying the number of occupied hours in an operation year.* Only school days when children attend school are regarded as occupied days. Same logic is applied to the daily occupied period, from 9.00am to 3.00pm inclusive of these times; 13 half hour counts per day.
- *Step 4: Calculating the running, exponentially weighted mean outdoor temperature.* The daily mean outdoor temperature of I(ext) is used to calculate a value of T_{rm} by using the same equation from de Dear and Candido's Overheating Policy (2012). This equation is very similar to exponentially weighted mean outdoor temperature by Nicol and Humphreys (2010).

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

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

- *Step 5: Calculate daily adaptive acceptable temperature thresholds.* The upper 90% acceptable temperature threshold from ASHRAE 55-2010 standard was calculated from T_{rm} for each day
  $T_{upper90} = 0.31T_{rm} + 20.3$ (°C) (2)
- *Step 6: Tally all temperature half hour counts greater than the threshold in the summer terms.* A count of how many times the classroom temperature was greater than $T_{upper90}$ for the range of half hour temperature readings between 9.00am to 3.00pm was done for each day. The results of the $T_{upper90}$ counts are in two values: actual counts and a percentage (counts/total counts for occupied period). Refer Table 1.
- *Step 7: Decision regarding remediation of comfort conditions*. In Step 7 for de Dear and Candido's client, their results indicated which rooms exceeded an overheating criterion (>1% of occupied hours exceeding 80% threshold). In this research project, whether this temperature analysis will be used in a similar way as a decision support tool for action is to be assessed. This assessment will come after the synthesis of the temperature data with qualitative data.

The second method for temperature analysis is the comparison of diurnal graphs of five-day weeks. Weeks are selected are when the maximum daily temperatures are 25-32°C and days have high (8-12) solar hours; this is when solar radiation has maximum effect on the building envelope and surroundings. Rise and fall patterns of temperature can be compared with other classrooms and outdoor temp I(ext).

4.3. Questionnaire and interview analysis

Perceptions of the classroom environment are being collected through an anonymous online Questionnaire and Interviews with teachers and the Principal. Questions include summary evaluation type questions of the classroom environment, of the Teachers' perceptions of the most recent summer term, similar to the type of questions asked in a post-occupancy evaluation (Deuble 2014). The Questionnaire aims to capture the range of adaptive actions the Teachers engage in to reduce discomfort during summer terms; their energy conserving practices and reasons why they do so; for Teachers in air-conditioned classrooms, triggers for its use in summer terms. In the Interviews, Teachers who have occupied the same classroom for three years or more provided their view of effects the strategies have had on the classroom. An Interview with the Principal discussed the strategies and their impacts on the school in a physical and social sense; range of adaptive actions taken by teachers in classrooms to reduce heat; heat wave action procedures in the school; energy conserving practices in the school; cultural expectation of air-conditioning in workplaces influencing school teachers.

5. Results

5.1. Overheating analysis results

It was anticipated that results would show an obvious decrease in the number of times classroom temperatures were greater than the upper threshold for the summer term 1 of 2015, compared to the 'before' periods of November 2012 and February and March 2013. A decrease would indicate that the passive cooling strategies are having an effect on classroom temperature. However there is no such obvious trend as can be seen in Table 1.

Table 1: Classroom temperature counts above $T_{upper90}$ threshold for summer terms.

Year	Month	Occupied Days	Total ½ Hour Counts	Actual counts				% counts			
				Building				Building			
				A	B	C	D	A	B	C	D
2012	NOV	11	143	100	87	95	102	70%	61%	66%	71%
2013	FEB	18	234	95	80	84	97	41%	34%	36%	41%
	MAR	15	195	62	58	60	86	32%	30%	31%	44%
	Cool Roof to A & D										
	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	Stack Ventilation to A B C D										
	JAN	4	52	13	14	9	10	25%	27%	17%	19%
	FEB	21	260	158	161	157	152	61%	62%	60%	58%
	MAR	10	273	105	115	112	97	38%	42%	41%	36%
	Shade Sails A B D, C B F / Garden Beds to A & C										
	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	Garden plants cover 25%										
	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%

The November % figures are indeed quite high; 61 to 71% of the time is over the 90% threshold, indicating overheating in these classrooms. Comparing the November figures of Buildings A and D after the Cool Roofs application, the percentage has dropped from 70% to 53% in A and 71% to 48% in D. This could be construed that the passive cooling strategy has had an effect. Moving onto the following November, after the shade sails have been installed to the north of D and south of A, the percentages go up 57% in A and 53% in D. This linear comparison of temperature across time periods is an inconclusive way to measure the effect of these strategies.

Counting the number of times temperature is over a threshold only counts that it is greater than the threshold; it could be by half a degree or by three or five degrees. Another measure that could be done to these classroom temperature data is to apply a degree-hour concept. For example one hour with a temperature three degrees over the threshold would carry the same weight as three hours with one degree over. This method could provide a tally of the degree of intensity of heating in the classrooms, and would require more calculations and tabulation of the temperature data. However at this point of the research it is being questioned whether applying another method of analyzing temperature data would provide compelling evidence that the strategies have had an effect. The concern is that there are other variable factors that could be influencing the temperature in the classroom that are not being directly observed at the same time of the temperature monitoring. Variables in the weather can occur from one month to another. For example, although two heat wave days were taken out for March 2015, there were two other separate days that were as hot and were included in the count. The previous March of 2014 was the wettest month of that year, with more constant temperatures from day to day.

The other method of temperature analysis, using diurnal temperature graphs, takes into account some climatic factors. Graphs show rise and fall in classroom temperature classroom during the day over a five-day week and can be compared with I(ext) and upper and lower thresholds of the adaptive comfort zone. Weeks for comparison can be selected to possibly match climatic factors, such as amount of daylight hours, prevailing wind direction, rainfall, humidity levels. These are recorded at the nearest weather station Brisbane City. However other immeasurable factors that could influence classroom temperature include how the building is used from one week to another. Some classrooms have had the same teacher from one year to the next, which could mean that a similar routine to opening windows occurs over summer terms. Yet routine could change at any time and this is not monitored.

5.2. Diurnal graph comparison

Using the diurnal graph comparison method, early analysis found that Stack Ventilation (SV) on Building F was observed to have a cooling effect. Before the SV implementation in the sunny week of 12-16 November 2012 the Building F's classroom temp at an average maximum of 30.2°C, was 2.4°C warmer than I(ext) max of 27.8°C. After SV implementation in a comparable sunny week of 25-29 March 2013, Building F's average maximum 29.4°C was 0.4°C cooler than I(ext) max of 29.8°C. However in other weeks the cooler morning temperature only lasted till midday as outdoor air proceeded to come in through the open windows and doors. Heat load could also be coming through the roof. Building F has bulk insulation only to its central flat ceiling area (67% of the classroom floor area) with raking ceilings to along the north and south of the classroom.

After the final coat of Cool Roof was applied to Buildings A and D on 03/10/13 over the holidays an immediate effect to classroom temperature was observed. Three days before 03/10/13 in both A and D max temps were warmer than I(ext) by 2.54°C in A and by 2.64°C in D. Four days after 03/10/13 in both A and D max temps were cooler than I(ext) by 1.85°C and 1.79°C. However when the classrooms were occupied the following week with doors and windows opened the effect was less noticeable and the classrooms were only a degree less than similar sized Buildings C and B for most of the day. Classroom temperatures in Buildings A and D peaked in the afternoon in a similar pattern as before.

6. Conclusion

6.1. Physical and social aspects of retrofitting passive cooling strategies

This research addresses a volume of existing building stock within SEQ schools in the important pursuit of the transition to a low carbon society (Shove *et al* 2008). This research attempted to analyse the temperatures before and after implementations of strategies at the school by using a method of overheating analysis based on the ASHRAE 55 adaptive comfort standard, with inconclusive results. But perhaps more importantly the research will provide the social context that changes to the physical environment have occurred in; the range of adaptive actions that teachers currently engage in to reduce their feeling of discomfort from heat; and any existing energy conserving practices in the classroom and reasons why the teachers do so. Combining passive cooling strategies with a range of adaptive actions could inform low–energy occupation measures for typical existing SEQ classroom buildings.

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