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Adaptive comfort actions and passive cooling interventions: implications from a Brisbane school

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Abstract: In subtropical southeast Queensland, a common approach to improving thermal comfort in existing 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. This paper increases understanding of low energy approaches to improving thermal comfort in existing school buildings. In a case study school in Brisbane the impacts of a number of passive cooling interventions to classroom buildings and their surrounds were studied together with the current adaptive behaviours of teachers during perceived over-heating in classrooms. The impact of the interventions on classrooms was evaluated through quantitative data, classroom temperature, collected over 2012 to 2015 and qualitative data, perceptions of teachers of the classrooms, though an online questionnaire and semi-structured interviews with teachers and the Principal in 2015. This paper discusses key findings from the case study: current adaptive actions of teachers and the social and cultural aspects of thermal comfort in classrooms. A significant finding was that air-conditioning some classrooms and not others in the school was seen as an equity issue. Implications from this study could inform a pathway for low energy occupation of classrooms in southeast Queensland.

Keywords: adaptive comfort; adaptive behaviours; passive cooling; overheated classrooms.

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 to gain greater understanding of the link between buildings and occupants.

Overheating in summer is a problem in existing classroom buildings in subtropical southeast 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 energy intensive air-conditioning (Roaf et al. 2010). Greater understanding of low energy approaches to improving thermal comfort in existing schools is needed.

This is the second paper reporting from a research project on a case study Brisbane school, where four passive cooling interventions were retrofitted to classroom buildings and their immediate surrounds (Kuiri 2015). The interventions were: 1) stack ventilation 2) cool roof 3) shade sails over courtyards and 4) schoolyard greening, as shown in Figure 1. The research project had three aims. Firstly, evaluate the impact of the four passive cooling interventions. Secondly, understand what is perceived to be an acceptable comfort zone for the classroom occupants. Thirdly, explore the adaptive behaviour of teachers during times of perceived over-heating in classrooms. The first paper (Kuiri 2015) discussed the background of the research project, the case study school, Brisbane climate, attributing factors to overheating of classrooms, the passive cooling strategies, and the results of applying an overheating metric developed by de Dear and Candido (2012) to classroom temperatures. This paper discusses key findings from the qualitative phase of the mixed methods case study: the current adaptive behaviours of teachers in the school and the social and cultural issues influencing thermal comfort in classrooms. At the end of the paper implications of these findings that could inform a low energy approach to occupation of classrooms in South East Queensland are discussed.

2. Literature

The Adaptive Comfort Model holds promise in the aim of increasing energy conserving behaviours. 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. Examples of adjusting the environment are by opening windows to increase cross-ventilation, using blinds to control solar gain on glazing and glare, and turning on ceiling fans to increase air movement for a cooling effect (Nicol, Humphreys and Roaf 2012). The Adaptive Comfort Model is based on extensive field studies providing statistical data to define the conditions that a percentage of occupants (80% and 90%) find thermally comfortable, in naturally ventilated buildings. These studies revealed a relationship between an indoor comfort zone (temperature band 5 degrees wide for 90% of the population) and the monthly mean of previous days' outdoor temperature (de Dear and Brager 2002). The Adaptive Comfort Model was first included in American Society of Heating, Refrigeration and Air-Conditioning Engineers Standard (ASHRAE) 55 in 2002. There are a number of conditions for using the Adaptive Comfort Model; that there is no mechanical cooling system, the windows are easily operable, the occupants are free to adapt their clothing to indoor/outdoor conditions to a range of 0.5 to 1.0 *clo* (lightweight clothing) and that the occupant have metabolic rates ranging from 1.0 to 1.3 *met* (near sedentary level) (ASHRAE 2013). The adaptive comfort zone varies seasonally. In summer, warmer indoor temperatures are acceptable to occupants compared to cooler indoor temperatures in winter. Nicol, Humphreys and Roaf suggest understanding the adaptive comfort approach to design comfortable buildings and encourage thermal comfort research in regions to better understand specific complexities of obtaining comfort (2012).

Thermal comfort studies of children in naturally ventilated classrooms in tropical and sub-tropical Asian countries question whether it is necessary 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). Japanese school children in naturally ventilated environments were satisfied with conditions well outside the adaptive comfort zone, although the children did prefer being cooler (Kwok and Chun 2003). In their study of school children in New South Wales schools, de Dear et al (2015) found children preferred an acceptable summertime temperature range of 19.5°C to 26.6°C, lower than the ASHRAE adaptive comfort zone and that children in schools from places with more varied outdoor temperature had higher adaptability (de Dear et al. 2015). Understanding how occupants adapt could be studied further in a school.

Although, thermal comfort studies of children's adaptive behaviours in classrooms in Brazil and Venice have shown that teachers, rather than children, have control of the classroom environment; this is attributed to children having restricted spontaneous movement in the classroom to comply with discipline codes (Bernardi and Kowaltoski 2006) or teacher's preference taking precedence over children's preferences (De Guili, Da Pos and De Carli 2012). A more direct research approach is to ask teachers of their adaptive actions in the classroom.

Studying occupants of naturally ventilated houses with high environmental values in Darwin, Daniel *et al* (2015) found these Australian householders 'thermal mavericks' live in wider temperature ranges than the ASHRAE adaptive comfort zone; they suggest this relationship could be relevant for occupants of other building types. Moloney and Strengers (2014) studied Australian householders 'Going Green' and argue that energy conserving actions are narrowly defined as being either small actions (turning lights off when not in use) or large actions (installing solar panels) and suggest exploring everyday social practices to provide more ways of reducing household energy consumption. They recommend studies be done of social practices of people in other building types, to increase the scope of energy saving behaviours. An interesting study in California investigated the effect of persuasive messages delivered to householders promoting energy and water conservation by measuring the corresponding use of energy or water in the household after receiving the messages (Nolan et al. 2008). Each message was written in one of five ways: descriptive norm (what your neighbours are doing to conserve energy), self-interest (conserving energy saves me money), environment (reduce my impact on the environment), social responsibility (conserving energy is socially responsible) and information-only (conserving energy has these quantitative effects). The most influential message was written in the descriptive norm.

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). A similar mixed method approach has been used in this case study to evaluate the impact of the retrofitted passive cooling strategies together with perceptions of the teachers in the classrooms. In addition, understanding the influence of social factors to thermal comfort such as performing the role of teacher is sought. A framework for understanding a complex problem that involves subjective viewpoints of people and their roles in system (or organization) of people is offered by Soft Systems Methodology (SSM) (Checkland & Poulter 2006). SSM can be understood as a learning cycle that investigates different points of view of a problematic situation that is then assembled into list of actions to improve the situation; a process used in action research (Checkland & Poulter 2006).

Other studies reviewed were those that involved evaluation of the environment and impact on productivity of the occupants. 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 could be revealed (Leaman and Bordass 2007; Heschong Mahone Group 2003; Deuble & de Dear 2014) or insights not obvious to the researcher (Yin 2014). These methods, a questionnaire followed by semi-structured interviews, were used in the qualitative phase of this case study research.

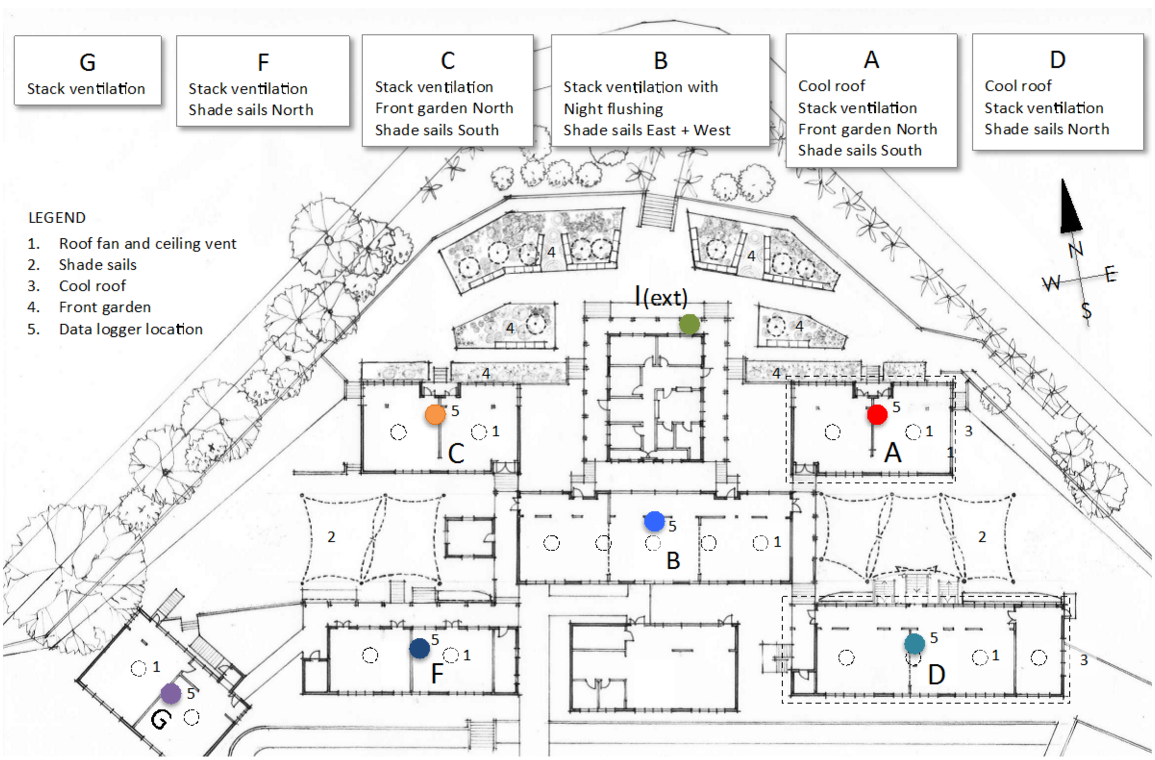

Figure 1: Case study group of buildings with interventions (source: Author, 2016)

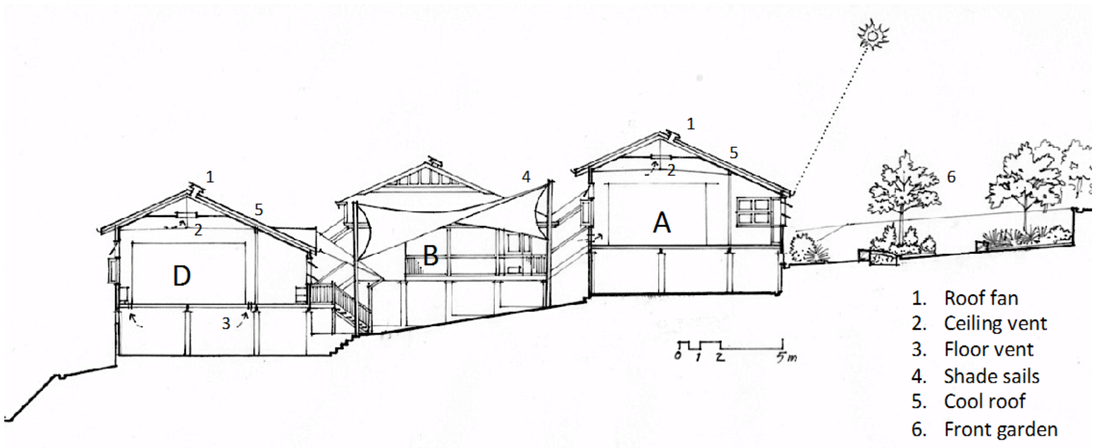

Figure 2: Section through Buildings A and D, east courtyard (source: Author, 2016)

3. Methodology

The research design was a single case study (Yin 2014) with a mixed method approach for analyzing the quantitative and qualitative data (Creswell 2014). Quantitative data, classroom temperatures, were collected by HOBO data loggers set for half hourly intervals placed inside classrooms before and after interventions, from 2012 to 2015 (refer Figure 1). Three methods were used to anlayse the classroom temperature; the overheating metric developed by Candido and de Dear (2010) for the Australian schools study (de Dear *et al.* 2015) was the first method used. The results from the temperature analysis and the impacts of the passive cooling strategies are merely noted in this paper and results from the temperature analysis are intended for more detailed discussion in another paper. The methods used to collect and analyse data in the qualitative phase of the study were 1) Online anonymous questionnaire to all classroom teachers and 2) Semi-structured interviews with the Principal and seven teachers who occupied classrooms with interventions. Key findings from the qualitative phase of the study are discussed in this paper. The design of the questionnaire and interviews are discussed next.

3.1. Questionnaire and Interviews

All classroom teachers in the school were invited to participate in an anonymous online questionnaire. The questions were grouped; evaluation of passive cooling strategies and teacher's perception of heat inside classrooms (Questions 1 to 10), exploration of current adaptive actions in the school (11–22), exploration of energy conservation practices by teachers (29-32), air-conditioner use (23-28), teacher's age and gender (33-34), children's age range (35) and an open question (Q36) for teachers to add any other comments. Out of the 34 classrooms, 19 teachers began the questionnaire, 13 (a proportion of 30%) responded to most questions including Question 11 about their adaptive actions in the classroom and 7 provided comments at the end. For Question 35 there were no responses from teachers of children aged 4 to 6, so it is inferred that no Prep teachers (from Buildings O and P, not in the case study group), answered the latter part of the questionnaire. Question 24 asked whether the classroom had air conditioning or not and this yes/no response allowed responses to be grouped into teachers who occupied naturally ventilated (NV) classrooms or air-conditioned classrooms (AC). Questions asking about teacher's perceptions of heat inside classrooms focused on the most recent summer term, Term 1 of 2015 (27 January to 4 April).

The semi-structured interviews had similar questions to the questionnaire but enabled teachers to provide more in-depth answers. Seven teachers were interviewed who occupied buildings A B C D. Five of these had occupied the same building from 2012-2015. The Principal was asked additional questions about the workings of the school.

4. Qualitative results

4.1. Impacts of the passive cooling strategies on classrooms

From the questionnaire, the time of day that more than half (7 out of 12) of respondents in both NV and AC classrooms felt uncomfortably hot inside their classroom was in the last teaching session of the afternoon (1.55-2.55pm). Most respondents (7 out of 9) in NV classrooms felt uncomfortably hot for more than half of Term 1. Two teachers in NV classrooms felt uncomfortably hot in the middle session (11.25am-1.05pm) and another three in NV classrooms all through the school day (8.55am-2.55pm).

In the interviews, some teachers summarized that the passive cooling strategies alone were not enough to provide comfort for on hot days in summer terms, especially months of November December, January, February and parts of March. 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. Although, Teachers in Building B had perceived less discomfort from heat in Term 1 compared to previous years. Also, Teachers in B and D commented in shoulder seasons (April/May and September/October) the classrooms were comfortable.

4.2. Current adaptive behaviours

In the questionnaire, Question 11 listed fourteen adaptive actions and teachers were asked to rate on a five-point scale how successful the action was in reducing discomfort from heat, refer to Table 1. Most teachers responded to all of the actions listed, indicating that they had practiced these at some time. Where classrooms had it, the action that was always successful was 'to turn on the air-conditioner upon arriving in the morning.' Generally successful actions were to 'increase air movement by using ceiling fans' and 'opening windows'. Actions that had varying responses of success were 'encouraging children to drink water' or 'spraying them with mist'. Allowing children 'to spread apart' or 'sit under fan of near windows' or 'changing the scheduled learning activity' were sometimes successful. Leaving the classroom to a cooler location were practiced by some teachers and regarded as sometimes successful in reducing discomfort from heat. In the interviews some year one and two teachers said that this action was problematic for a whole class, as children require writing surfaces and materials that they need to keep with them and teaching resources needed for learning activities are on display are kept in the classroom. Commonly practiced in outdoor locations near the classroom was 'one-on-one time' between a child and adult, or small groups of children with an adult reading books. A child's voice is more easily heard when away from the background noise of children in the classroom. Another common action was scheduling more intense teaching in the morning. Teachers observed the effects of heat on children, especially in the afternoon, as lethargy and irritability that impacted on their learning. Teachers observed children returning to classrooms after having active breaks on hot days were overheated "as red as beetroots" and unable to cool down in a warm classroom.

Table 1: 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	Sometimes	Generally	Mostly	Always	*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
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						
Responses to respondents as %	0%	< 15%	16-32%	33-49%	50-66%	>66%

Questions from 12 to 22 asked particulars of window and ceiling use in classrooms. Most teachers opened windows and/or switched on ceiling fans in the morning and closed or switched off the same when leaving the classroom at the end of the school day. Increasing air movement by ceiling fans was limited due to fans being too far away from people to be effective at cooling (fans mounted on 4.1m ceilings) or too noisy at higher speed. Fans on high speed were disruptive to children when doing cutting and pasting paper activities and turned down or off. Half of the teachers (5 out of 10) used windows effectively for cross ventilation and perceived the best breezes to come the south, from the direction of the school oval. Usually in Brisbane the best prevailing breezes in summer are from the north to southeast. The location of the school on the south slope of a hill could be reducing the amount of breezes reaching the classrooms (Kennedy 2012).

4.3. Emergent themes from the study

A significant finding in the school was the situation that some classrooms being air-conditioned and others not, was an equity issue. Teachers perceived as unfair the expectation to perform the role of teacher in an uncomfortable warm classroom alongside peers in comfortable air-conditioned classrooms. For the open question at the end of the questionnaire all seven respondents stated that air conditioners should be installed to all classrooms. This sentiment was echoed in both teacher and Principal interviews that all classrooms should have the same controls available to teachers for providing comfort from hot or cold weather conditions. Other findings were: that some teachers perceived air-conditioned environments to be the social norm for professional workplaces in Brisbane; naturally ventilated classrooms were perceived as thing of the past; and air-conditioned classrooms were increasing in other schools as the social norm. Another theme that emerged from interviews was that maintaining an expected professional appearance of teachers is limited in clothing choice when teaching in warm conditions. Women wore lightweight clothing that was not obvious beach or house wear. The Principal commented on how he could wear a tie due to his office being recently air-conditioned.

Current energy conservation practices included turning off lights and appliances when not in use, small actions (Moloney and Strengers 2014) in in keeping with recommendations from the Department of Education. 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. Discussion

In this case study it was found that retrofitted passive cooling strategies to the school impacted on classroom temperature. Before the interventions, classrooms were warmer than the outside temperature by 3°C for the entire afternoon. After the interventions, classroom temperatures were reduced in the duration of overheating in the afternoon, some only reaching outside temperature for short periods of time. However the classrooms were not cool enough to be within the comfort zone. When outside maximum temperature on summer days are over the upper comfort zone threshold, averaging 28°C for summer months, it follows that there are times when classrooms with open windows and doors and thin-skinned walls will reach outdoor temperature. In the study of Australian school children by de Dear *et al*, cooler temperatures were preferred than the comfort zone (2015). However, Daniel *et al.* (2015) showed 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.

Previous thermal comfort studies of school children suggest 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 school except for two; that windows should be easy to operate and the metabolic level of the occupants be sedentary. In the case study school it was found that inoperable windows prevented teachers from using them to improve their comfort. Also, teachers observed children to be active on hot days during breaks, possibly elevating their metabolic rate to 3.0-4.0 *met*. Back in the classroom time needed to pass before their *met* levels were lower and nearer a sedentary level of 1.2. Active children possibly require cooler classroom conditions than that suggested by the Adaptive Comfort Model in ASHRAE 55.

This study revealed current adaptive actions of teachers to reduce theirs and the children' discomfort from heat in naturally ventilated classrooms. These actions have limitations but an awareness of when they are effective could inform a low energy approach to occupying classrooms.

6. Implications

From this study arises the question 'how can schools in south-east Queensland improve thermal comfort levels in existing classrooms using low energy approaches?' Knowing what times of the day and year comfortable and uncomfortable temperatures generally occur in the classroom can increase low carbon behaviours. Especially in lightweight timber buildings that are affected by outside temperature swings. Mornings (9.00 to 11.00am) are generally the coolest time of the school day. The research identified months of the year when the classrooms with retrofitted interventions were within an acceptable comfort range, May and September. In these months air conditioners should be kept off. In shoulder seasons adaptive actions such as using open windows for cross ventilation, scheduling less intense activity in the afternoon or moving the class to cool locations outside could occur. In summer, an air conditioner could be turned on later in the morning (10.30am) on hot days, even later (12.00pm) on warm days, only as required to cool the classroom for the afternoon. In winter, the air conditioner could be used to warm the classroom on cold mornings then turned off for the afternoon when the sun has warmed the surroundings outside. Changing the habit of turning the air conditioner on in the morning and leaving it run for the full day, to being aware of when to switch it on and off during the day and year, could have enormous implications for schools, financially and environmentally.

The equity issue that emerged from the study was discussed as the notion that all teachers should have the same resources available to them to provide thermal comfort to children and themselves. Another way of viewing the idea of 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 individual effort (Kania and Kramer 2011). In a school the challenge to overcome is that individuals hold different levels of adherence to low energy behaviours and acceptance of comfort (de Dear and Brager 1998). However if a group of teachers valued sustainable occupation of their classrooms highly, they may limit air conditioner use and practice a range of adaptive actions to occupy their classroom instead. Especially if they knew that neighbouring teachers were acting in ways to conserve energy (Nolan et al 2008). A Principal would have a leading and coordinating role in this action. If left up to the individual, there could be some teachers putting more effort into saving energy, but others not giving it any thought, following a habit of cooling all day every day in summer using air conditioning. Observing the latter behaviours could be discouraging to those teachers trying to conserve energy (Ockwell et al 2009). Increasing the range of adaptive behaviours of teachers in classrooms, combined with retrofits to buildings and surrounds to reduce heat load, are key pathways towards low carbon occupation of classrooms in southeast Queensland.

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