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Simple strategies for improving the thermal performance of the NSW demountable classroom in four climates

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Abstract: This paper provides an overview of the results of a project that explores strategies for improving the thermal performance of the New South Wales Demountable Classroom in the diverse climates that occur across New South Wales, Australia. The climates in NSW vary between cool or mild temperate climates, sub tropical climates and hot dry desert climates. The demountable classroom is expected to provide comfortable teaching spaces in any of these climates. The NSW Demountable Classroom was designed 50 years ago and accounts for 12% of all government classrooms across the state. The thermal performance of existing classrooms is poor. The project uses a design led methodology to develop strategies that can be implemented by community groups to improve the performance of individual classrooms in particular locations. The strategies are evaluated using a computer simulation model. Predicted thermal comfort and annual energy consumption are used as the benchmarks for performance. The results illustrate that there are multiple strategies and combinations of strategies for improving the thermal performance of lightweight buildings in all of the diverse climates of NSW and Australia. The results also demonstrate that some of the orthodox conventions of bio-climatic design need more thorough interrogation.

Keywords: Demountable classrooms, lightweight buildings, computer simulation, thermal performance

1. Introduction

The New South Wales demountable classroom is a lightweight, modular, relocatable classroom system designed by the NSW Governments Architects Office in 1965 (Mk I) and an updated version designed in the late 1970's (Mk II). This classroom system was created to allow the government to respond to the rapidly changing demographics of communities across the state as well as emergencies created by disasters such as bushfires, floods or arson. There are 6000 of these classrooms across the state, accounting for 12% of all classrooms in state government schools (NSW Government, 2014).

The original design brief led to the creation of a rapidly deployable and relocatable, robust and necessarily lightweight modular system that is expected to create appropriate teaching space in any of the state's diverse climates. 50 years later the need for these classrooms remains and they continue to provide the state government and communities across the state with vital teaching spaces. The "demountable" has become a "pejorative" and they are widely regarded as providing inferior teaching accommodation. Communities regard these buildings as obsolete due to their thermal performance and their appearance (Slee and Hyde, 2015b). A baseline study of the thermal performance of these classrooms and review of literature illustrated that the concerns about internal environmental quality (IEQ) in the classrooms and its detrimental effect on teaching and learning in the classrooms are well founded (Slee and Hyde, 2015a)

The way in which students are taught has also changed over the last 50 years and these buildings are thought by some to be unable to provide the flexible accommodation that is required by contemporary pedagogy. A review of the original drawings reveals that, in fact, these buildings were designed to be adaptable and flexible and that the prefabricated industrial nature of the system lends itself to continuous improvement and adaption (Slee and Hyde, 2015b).

This paper presents the initial results of an analysis of "Solution Sets" designed to allow communities to improve the environmental performance of the demountable classrooms in their schools. The paper models the performance of classrooms on four existing sites across the state representative of the diverse climates in which these classrooms are expected to operate. The climates are Broken Hill (**BH**) (dry desert), Canberra (**CB**) (cool temperate), Williamstown (**WT**) (warm temperate) and Coffs Harbour (**CH**) (sub tropical).

1.1 The existing situation

The original buildings, many now 50 years old, are still used. The modules are occasionally refurbished at Cessnock or Golburn jails by prisoners. This refurbishment process adds a further socially progressive rehabilitation dimension to these buildings. The opportunities for adaption and modification offered by the industrial modular construction system have been largely ignored with the exception of the addition of split cycle air-conditioning units in about 2003. A detailed physical survey of the buildings during refurbishment and subsequent thermal analysis reveals that what limited insulation is present is rendered redundant by the quantity of thermal bridging within the construction system (Slee and Hyde, 2015a).

The diverse climates across NSW share a common feature of high levels of solar radiation and warm to hot summers. Extremely lightweight buildings such as these tend to exacerbate rather than reduce the thermal fluctuations in their local external environments (Pearlmutter and Meir, 1995, Cardinale et al., 2010).

2. Methodology

Buildings are an intrinsically complex system and exist within other complex environmental and social systems. Therefore there can be no single optimal solution to the challenges raised by function, climate or social contexts and therefore no simple route to find "the solution".

The problem of the performance of Demountable Classrooms across the State of New South Wales, understanding how their performance can be improved and why this may be important from an environmental, social and economic perspective requires an approach that is integrative, that does not seek to identify a single optimal answer but accepts, implicitly, that no single optimal solution can be found for a problem consisting of so many indeterminate and interrelated variables.

The scientific paradigm, based on the fragmentation of the problem and the isolation of individual variables (Buchanan, 1992) is very appropriate for establishing deep knowledge around very specific criteria, but for problems with the technical, cultural, social and economic constraints, their applicability is limited. This paper adopts a design led methodology because it seeks to put things together, to integrate, rather than to fragment. The design methodology has the advantage that it is permissive and ecumenical. It understands the value sociological and scientific paradigms of thought can contribute to the search for solutions.

It is clear from literature (Hacker et al., 2008, Cardinale et al., 2010, Smith et al., 2012) (etc.) that many of the individual aspects of the problems and symptoms of problems with the demountable classroom have been explored and strategies for improving individual areas of performance tested. It is also clear that little work has been done to integrate these strategies and knowledge and evaluate them holistically as a larger system. This is the task of this paper. The process of developing the "solution sets" (Slee and Hyde, 2014) involves a qualitative assessment to work out whether or not they are practical before a quantitative assessment using a computer simulation model to simulate the classrooms and a series of modified classrooms (table 2) in the four climates.

2.1 A computer simulation model

Table 1: Simulation assumptions

Climate data:	A climate file based on data collected at local airports and collated to create "a typical year" by exemplary energy (Exemplary Energy, 2014).
Occupancy:	A standard school day was devised from 9am - 3pm with the teacher and some students arriving at 8am and leaving at 6pm. 30 students and 1 teacher. Occupancy was modelled for a 7-day week through the whole year (365 days) to maximise useful data.
Thermostat settings	The NaTHERS thermostat settings (NatHERS, 2012) because they respond to local climate. Heating: 20 deg. C / Cooling (varies): BH – 26.5^{o}C; CB – 24.0^{o}C; WT – 25.0^{o}C; CH – 25.0^{o}C. Natural ventilation occurs between these temperatures and heating or cooling is active below or above the temperatures respectively.
Ventilation	Ventilation is based on 8 l/s per person and calculated based on the occupancy schedule. When the building is operating in naturally ventilated mode the ventilation rate is calculated based on local conditions by the software.

This paper adopts the methodology described in a previous papers on the same project (Slee and Hyde, 2015a, Slee and Hyde, 2016) and uses the established thermal simulation software Design Builder (Energy Plus). A model of the demountable classrooms is created using detailed survey information from physical surveys of existing buildings and original drawings. This information is used to calculate the overall U-value of various elements of the building using Therm 7 (THERM 7.3, 2015). It is important to emphasise that the model is comparative rather than absolute and is used to indicate how the performance of the building changes over a whole year compared to a base model. The results are compared using a multi-parameter sensitivity analysis (Smith et al., 2012, Hacker et al., 2008). The key assumptions in the simulation model are outlined in table 2 above. The classrooms operate using a mixed mode strategy with split cycle air conditioning units used to cool or heat the air inside the classroom while opening windows or a mechanical fan are used to provide ventilation directly from outside.

2.2 Evaluation criteria

The primary objective of the research is to develop proposals that will improve the thermal performance and consequential indoor environmental quality of the classrooms. The second objective is to reduce the annual energy consumption which is electrical and measured in kilowatt Hours (kWh). The Green Star Council target energy consumption for heating and cooling in classrooms is 26.8 kWh/m^2.year (GBCA, 2009) in NSW irrespective of the local climate. The MK I classrooms are 72.1 m^2 leading to a GBCA target of 1932 kWh/year.

In order to assess the thermal performance in the simulation model we have chosen to use the adaptive comfort model to predict comfort. Specifically we have used the daily running mean formula proposed by de Dear and Candido (de Dear and Candido, 2012) for naturally ventilated buildings in NSW.

The demountable classrooms operate in a mixed mode. Some may argue that the presence of the split cycle cooling system means that the adaptive model is not appropriate. We have chosen to use it because:

- The adaptive comfort method considers comfort in response to the local outdoor climate that the students and teacher as they experience move between classrooms and the outside.
- The ventilation to the classrooms is direct from the outside either through open windows or a mechanical fan in the wall. There is no air handling unit.
- the split cycle unit cools or heats the air in the classroom when it is too cold or too hot and so it can be considered to be an adaptive strategy (Nicol and Humphreys, 2002).

The two criteria used to assess the performance of the classrooms are:

1. The total annual energy consumption of the building
2. The number of “degree hours” above or below the comfort zone. (number of hours multiplied by number of degrees above or below comfort zone)

3. Solution sets

The synthesis of individual strategies to create a series of solution sets for quantitative assessment follows two stages

3.1. Defining the resources available: Implementation strategies

If the environmental performance of the NSW demountable classroom is to be improved, particularly the internal thermal environment and other IEQ factors is to be improved then the strategies that are proposed need to be founded in the practical reality of the social and economic systems in which these classrooms exist. There are three possible approaches (Slee and Hyde, 2016) : (i)To replace all existing demountable classrooms with a new design: Replacing 6000 functioning classrooms is an unrealistic financial and environmental cost. (ii) “Deep” refurbishment and upgrade in ‘factory’ conditions at Golburn or Cessnock jails. This strategy will take too long or, if carried out rapidly, remove too many classrooms from use to be practical. (iii) On-site refurbishment. On site refurbishment presents its own challenges as well as a number of opportunities for the use of climate specific adaption, social engagement and the development of practical education experiences that can be integrated into the school curriculum.

This paper proposes following the third strategy. Solution sets that fit with the overall resources available to a community led approach must be relatively low cost, simple to implement, use readily available building materials and not impede the relocation of the classroom.

3.2. Solution sets

A baseline study by the author (Slee and Hyde, 2015a) identified the lack of insulation and extremely lightweight construction combined with the high levels of incident solar radiation as the three primary problems. Hi-tech strategies such as vacuum insulating panels or phase change materials cannot be considered because they do not meet the criteria for simplicity, availability and cost set out above. Strategies that may be considered include:

Shading

Fly roofs have been shown to be effective (Cardinale et al., 2010) and used to be used on these buildings. Shading using trees either around the perimeter (Akbari et al., 1997) or from locating the building under larger local trees (Chagolla et al., 2012).

An alternative to physical shading may be the use of High-emissivity paints. These are now readily available and simple to apply. The paints reflect solar radiation thus minimising the absorption of thermal energy from the sun. The paints are also good at emitting far infrared radiation, i.e. thermal radiation, so they are able to help keep the roof cool by dissipating or emitting the thermal energy absorbed by the roof or wall surface (Akbari, 2003, Gentle et al., 2011).

Resistive Insulation

There is very little resistive (bulk) insulation in the existing classrooms. Li et al (Li et al., 2013) observes that resistive insulation tends to be more effective in heating dominated climates. Other studies suggest that resistive insulation is useful I n warm climates but that its utility rapidly diminishes with quantity (Giovanardi et al., 2008) and may become counterproductive (Masoso and Grobler, 2008).

Thermal mass

Thermal is traditionally recommended for buildings in warm climates with high diurnal variations and high occupancy. Traditionally mass is introduced using concrete (or masonry) and is, by definition, heavy and so too much may make the relocation of the building modules difficult. Studies by Slee et al (Slee et al., 2014) show that relatively small amounts of thermal mass can make a significant difference to temperature fluctuations and that more mass may not be useful.

3.2 Creating and modelling solution sets

This paper explores the effect of introducing the strategies outlined above in various pragmatic combinations that fulfil the requirements for low cost simple strategies. The materials used are insulation using 40mm and 80mm PIR board, thermal mass using 6mm, 18mm and 36mm Fibre cement sheet, a fly roof and high-e paint. The combinations or “solution sets” are set out in table 2 below.

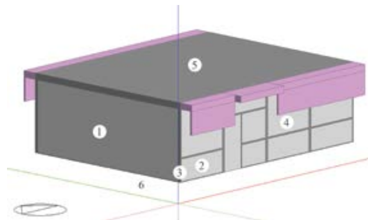

Figure 1: The design builder model with elements numbered to refer to elements in table 2 below. (3) Structural steel frame; (4) windows.

Table 2: Construction and U-values

Solution Set	**Walls (1 & 2)**	**U-value W/m².K**	**Roof (5)**	**U-value W/m².K**
MX 01 Base	Steel framed panels	(1) 1.04 (2) 0.90	Foil-faced blanket	1.25
MX 02	40mm PIR insulation board 6mm Fibre-cement sheet Fixed to inside on walls.	(1) 0.32 (2) 0.73	40mm PIR insulation board 6mm Fibre-cement sheet Fixed to existing ceiling.	0.42
MX 03	80mm PIR insulation board 6mm Fibre-cement sheet Fixed to inside on walls.	(1) 0.20 (2) 0.42	80mm PIR insulation board 6mm Fibre-cement sheet Fixed to existing ceiling.	0.26
MX 04	40mm PIR insulation board 18mm fibre-cement sheet Fixed to inside on walls.	(1) 0.32 (2) 0.73	40mm PIR insulation board 18mm Fibre-cement sheet Fixed to existing ceiling.	0.42
MX 05	40mm PIR insulation board 36mm Fibre-cement sheet Fixed to inside on walls.	(1) 0.31 (2) 0.72	40mm PIR insulation board 36mm Fibre-cement sheet Fixed to existing ceiling.	0.41
MX 10 series is as above with a fly roof (i.e. MX 11 is the base building with a fly roof). MX 20 series has a High-E paint on the outside of the walls and roof.				
Floor (6)	MX 01 Base: Plywood floor.			U Value: 2.11 W/m².K
	Improved floor (all other floors: R2.5 insulation between existing steel joists. Fiber-cement soffit to the underside.			U Value: 0.70 W/m².K

The modelling process followed a staged approach. The exiting situation (base case) was simulated (MX 01). In stage 2 insulation was introduced to the classroom building (MX 02 and 03) with a 6mm Fibre-cement sheet to protect the insulation. In stage 3 thermal mass was added to MX 02 by increasing the FC sheet, (total of 18 and then 36mm) (MX 04 and 05). Stage 4 applied a fly roof to the building and repeated stages 1 – 3 (MX 11 – 15). Using the knowledge gained in stages 1 -4 in stage 5 a high-E paint was applied to all the external surfaces of the base case (MX 21) and the case with the most thermal mass (MX 25).

4. Results and Discussion

The results are illustrated in figures 2 and 3. Note that the scale of the graph for the number of degree-hours above the comfort zone in Broken Hill extends to 3000 and not the 1500 degree hours shown on the graphs for the other three climates.

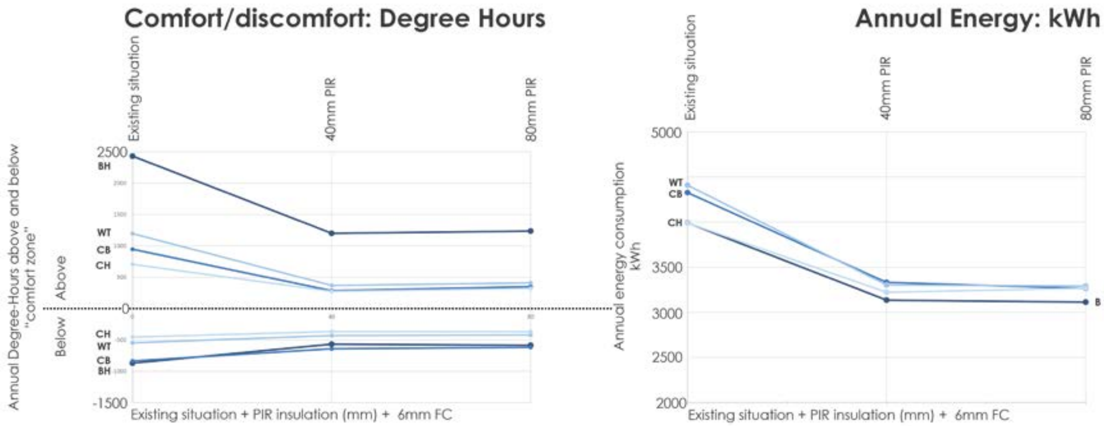

Figure 2: The impact on comfort (degree-hours) and energy consumption (kWh) of adding insulation to the classroom fabric. (BH – Broken Hill; CB – Canberra; WT – Williamstown; CH – Coffs Harbour)

Additional insulation

The first stage of the exercise introduced 40mm and then 80mm of insulation to the building system (MX 02 and 03) to the walls and ceiling. The floor was also insulated. The simulation results indicate that in all climates insulating the floor and adding 40mm of insulation significantly reduces discomfort in the classroom, particularly the problem of overheating. There is also a significant reduction in annual energy consumption. Increasing the insulation on the walls and ceiling to 80mm makes no additional impact on reducing discomfort or reducing annual energy consumption. It is for this reason that the in all the other solution sets insulation was maintained at 40mm (MX 02).

Thermal mass

The introduction of additional thermal mass (F/C sheet) causes a small but significant reduction in both - over-heating and under-heating (fig. 3).

Fly roof and High-E paint

The introduction of the fly roof has the most dramatic effect on the comfort of people in the building and the annual energy consumption. The use of a high-e paint has a very similar effect. Both strategies significantly reduce the impact of solar radiation on the thermal performance of the building.

Overview

Overall the pattern of performance is the same across all of the four climates simulated even though they range from the famously benign climate of Coffs Harbour to the famously extreme desert climate of Broken Hill.

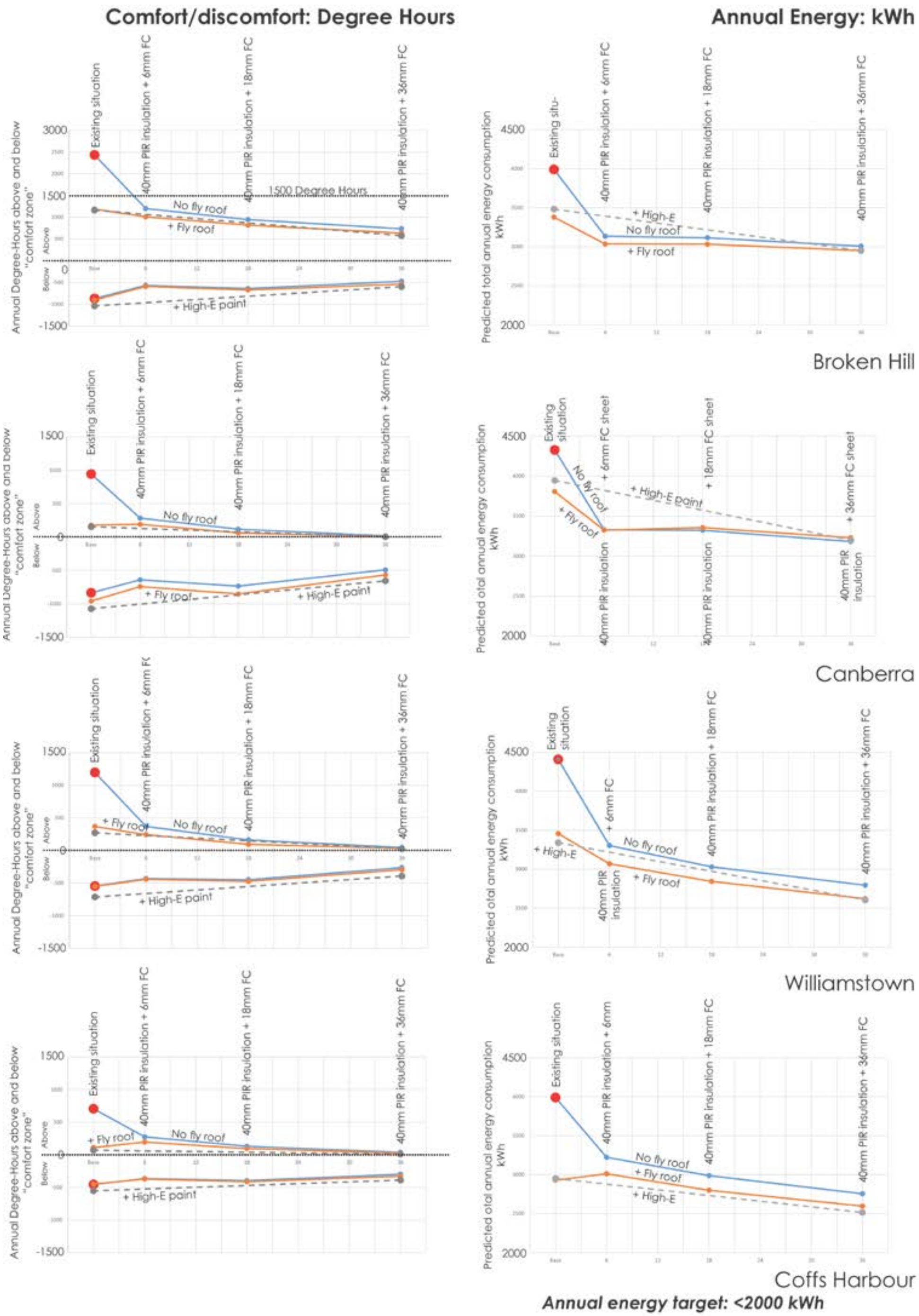

Figure 3: The impact on comfort (degree-hours) and energy consumption (kWh) of different solution sets in the four climates simulated.

The use of a fly roof or High-E coating is the most effective intervention, particularly given the ease of painting a classroom building or re-establishing the use of the fly roofs that exist but are no longer installed. The installation of insulation has almost the same impact on comfort and a greater impact on energy consumption compared to the fly roof in all climates except Coffs Harbour where comfort and energy consumption are improved if there is no fly roof but if there is a fly roof there is a slight reduction in performance. Additional thermal mass causes improvement or no significant change in all scenarios.

A second surprising observation is that while the introduction of thermal mass has a modest effect on improving comfort in all climates it only reduces energy consumption in the two more moderate climates of Williamstown and Coffs Harbour. In the two more extreme climates with higher diurnal temperature ranges where traditionally the use of thermal mass would be expected to be a more significant or effective strategy the effect on energy consumption is minimal, the effect on comfort is modest.

Conclusion

A series of simple, pragmatic and economic strategies for improving the thermal performance and consequential thermal comfort of the classroom users have been simulated using a detailed computer simulation model in four diverse climates from across NSW. The results were compared using a simple sensitivity analysis. The strategies were (i) Increasing the insulation levels, (ii) introducing thermal mass and insulation, (iii) reducing the impact of solar radiation on the building fabric. Overall the pattern of improvement in comfort and energy consumption is the same in all four climates despite the range of conditions that occur in those climates. Each of the strategies causes an improvement in comfort and energy consumption in each of the four climates. The two most effective solution sets are the introduction of insulation and strategies that reduce external solar gain on the building fabric (Fly roof or high-E paint). The introduction of thermal mass leads to further improvements in comfort and, particularly in the more moderate climates, additional reduction in annual energy consumption. The combination of all three strategies (MX 15 and 25) is overall the most effective but not always by a significant margin. The results illustrate that there are multiple strategies and combinations of strategies for improving the thermal performance of lightweight buildings in all of the diverse climates of NSW and Australia. The results challenge some of the assumptions in deign guidance commonly used by practitioners (eg. www.yourhome.gov.au) (Hollo, 1986) and suggests that the orthodox conventions of bio-climatic design need more thorough interrogation.

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