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Adaptation of Australian houses and households to future heat waves

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Abstract:
Climate change predictions indicate more extremes in weather conditions in the coming decades with more frequent and severe heat waves in certain locations including Australia. It is likely that the more vulnerable members of the community will be at risk during heat waves in the future from both health and financial perspectives. The trend towards fully air conditioned larger homes has already seen very large peaks in electricity demand during past heat waves with associated system failures. The impact of increased periods of hot weather, electricity price rises and system failure can be addressed in part through household behaviour; however it is concurrently exacerbated by housing designs which limit occupant choice. This paper employs outputs from the thermal analysis of typical Australian housing types to discuss this relationship between behaviour and design in future heat wave scenarios. Particular attention is given to populated regions forecast to experience a significant increase in heat waves in the future. Alterations to existing buildings and modifications of typical new house designs are utilised to demonstrate methods of reducing risks associated with extended periods of hot weather. In conclusion, a summary of the positive environmental and comfort implications of the modified designs is presented.

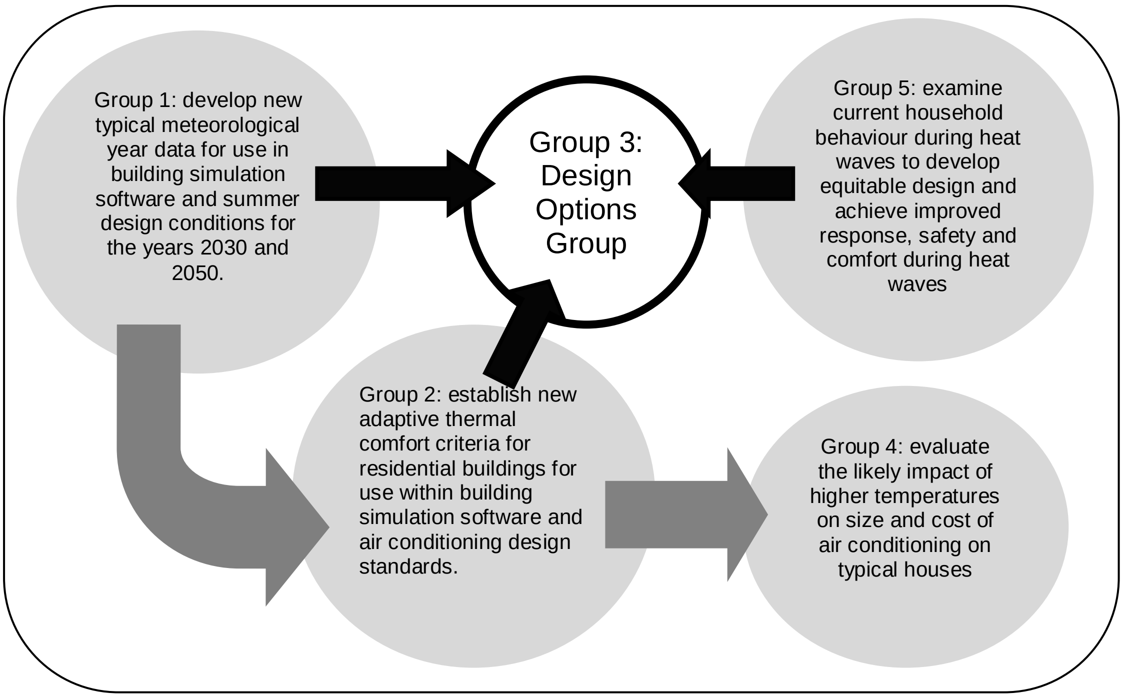
Keywords:
adaptation, heatwaves, Australia, behaviour, housing design

1.0 Introduction

With predicted changes in future climate across the globe it is anticipated that extreme heat events will increase in frequency and severity in various locations, including the more highly populated regions of Australia. Numerous reports and studies have outlined a range of adverse impacts of heat waves including health impacts, financial implications, infrastructure failure, bushfire etc. (ISR 2010, PWC 2011). The risk and severity of such impacts are likely to increase with climate change, with vulnerable members of society such as the aged, young, ill and poor at greatest risk. It is possible to mitigate these risks by identifying and addressing those factors that contribute to cooling demand. As such building design is an important parameter for consideration in both climate change mitigation and adaptation. Technical and quantifiable mitigation measures frequently receive greater attention than adaptation strategies as the latter require a willingness to adapt social and behavioural norms and expectations. With an anticipated increase in extreme weather events including heat waves in the future, adaptation of both building design and occupant behaviours are required to ensure the negative impacts of such events are minimised. This research seeks to determine a means of measuring building performance specifically during heat waves, and to investigate options for achieving thermal comfort via means other than the routine air conditioning of residences – to consider how social and behavioural variables might be utilised.

This paper presents a summary of work undertaken as part of a research project entitled 'A Framework for Adaptation of Australian Households to Heat Waves' supported by the Australian Government's National Climate Change Adaptation Research Facility (NCCARF).Led by the University of South Australia, the project also involves researchers from Queensland University of Technology, University of Sydney and University of Adelaide. The objective is to develop a national framework for reducing the adverse risks of heat waves and their impact on peak demand and energy cost. The project involves five research groups whose work is independent yet interrelated (Figure 1). The authors of this paper constitute the 'Design Options Group'.

Figure1: NCCARF Project "A Framework for Adaptation of Australian Households to Heat Waves"



Recognising that the vast majority of the built environment which will be inhabited in 2030 and 2050 is already in existence or will be constructed in the near future, Group 3 has been tasked with investigating building design options for 2030 and 2050 by

- examining the effectiveness of retrofitting existing dwellings to reduce heat related stress;
- developing affordable new design options for buildings and cooling equipment to avoid heat stress; and
- together with the members of the broader project, identifying regulatory changes required for the design of future housing.

2.0 Current Houses, Households and Heat Waves

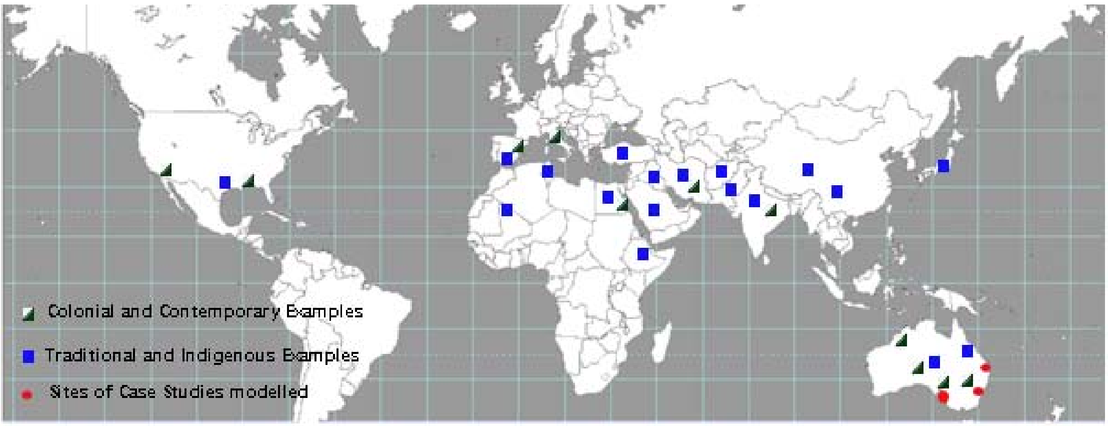
In a detailed study of the thermal properties of vernacular housing Wilkins (2007) observes the evolution of ‘silent technologies’ of thermal choice and thermal control. Discussing “(t)he range of thermal states and microclimates that a building is capable of providing to its occupants” (Wilkins 2007:3) the study demonstrates that early vernacular buildings which provided their occupants minimal thermal choice fell out of use. In contrast thermally complex buildings offered their occupants greater thermal choice and thermal control and have persisted through time, evolving into highly complex climatically appropriate dwellings. “The later vernacular buildings of Egypt and Pakistan .....were highly complex, with more rooms, more levels, more transitional space, more courtyards, and more variation in room size and shape ....they possessed a wide range of potentially different thermal environments: high thermal choices,” (Wilkins 2007:6) providing thermal satisfaction through variation. Australia’s typical free standing family homes comprised of a series of functionally specific spaces with consistent ceiling heights with materials and volumes that do not provide a high degree of thermal variation or choice. Hence they require the provision of comfort through mechanical services.

Current Australian building regulations focus on reducing the load placed on mechanical services through the basic passive design techniques of heat load management, primarily via improved material technologies and building orientation. Such techniques do very little to encourage reflection on the appropriateness of the typical house being constructed or to promote consideration of alternative solutions. Energy efficiency measures are hence applied to existing housing solutions in a manner which can be described as ‘Ecotechnic Logic‘, an approach to sustainability which places its faith in the potential of technological development as a panacea for our environmental ills (Guy and Farmer 2001).

Whilst such energy efficiency approaches successfully improve comfort conditions, reducing both health risks and energy demand in summer periods, they do not lead to better protection during extended heat events. An extensive study carried out by Saman and Halawa (2009) demonstrated through detailed monitoring of energy consumption of 6 energy efficient houses for 2 years that while the energy consumption dropped by an average of 35% compared with the local average, the peak electricity demand for air conditioning during heat waves was still very high and constituted a larger proportion of the total electrical demand. Adding further emphasis on the need to increase attention on adaptation rather than mitigation, Ren et al. (2011), reporting on an investigation into the impacts of global warming on energy consumption and CO2 emissions, state that new high energy efficient housing is actually more sensitive to future climate change.

Seeking alternative solutions to the challenges of extreme heat events beyond improving the efficiency of existing housing typologies, an extensive literature review has been undertaken of dwellings intended to provide comfort conditions in hot climates without mechanical cooling. The dwellings reviewed cover five continents and range from indigenous and traditional homes to colonial and contemporary examples as shown in Figure 2.

Figure 2: Location of Dwellings and Dwelling types reviewed



For each example observations were made of physical attributes (e.g. materials, spatial qualities, spatial interactions, furnishing and built form) as well as functional attributes (e.g. use of spaces, patterns of occupation and interaction between the occupant and the building fabric). A summary of the most relevant observations are included Table 1 – for a full discussion of this stage of the project see Palmer et al (2013).

Table1: Summary of physical and functional attributes of a sample of hot climate housing observed.

			Indigenous / Traditional Examples										Colonial		
			Australian Desert	Tunisian Pit Houses	Afghanistan Terrace	Middle Eastern Courtyard Housing	Chinese Courtyard / Cave Dwellings	Spanish Urban Courtyard Housing	Japan	Turkish (Sofa Room)	Gujarat India	Pakistan	Australian Summer Rooms (Basements)	Indian Bungalows	**Typical Australian Suburban Residence**
Attributes employed in housing to achieve thermal comfort in extreme conditions	Physical Design Attributes	Variation in volume of interior spaces		*	*	*	*	*		*	*			*	
		Complex spatial relationship between interior and exterior space		*		*	*	*			*	*			
		Use of transitional, semi enclosed spaces between interior and exterior	*	*		*	*	*	*		*	*		*	
		Below ground or sub grade construction for earth coupling	*	*	*	*	*	*					*		
		Shared walls with neighbours to minimise solar and heat exposure				*		*			*				
		Use of internal courtyards as microclimate		*		*	*	*			*				
		Exposure of high mass material located for occupant comfort	*	*	*	*	*	*					*	*	
		High levels of air movement	*			*		*	*	*	*	*		*	
		Air movement promoted by building form and layout	*			*		*		*				*	
		Air movement facilitated by shading ventilation screens to openings				*		*	*	*	*	*		*	
	Functional Attributes	Daily activities not limited to a single interior location				*	*		*		*	*			
		Complex relationship between interior and exterior activities	*	*		*	*				*	*		*	
		Inclusion of specific spaces for use as summer room			*	*	*	*		*	*		*		
		Highly adjustable spaces suitable for various uses	*	*	*	*			*	*	*	*			
		In-built furnishing promoting thermal interaction between occupant and building fabric				*				*					
		In-built furnishing to enable flexibility of space				*				*					
		Furniture easily relocate and adjusted for comfort			*	*					*	*			
		Guest room / storage space used as summer room (low winter occupation)			*										
	Environmental Adjustment	Employ a variety of thermal conditions in the dwelling, providing contrast			*	*	*	*	*	*	*			*	
		Evaporative and psychological cooling through water features		*		*		*		*	*	*			
		Operation of building requires active participation by occupants				*			*	*	*	*			
		Daily movement between spaces to seek comfort (including for sleeping)				*			*	*	*	*			
		Seasonal movement between spaces to seek task appropriate comfort			*	*	*	*			*	*	*		
		Exposure of high mass materials varied throughout year by changing wall and floor coverings (mats)			*	*		*						*	
		Summer thermal comfort prioritised over winter thermal comfort		*		*	*		*	*	*			*	
	Cultural Adjustment	Seasonal variation to daily scheduling such as work hours and siestas				*		*		*	*	*		*	
		Flexibility in sleeping location as needed			*	*				*	*	*		*	
		Willingness to accommodate co-location of household members and tasks in smaller, cooler spaces when needed			*	*		*	*	*	*		*		

In the housing examples reviewed thermal comfort is achieved through a combination of building performance and occupant choices (physical and social), the success of which is dependent upon an occupant's understanding of, and active participation in, the building operation. This understanding is developed through thermal variation, through experience of discomfort and the availability of thermal choices. Whilst an occupant may express an interest in 'greener living' one cannot expect significant alteration to occupant behaviour if building designs do not provide opportunities for choice and learning, promoting positive adaptive behaviours.

3.0 Cool Retreat

In response to the adaptation challenges posed above and drawing upon the housing examples reviewed, the introduction of a Cool Retreat to Australian houses is proposed (Bennetts et al 2012; Palmer et al 2012). The Cool Retreat proposed consists of a portion of the dwelling able to provide an appropriate level of comfort during heat wave periods. It draws upon the experiences of 'summer rooms' in both Australian and international precedents to offer an alternative solution to challenges of heat waves for both new and existing housing. The Cool Retreat does not seek to provide comfort for one hundred per cent of household activities during extreme conditions, but provides contrasting conditions, encouraging an adaptive understating of comfort and questioning the perceived need for constant conditions. The Cool Retreat provides an increase in thermal choice: the choice to create thermal zones as needed, the choice to move between these zones throughout the day and/or year as conditions vary, the choice to alter daily activities in relation to comfort options, and hence increased options regarding the need to employ active cooling technologies.

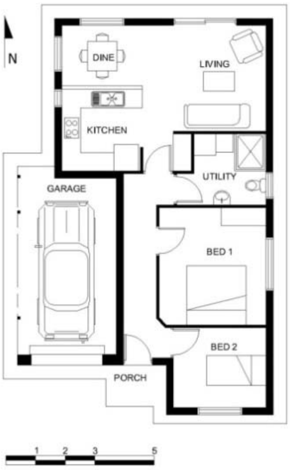
3.1 <u>Design Modifications</u>

Five typical Australian housing designs are used to examine the effectiveness of the Cool Retreat proposal (see Figure 3). The houses were selected to represent typical new dwellings occupied by households at greatest risk of adverse effects from heat waves. All modified designs include a Cool Retreat for use during heat wave conditions that is also appropriate for day-to-day use year round and separated from spaces generating high internal heat loads (kitchens). Living and sleeping spaces used during heat wave periods are located in the coolest possible position in the building, away from areas of high solar gains. The modified designs improve the performance of the dwelling, increasing thermal comfort and thermal choices for occupants, thereby encouraging behavioural adaptation.

More significant modification (or alternative design solutions) would offer greater potential for behavioural change and energy efficiency during heat waves. However, it is important the proposals made meet the perceived needs of the current market and abilities of the construction industry, making them immediately implementable. Therefore, in most cases, the Cool Retreat is incorporated with minimal alteration to the existing plans.

Figure 3: Description of Case Study Houses and Design Modifications.[i]

<table>
<tr>
<td>Case 1</td>
<td>Small House</td>
<td>78m2 free standing
Single Storey
2 bedroom
Brick veneer



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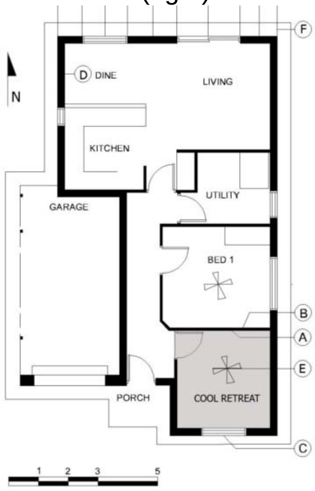
<td>Base Case: Typical new public housing design for people on low incomes and for accommodation for the elderly in retirement villages. (left)

Modifications: Bedroom 2 altered to act as Ground Level Cool Retreat. (right)



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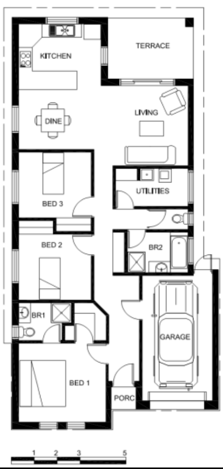
<tr>
<td>Case 2</td>
<td>Small Project Home</td>
<td>150m2 free standing
Single storey
3 bedroom / 2 bath
Brick Veneer



</td>
<td>Base Case: Project home design common to new housing estates. Smaller than the average Australian new home it represents a low price point in the market. Typically occupied by private tenants or owner occupiers with moderate household income.

Modifications: Basement provides an additional living/spare room throughout the year, acting as below ground Cool Retreat. House size increased by 14m2.

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<table>
<tr>
<td>Case 3</td>
<td>Medium
Project
Home</td>
<td>189m2 free standing
Two storey
3bedroom/ 2 bath
Brick Veneer

</td>
<td>Base Case: Project home for a narrow block, suitable in urban consolidation areas. Represents cost effective new construction currently available in inner urban areas suitable for a family with children. The design is free standing and has been modelled as such; however it is able to be constructed as a semi-detached or row house, improving thermal performance.

Modifications: Transformed from 2 stories above ground to one storey above ground with basement. Internal Courtyard added. Basement level becomes multi space Cool Retreat without need for additional floor area.

</td>
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<tr>
<td>Case 4</td>
<td>Apartment
Medium
Density</td>
<td>159m2
Two storey
3 bed/ 3 bath
2 living spaces
Concrete
substructure

</td>
<td>Base Case: This medium density apartment is located on levels 3 and 4 of a 4 storey development. It represents a growing housing type, one which is actively promoted in activity centres and transit oriented developments. Able to accommodate a range of households overtime including group households and families.

Modifications: Reorientation. Internal planning altered to enclose living area as Cool Retreat.

</td>
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</table>

Case 5	Apartment High Density	82m2 2 bedroom/2bath Concrete substructure	Base Case: Located on the 3rd floor of a 7 storey building this case represents a growing housing type for urban densification. With mechanical lifting services it offers a future alternative to Case 1 for elderly residents. Modifications: Internal planning altered to enclose living area as Cool Retreat separate to kitchen.

4.0 Thermal Analysis

Thermal analysis of the five cases was undertaken to determine the effectiveness of a number of energy efficiency retro-fit measures as well as the Cool Retreat design modifications. All analysis was undertaken using Accurate software[ii].

4.1 <u>Location and Climate Data</u>

Three locations have been chosen for the thermal analysis, representing differing climate zones as defined by the Building Code of Australia (BCA). Adelaide, Sydney and Brisbane are all predicted to experience increases risks associated with extreme heat events by 2030 (PWC, 2011)and are areas of significant population with continuing housing growth.For each location a 4 day extreme heat event was sourced from theAccuRate climate data. AccuRate uses data in the Typical Meteorological Year(TMY) format which represents typical weather conditions for the location, as such the weather files do not contain data that represent extreme events such as heat waves. However the weather file for Adelaide (South Australia) contains a four-day hot period which would trigger high watch conditions under Adelaide's Extreme Heat Plan as the maximum temperature is ≥ 35°C for 3+ consecutive days and minimums >21°C for 3+ consecutive nights giving an average daily temperature of 28°C (SA SES 2010). Four-day hot periods have also been sourced for Brisbane and Sydney from the TMY files for Amberley (Queensland) and Richmond (NSW) respectively.[iii]

4.2 <u>Modelling Stages</u>

Each case has been modelled in 3 stages. Firstly, the 'Base Case' was modelled with material specifications to achieve 6-star energy rating according to The Australian Nationwide House Energy Rating Scheme (NatHERS). 6-star is the current mandated minimum for building approval in a number of states. Secondly, each case was modelled with 'retro-fitting measures' which could be applied to an existing house (see Table 2).

Table 2: Retro-fit measures

Glazing	Retro-fitted double glazing or replacement with low-e glass U value= 4.63, SHGC=0.69
Shading	External vented canvas blinds to all windows
Insulation	Ceiling insulation increased to R6
Foil	Reflective attic space & anti-glare air gap beneath metal sheet (40mm 0.2/0.9)
Roof Colour	Light external surface, solar absorptance=30%, emissivity=0.9
Attic	Increase Ventilation (ie “well-ventilated with large openings”)
Wall Colour	Light external surface, solar absorptance=30%
Ceiling fans	1200mm fans to habitable zones (Living & Bedrooms)

The third stage involved the modelling of the modified designs incorporating Cool Retreats. It was assumed occupants will employ the full range of adaptive strategies such as adjusting clothing levels and activity, adjusting window shading, opening and closing windows and external doors as appropriate, closing internal doors when cooling to minimise volume to be conditioned (zoning) and occupying a restricted area (Cool Retreat) during extreme conditions.

At each modelling stage the following data was recorded for living and sleeping spaces during ‘heat wave’ conditions, and for the Cool Retreat where applicable:

- Maximum interior temperatures without the use of air conditioning
- Percentage of hours exceeding maximum comfort temperatures without air conditioning
- Total cooling energy demand if air conditioning used
- Peak energy demand if air conditioning used

Additionally, the following was collated at each stage in AccuRate rating mode :

- NatHERS Star Rating
- Annual Heating Energy load as determined by NatHERS
- Annual Cooling Energy load as determined by NatHERS

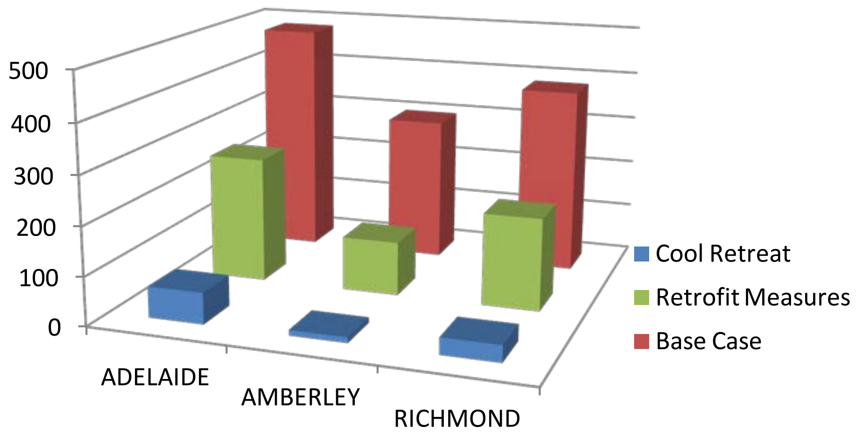
In total, the modelling approach taken generated 3 versions of 5 houses in 3 locations, giving 45 sets of results. In addition, within each of the retro-fitting models the 8 modifications were assessed separately in each location, giving an additional 120 sets of results.

4.3 <u>Modelling Results</u>
A summary of thermal modelling results is presented here, with particular attention on cooling energy requirements, peak demand and thermal comfort. For complete thermal modelling results, including the application of both individual and cumulative retro-fitting measures see Saman et al.2013.

4.3.1 Cooling Energy Requirements
In the context of rapidly increasing electricity prices the total cooling energy required for a household to affordably maintain healthy and comfortable temperatures during a heatwave period is of importance. The modelling shows both the retro-fitting and Cool Retreat approaches offer financial benefits to the household in operating costs in all cases across the three locations. See Figure 4 and Table 3. Reduction in cooling energy requirements in the heat wave period due to retro-fitting ranges from 31 to 46% in Adelaide and from 32 to 51% in Richmond. The greatest relative savings from retro-fitting occurred in Amberley (39-63%), where the largest diurnal variation is experienced and the lowest minimum temperatures occur. Figure 4 shows the results for Case 1, a small 2 bedroom single storey home. Whilst significant reductions in cooling loads and resultant financial costs can be

seen in each case, note also the different cooling loads experienced by the base case in each location.

Figure 4: Cooling Energy Demand During Heat Wave (MJ): Case 1



Variations by location can be seen, with the greatest relative saving occurring in Amberley in all cases. However the highest actual reduction in MJ demand occurs in Adelaide in all cases. Case 1 incorporates a Cool Retreat at ground level, an approach which is shown to be effective in all locations. The below ground Cool Retreats (Cases 2 and 3) offer the greatest further benefits in Adelaide, with only marginal additional benefits experienced in the other locations (See Table 3). This suggests the additional costs of below ground construction may not be justified in all locations when considering operational energy savings alone. The upper storey Cool Retreats in Cases 4 and 5, although unable to take advantage of earth coupling and reduced conduction gains through external surfaces, continue to offer substantial advantages. In summary, the modelling indicates the benefits of the Cool Retreat design approach in reducing cooling demand and associated financial stress in extreme heat situations.

Table 3: Cooling Energy Demand during 4-day heatwave

		Adelaide		**Amberley**		**Richmond**	
		(MJ)	**% of Base Case**	**(MJ)**	**% of Base Case**	**(MJ)**	**% of Base Case**
on-ground Cool Retreat	**Case 1**						
	Base Case	483	100%	299	100%	385	100%
	Retrofit Measures	259	54%	111	37%	190	49%
	Cool Retreat	64	13%	11	4%	34	9%
below ground Cool Retreats	**Case 2**						
	Base Case	645	100%	473	100%	554	100%
	Retrofit Measures	443	69%	259	55%	353	64%
	Cool Retreat	15.3	2%	10.8	2%	37	7%
	Case 3						
	Base Case	963	100%	598	100%	914	100%
	Retrofit Measures	641	67%	364	61%	552	60%
	Cool Retreat	58	6%	14	2%	25	3%
above ground Cool Retreats	**Case 4**						
	Base Case	1051	100%	861	100%	1018	100%
	Retrofit Measures	698	66%	451	52%	695	68%
	Cool Retreat	129	12%	31	4%	104	10%
	Case 5						
	Base Case	700	100%	442	100%	664	100%
	Retrofit Measures	482	69%	177	40%	433	65%
	Cool Retreat	176	25%	56	13%	175	26%

4.3.2 Peak Demand

With increased demand for cooling energy predicted in the future, it is essential to also observe trends in relation to peak demand and requirements placed on the electrical supply and infrastructure system. It is predicted that air conditioner use will continue to increase and that by 2020 nearly 80% of dwellings will have some form of air conditioning (EES 2008). Hot conditions cause problems with power generation and transmission and are also associated with higher greenhouse gas emissions (Matzarakis et al 2011). Electricity transmission systems are vulnerable to high temperatures, particularly when night-time temperatures are high as this reduces the ability of the system to shed excess heat (ISR 2010). A report issued by the Equipment Energy Efficiency Committee (EnergyConsult 2010) states that "energy consumption by air conditioners is driving peak electricity demand growth in all States and Territories, except Tasmania.....creating the need for network augmentation and additional investment. This peak demand is threatening security of electricity supply, causing high prices in the wholesale energy market and generally driving up costs."In Australia, peak demand for power occurs during the hottest weather even for Victoria where peak demand shifted from winter to summer during the late 1990s (EES 2004).

Figures 5 and 6 show the cooling energy requirements and peak demand for Case 1 in each location. Together they show that the reductions in cooling energy demand do not directly relate to reductions in peak demand. Hence, the positive benefits generated for the householders through retro-fitting measures do not translate to equivalent benefits to energy generation and infrastructure.

In all cases but one (Case 2 Adelaide) the reduction in peak load resulting from retro-fitting is significantly less than the reduction in cooling energy demand, with the lowest reductions in peak demand consistently occurring in Richmond. In contrast, the modified designs with Cool Retreats facilitate a far greater reduction in peak demand.

Figure 5: Cooling Energy Demand During Heat Wave (MJ) Case 1

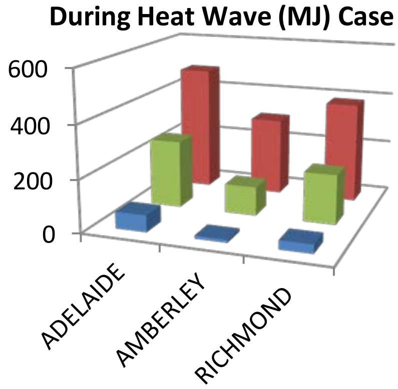
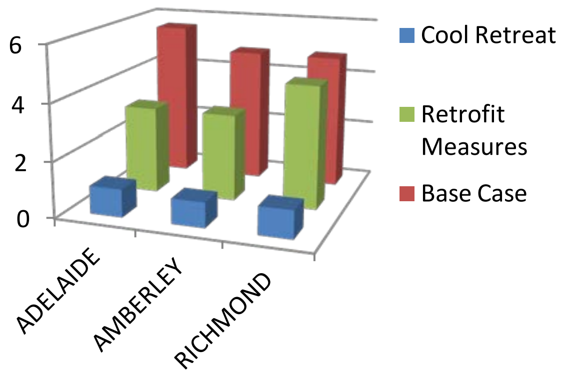


Figure 6: Peak Demand (kW) Case 1



There have been suggestions in the past that the National House Energy Rating Scheme (NatHERS) should be supplemented by a measure of a dwelling's performance during days of peak electricity demand. Different approaches have been investigated, the most relevant by Woolcock, Joy and Williamson (2007). They compared the NatHERS ratings and peak load performance of 12 designs, finding a relatively significant linear relationship between the peak load and star rating of the cases. However, for a given star rating there was a ±30% variation in peak load, suggesting the thermal performance of houses with a given star rating does not directly relate to performance under peak load conditions during heat waves.

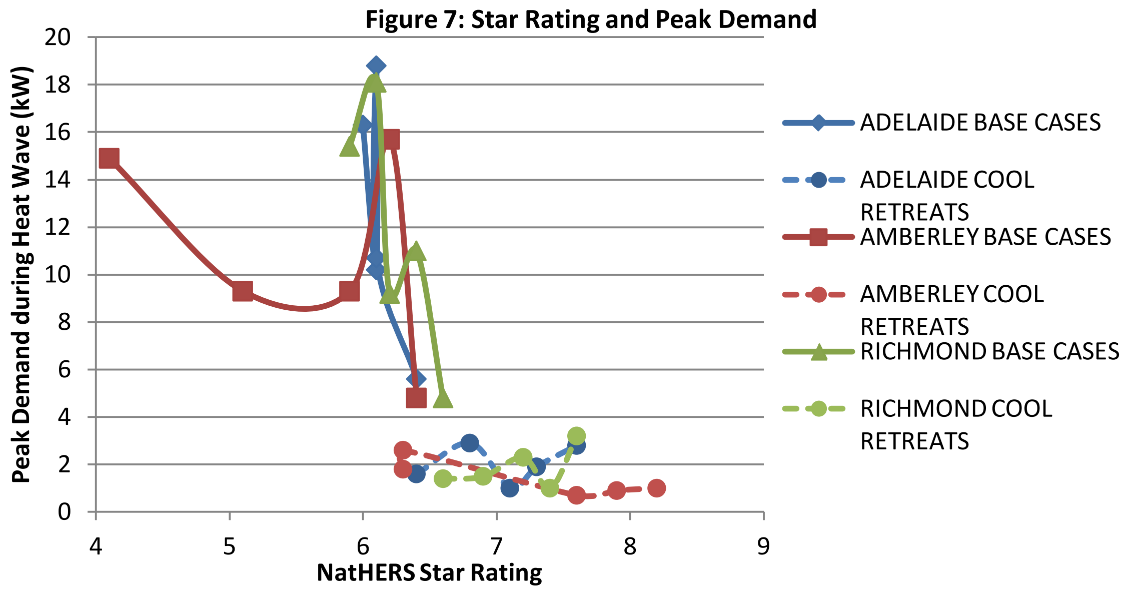


Figure 7 shows the relationships between NatHERS ratings and peak cooling energy demand in the 5 Base Cases and the Cool Retreats during the 4 day heatwave period in all locations. A clear disjunction exists between cooling energy load and peak demand, with cases of the same or very similar star ratings in the same location varying by up to a factor of 2; with no discernable trend. This clearly shows the potential for the modified design, operating in Cool Retreat mode, to significantly reduce the risks associated with peak demand. In summary, Cool Retreats reduce peak demand and risks associated with heat waves even though the extent of impact is not easily quantified by existing building rating schemes.

4.3.3 Thermal Comfort

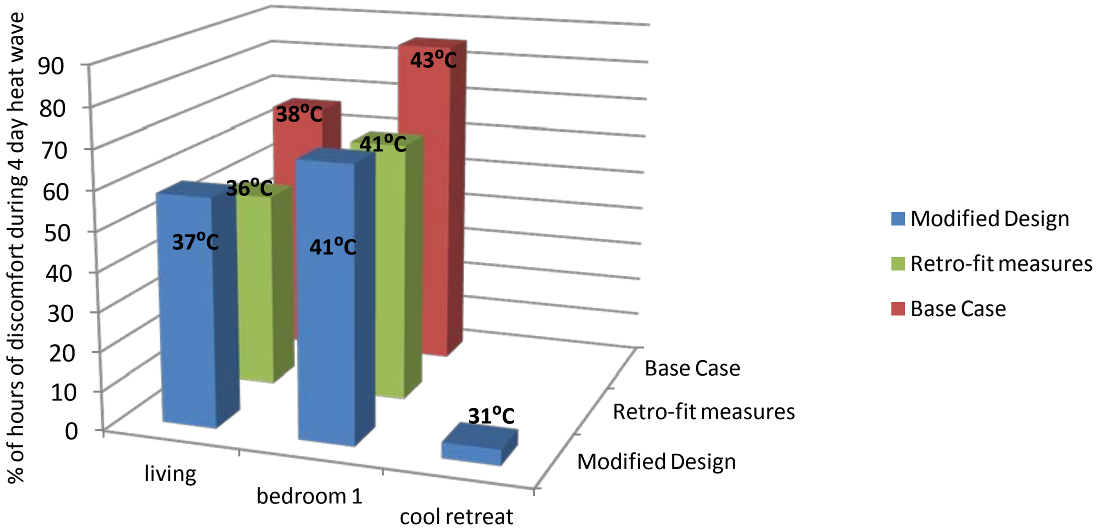
Power outages are common during severe heat waves (ISR 2010). During the 2009 heat wave in southern Australia many households in Adelaide and Melbourne were without power during the extreme heat either due to direct failure of the system or controlled load shedding designed to avert system breakdown. A number of deaths were connected to a lack of air conditioning either due to power cuts or because the household did not have an air conditioner (Son et al. 2012). Access to air conditioning is frequently described as a ‘protective’ factor in reports of morbidity or mortality associated with heat events (O’Neill, Zanobetti and Schwartz 2003; D'Ippoliti et al. 2012) and some researchers advocate increasing the use of air conditioners to address heat-related health issues (Harlan et al. 2006). This can increase problems if power outages occur during heat waves and air conditioning is the only means of mitigation.

In light of the negative impacts of power outages the modelling undertaken here has sought to determine the percentage of hours during the 4-day heat waves in which the houses can provide thermally comfortable living conditions without air conditioning. This is achieved by using AccuRate in non-rating mode to simulate a free-running house. In the Base Cases the upper comfort limit of 30°C for living spaces and 26°C for sleeping spaces is used to calculate hours of discomfort. The upper comfort limit changes to 29°C in the retro-fitted houses due to the introduction of ceiling fans and subsequent increased air movement. As the Cool Retreat in modified designs is proposed for use as a living and sleeping space during heat waves an upper comfort limit of 29°C is used. These upper limits of thermal comfort were developed by Peeters et al. (2008). In the base cases the percentage of hours exceeding acceptable comfort conditions ranges from 26% to 97%, with the most hours of discomfort consistently occurring in Adelaide and the least in Richmond (Table 4).

Table 4: % of hours of discomfort during 4 day heatwave period

	Adelaide			Amberley			Richmond		
	living	bed 1	cool retreat	living	bed 1	cool retreat	living	bed 1	cool retreat
Case Study 1									
Base Case	67	91	n/a	36	73	n/a	32	72	n/a
Retro-fit	47	51	n/a	22	18	n/a	14	3	n/a
Modified Design	57	72	64	29	46	31	22	26	19
Case Study 2									
Base Case	67	86	n/a	40	71	n/a	35	70	n/a
Retro-fit	60	65	n/a	32	35	n/a	26	32	n/a
Modified Design	60	68	1	31	41	0	29	41	0
Case Study 3									
Base Case	66	85	n/a	32	67	n/a	26	63	n/a
Retro-fit	50	66	n/a	20	27	n/a	12	53	n/a
Modified Design	58	69	4	29	43	0	24	44	0
Case Study 4									
Base Case	80	97	n/a	52	97	n/a	49	93	n/a
Retro-fit	72	90	n/a	33	74	n/a	35	72	n/a
Modified Design	n/a	87	71	n/a	54	16	n/a	65	23
Case Study 5									
Base Case	79	95	n/a	36	86	n/a	45	85	n/a
Retro-fit	76	82	n/a	7	30	n/a	23	44	n/a
Modified Design	n/a	83	74	n/a	24	9	n/a	16	0

Figure 8: Hours of Discomfort and Maximum Temperatures Case Study 3 Adelaide.



Also important to consider is the extent of discomfort, not just the duration. In all base cases predicted internal temperatures are highest in Adelaide with the living area of Base Case 2 reaching 40.9°C and the bedroom of Case 3 topping 43.4°C. Retro-fitting reduces the degree of discomfort in all cases in all locations, with maximum internal temperatures reducing by an average of approximately 2.2°C in Adelaide, 2.9°C in Amberley and 2.5°C in Richmond. As these improvements are relatively minor, maximum temperatures after retro-fitting continue to exceed comfort levels for extended periods by a considerable degree, posing health risks to vulnerable occupants during power outages. More significant improvement is seen in the modified designs with the underground Cool Retreats in Cases 2 and 3 providing 100% comfort without air-conditioning in Amberley (max. 28.7°C) and Richmond (max. 27°C), and maximum temperatures in Adelaide reduced to 31.2°C and 31.4°C respectively. The above ground Cool Retreats in Cases 4 and 5 are also shown to be extremely effective in Amberley and Richmond with low hours of discomfort and maximum temperatures which exceed comfort levels by less than 2°C. However, above ground retreats achieve less success in Adelaide, with maximum temperatures of 35.8°C and 36.4°C respectively and a high number of discomfort hours. Similar observations can be made of the ground level Cool Retreat in Case 1 with maximum temperatures of 31.1°C in Richmond, 32.4°C in Amberley and 34.5°C in Adelaide.

In summary, the potential for retro-fitting houses to improve comfort in extreme heatwave events by 2-3°C exists and is beneficial, but greater potential for achieving comfort and reducing risk to health in the event of power system failure requires the implementation of a Cool Retreat. The Cool Retreat can be effective in all the locations analysed however on or above ground situations are significantly less successful than below ground in Adelaide.

5.0 Discussion

The Cool Retreat is proposed as a means of providing greater thermal choice in Australian housing, increasing possible variants in occupation modes and encouraging greater occupant engagement with thermal controls via minor alterations to building planning, zoning and servicing. The thermal modelling reviewed above has demonstrated the Cool Retreat is more effective than retro-fitting approaches in relation to minimising:

- Financial cost to occupant
- Peak demand impacts on infrastructure requirements and system failure risk
- Risk of adverse effects on occupants in the event of system failure during a heatwave

Additional benefits beyond heat wave management are also demonstrated, with the shift from cooling to heating load demand throughout the year providing generally cooler housing. Shifting times of thermal discomfort from the cooling to the heating season gives households greater comfort control and offers significant reductions in greenhouse gas emissions. Whilst the potential benefits of the approach are demonstrated, it is necessary to determine whether or not the Australian public are willing to embrace the proposition. Research group 5 has employed a number of social research instruments, including household interviews with key informants and an on line survey of 500 individuals from Brisbane, Adelaide and Sydney to establish current household behaviour during heatwaves (Saman et al 2013).Currently, 43.1% of on-line respondents report they ‘move to a cooler room in the house’ and a further 31.5% indicate a willingness to move to a cooler room to improve future capacity to deal with heatwaves. The potential for behaviour change through appropriate design solutions is therefore evident. The surveys also addressed issues of retro-fitting costs; showing households are more willing to change behaviour than spend money, with around half of respondents willing to spend up to $2,000 and another 30 per cent not willing to spend any money. As the thermal analysis demonstrated that retro-fitting only has the potential to reduce internal peak temperatures by 2-3°C in an existing 6 star house, this is not unreasonable as the financial savings to the occupant would not be significant. However, far greater benefits would be experienced in the retro-fitting of older, less energy efficient homes. Such expenditure on retro-fitting specifically for heat waves is distinct from the Cool Retreat proposal, which in many dwellings (eg Cases 1, 4 and 5) can be implemented during initial construction or remodelling at minimal additional cost as the main differences are spatial rather than material or technological. .

5.1 <u>Recommendations</u>

Gul and Menzies (2012) assert housing should take account of both passive and active measures to reduce the risk of overheating, and the ability of additional measures to be adapted in the future. The Cool Retreat provides such an adaptive feature. However, the current mechanisms for assessing the thermal performance of Australian dwellings do not recognise such adaptive potential or accommodate possible future variations in occupant behaviour as they remain focused on the reduction of mechanical heating and cooling loads required to maintain a set comfort temperature range in all occupied zones (NatHERS). This active conditioning focus does not specifically address the World Health Organisation advice for building design and heat waves which suggests climate adapted buildings and energy-efficient design should be stressed over air-conditioning (WHO 2004).

Based on the preliminary thermal analysis discussed here, it is suggested energy efficiency building regulations be amended to recognise housing designs which provide occupants with increased thermal choice and provide opportunities to reduce risks associated with heat waves which may not be directly reflected in the annual heating and cooling load. For example, providing a Cool Retreat complying with a series of preset criteria, relative to location. This would require further research to ascertain appropriate criteria for different climate zones, since it has been shown here that while Cool Retreats can be beneficial in all locations, above ground Cool Retreats are less effective in some climate zones than others.

6.0 Conclusion

The Base Case designs representing typical Australian construction are shown to offer occupants minimal thermal choice and fail to provide thermal comfort during heat waves. Drawing on hot weather housing examples from other locations the Cool Retreat is proposed as a spatial means of reducing risk of adverse effects from extreme heat events. The benefits Cool Retreats provide to thermal comfort, financial stress, infrastructure and environmental costs are demonstrated to significantly exceed the benefits possible from material retrofitting via an ecotechnic logic. A limitation of the study to date is the relatively narrow focus on cooling related energy consumption and peak demand. Further interrogation of the Cool Retreat proposal through alternative lenses is required, including a study of the resultant shifting balance between annual heating and cooling loads.

The Modified Designs vary from the Base Cases in relatively minor details, encouraging behavioural changes through possibility, as opposed to the current circumstances where building design effectively limits occupant choice. The Cool Retreat requires active engagement by occupants through behavioural and spatial variation, the willingness for which has been demonstrated. Preliminary recommendations are made in relation to the integration of Cool Retreats in building regulations for energy efficiency. This will require further research to determine practicalities in relation to appropriate climate zones for implementation and a detailed cost benefit analysis of associated construction expenses.

7.0 Acknowledgements

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[i] For full description of the Base Case and Modified Design for all cases, including building plans and material descriptions, see Palmer et al. 2013 and Saman et al. 2013.[ii] The temperatures and energy use in the case study houses are modelled using AccuRate software (Delsante 2005). The AccuRate engine forms the basis of software used for rating houses under the Australian Nationwide House Energy Rating Scheme (NatHers) (DCCEE 2011), has been validated using BESTEST(Delsante 2004) and is widely used for residential building energy research. When used in rating mode AccuRate has default settings for many inputs including the hours of occupation, internal heat loads , heating and cooling set-points and internal window coverings. The program calculates annual heating and cooling energy demand for the building design in the designated climate zone and an area-correction factor is applied to convert the total heating and cooling energy demand to the star rating. When run in non-rating mode, AccuRate can be used to calculate temperatures in a free-running house (i.e. one with no heating and/or cooling applied). In this case some of the defaults still apply (e.g. hours of occupation for different zone types) while others can be changed (e.g. internal window treatment).

[iii] For full details of the Climate Data utilised in the thermal modelling for the four-day heat wave scenarios see Saman et al. (2013).