Heat wave risks and residential buildings

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ABSTRACT: The modelling of the global climate over the 21st century indicates various changes including sea level rise and an overall warming effect of between 1.4 and 5.8 °C. The local effects of these long term global changes are currently being considered. It is probable that more severe and frequent heat waves will pose an increasing risk to the occupants of buildings in Australia and regions around the world. Recent heat waves have caused significant morbidity and mortality as well as a range of disruptive effects in the urban environment. This paper reports on a research project that aims to determine possible design options for adapting residential buildings to more severe heat waves. The focus of the research is on particular residents who are the more vulnerable in the community in terms of both health and financial resources. The paper reviews past and future impacts of heat waves and available mechanisms for dealing with their effects. The paper concludes by suggesting a number of design options that can be considered to adapt dwellings to more severe heat wave conditions.

Conference theme: Architecture and the environment
Key words: Heat waves, dwellings, adaptation options.

INTRODUCTION

One of the primary objectives of housing design is to ensure the health, safety and comfort (both physical and psychological) of occupants, particularly at time of comfort extremes. The majority of people spend most of their time indoors (WHO 2004) and the link between health and housing is well-established (Maller and Strengers 2011). A number of studies have reported on the linkages or relationships between building design and climate change. Until recently much of the information related to building design and climate change has been concerned with mitigating the effects of climate change through reducing CO_2 emissions associated with the building sector. It is increasingly being acknowledged that it is essential to consider both mitigation and adaptation, where adaption focuses on 'reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot fully be eliminated' (IPCC 2012). For example, Kwok and Rajkovich (2010) maintain that even if greenhouse gas concentrations are stabilized in the atmosphere, extreme climatic events and sea level rise will continue for several centuries due to the inertia of the atmosphere. They maintain that policy needs to address both mitigation and adaptation at the regional planning, urban design and building design.

The purpose of this paper is to review literature related to the impacts of heat waves on the built environment and its occupants. It aims to identify the current mechanisms for dealing with the effects of heat waves in residential buildings, and to recommend a number of options that can be considered to adapt dwellings, both existing and new, to more severe heat wave conditions. This paper presents the early stages of one component of a research project titled "A Framework for Adaptation of Australian Households to Heat Waves" supported by the Australian Government's National Climate Change Adaptation Research Facility (NCCARF). The adaptation and design options suggested here will form the framework for subsequent stages of the project.

1. BACKGROUND – WHY ARE HEAT WAVES A PROBLEM?

1.1 Health

Heat waves are associated with a range of health impacts from sunburn, heat stress and heat exhaustion to kidney failure and heart attacks (WHO 2004). Whilst many health concerns can be related directly to heat, it can also play a secondary role through the exacerbation of pre-existing mental and physical ailments or by causing fatigue which can lead to a lack of concentration and consequent accidents (Hansen 2010).

In 2003 heat waves in southern Europe had a devastating impact with estimates of nearly 15,000 deaths in France alone (Vandentorren et al. 2006) and between 25,000-70,000 throughout Europe (D'Ippoliti et al. 2010). Heat waves are also a major source of weather-related fatalities in Australia. During the 2009 heat wave in there was a 62% increase in mortality in Melbourne, a 10% increase in Adelaide (Nitschke et al. 2011) and up to 500 deaths Australia-wide (Kiem et al. 2010).

Of particular concern is the impact on vulnerable sections of the community such as the young, elderly, homeless and socially or financially disadvantaged (Vandentorren et al. 2006). Harvison et al. (2011) suggest that the combination of an ageing population and the impact of aspects of climate change, such as increasing heat waves, introduces particular concerns in relation to the built environment. There is little information about specific aspects of building design and the heat-related health of the occupants. At a general level, studies have shown that most heat-related deaths are likely to occur in the home or in nursing homes (Dhainaut et al. 2004). Bedrooms have been singled out as an area of particular concern. Lack of sleep is one of the factors that pre-disposes people to heat-related illness (WHO 2004) and increased heat-related morbidity and mortality has been identified after a second night of elevated minimum temperature (Nitschke et al. 2011). A study of risk factors associated with deaths during the 2003 heat wave in France highlights two that relate to bedrooms: having a bedroom directly under an un-insulated roof and the number of hours that the bedroom receives sunlight (Vandentorren et al. 2006). Other building-related risk factors identified are a lack of insulation, greater number of windows per floor area and smaller dwellings.

1.2 Power consumption, peak loads

A number of studies have reported on the impact of heat waves on power consumption due to increased reliance on air conditioning (Vandentorren et al. 2006; D'Ippoliti et al. 2010). Power outages are common during severe heat waves due to both high peak loads and problems with power generation and transmission. Transmission systems are particularly vulnerable when night-time temperatures are high, as this reduces the ability of the system to shed excess heat. This was evident during the 2009 heat wave in southern Australia when 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.

Access to air conditioning is frequently described as a ‘protective’ factor in reports of morbidity or mortality associated with heat events (D'Ippoliti et al. 2010) and consequently some researchers advocate increasing the use of air conditioners to address heat-related health issues (WHO 2004). However, Maller and Strengers (2011) caution against the suggestion that increased air conditioning is the best way to address heat-related health problems. They maintain this ‘techno-fix’ may mean other strategies such as passive design measures are ignored, increasing both financial and environmental costs of achieving comfort. Where air conditioning is employed as the sole means of adaptation more significant problems can be experienced if power outages occur during heat waves. In addition, it is suggested that increased reliance on air conditioning may reduce acclimatization (Institute of Sustainable Resources 2010), further driving energy demand. None-the-less, it is predicted air conditioner use will continue to increase and that by 2020 nearly 80% of Australian dwellings will have some form of air conditioning (EES 2008).

1.3 Other impacts

There is a range of other impacts associated with heat waves such as damage to transportation systems (Institute of Sustainable Resources 2010), reduced economic activity (PwC 2011), increased risk of bushfires (CSIRO 2007), increased water consumption and problems with water quality (PwC 2011). The impacts can be inter-related. For example, disruptions to transport can have a flow-on impact on business activity and productivity and power outages may increase the difficulty of dealing with bushfires.

2. ADAPTATION AND DWELLING DESIGN

Current impacts associated with heat waves have been well-researched. Less clear is the connection between residential buildings, increased heat waves anticipated in the future and the potential for building and occupant adaptation. A literature review has been undertaken of past adaptive strategies employed in other cultures and in pre-air-conditioning times that can inform the design of dwellings for greater thermal comfort during heat waves. The literature review suggests that adaptation to future heat waves requires integration of knowledge from past, present and future. This section of the paper is structured around this required knowledge.

- Past: reflection on responses to hot climates and heat waves prior to reliance upon mechanical cooling,
- Present: recognition of the state of existing housing stock and current mechanisms for dealing with effects of heatwaves in the built environment,
- Future: prediction of future climatic conditions, dwelling needs and policy requirements.

2.1 Past responses to hot climates

While not as extensive as the literature for temperate and cold climates, there is considerable material about designing for hot climates (see for example work by Hassan Fathy (1986) and Paul Oliver (2003) about vernacular architecture and Koenigsberger et al. (1974) and Konya (1980) for early scientific approaches to design for hot climates). In many cases design for heat waves may be different from designing for climates that are generally hot – the period of discomfort may be brief but intense and design solutions that focus on adaptation may involve not just changes to the building stock but also to the way we occupy spaces and to design practices and cultural attitudes.

2.1.1 Australia: Some of the earliest European settlements in regional Australia were in locations with inhospitable climates due to their connection with mining activities. In many regions dwellings were excavated into hillsides or creekbeds or created underground to escape the desert heat (Bell 1998). Lewis (undated) reports that early miners' houses in Broken Hill often had a stone-walled sleepout below ground level where the night shift workers slept during the day. Dugouts still exist in mining towns such as Coober Pedy and Andamooka.

A more widespread example of sub-grade construction is the basement. South Australia has a number of larger residences built in the 19th century that incorporate basements or sub-grade rooms that appear to be designed specifically for use during hot weather as evidenced by their name: for example the 'summer room' of Ayers House (National Trust of S.A. undated). Lewis (undated) lists 19th century examples in other regions in Australia including the more temperate climates of Melbourne and Ballarat as well as hotter areas such as Hay, south-western Queensland and Mildura (where irrigation pioneer W. B. Chaffey had an underground ballroom).

The integration of cooler rooms for summer comfort is not limited to basements. In some early buildings internalised halls at ground level provided respite from the heat through the use of sheltered thermal mass. Writing about Denham Court, constructed in New South Wales in 1835, Roxburgh et al note; "The early settlers were more troubled by the heat than cold and the fine stone-flagged hall was probably designed as a hot-weather sitting room." (1974:78). The coolness of the room is further enhanced by its connection to the volume of the upper levels of the house via the open stairwell which enables heat to rise via buoyancy.

The early Australian examples of summer rooms are most commonly seen in residences of the upper classes. Among the less privileged residents of Australian cities and towns many behavioural and adaptive techniques were employed in response to hot weather. These ranged from changing clothes, reducing activity, rescheduling activity to cooler periods of the day and drinking more water to 'manipulating' the building, by changing floor coverings and opening or closing screens and blinds. Individuals' routines were inevitably more connected with the thermal cycles of the day and residents had the knowledge and lived experiences to interact with their built environment, adjusting and refining thermal conditions as best as possible. It is inevitable that some discomfort will be experienced in heat wave periods when purely passive control techniques are employed. Unfortunately, the historic willingness to modify behaviour and alter thermal expectations with time has arguably diminished with the wide spread introduction of air-conditioning and with it the knowledge of ways to 'deal with' hot weather is being lost.

2.1.2 International: Examples of international adaptation to climate through traditional building techniques provide a plethora of information. Much is known of traditional building from around the globe in relation to passive design, orientation, shading, ventilation and evaporative cooling. Such properties are omitted from this discussion as an understanding of adaptive spatial design strategies and adaptive behaviour relative to heat is specifically sought. Common features of traditional hot climate housing is briefly summarised below.

Table 1: Adaptive spatial design strategies and adaptive behaviours in hot climates

Adaptive Behaviours		Example/Location
Movement/ relocation	Numerous cultures experiencing climatic extremes occupy space in a seasonally appropriate manner. People move between rooms over the year and, when necessary, relocate bedding to the coolest room of the house. Daily movement is also important in summer months, with morning activities undertaken in cool, ground-level spaces, siestas in basement rooms ventilated by evaporative wind catchers and night time sleeping moves to the roof when temperatures permit.	Baghdad (Warren 1982) Saudi Arabia (Talib 1984) Egypt (Elawa 1981)
Spatial Design Strategies: Dwelling		
Variation in volume	High volume spaces allow hot air to rise above the occupied zone and promote cooling air movement where high level openings are employed. Many examples combined occupied spaces of varying volumes, providing varying thermal experiences to the occupants over the course of the day or year, extending the period of time in which perceived comfort is achieved.	Indian bungalow Middle East Turkey (Ertug 1980)
Multi-purpose spaces (daily)	Flexibility of function enables activities to occur in almost any space of a dwelling, allowing selection of the most thermally appropriate space at any time of day. To maximise flexibility the need for additional furniture is minimised, allowing a living space to be easily transformed to a dining or sleeping space as required.	China (Knapp 1989) Middle East Egypt (Elawa 1981) Syria (Yagi 1980)
Multi-purpose spaces (seasonal)	In some cases, rooms utilised primarily in summer are employed as storage spaces as they are too cold to inhabit in winter. For example, Afghanistan terrace houses typically have a guest room to accommodate travellers. The guest room is located in the coolest area of the house, providing appropriate conditions for storage through winter and enabling the space to double as a summer living room.	Middle East (Warren 1982) Afghanistan (Samizay, 2003) Egypt China (Ho 2003)
Spatial internalisation / buffering	For example, the Turkish sofa room is located in the centre of the ground floor of the 2-3 storey home with typically one short wall exposed to the exterior. It provides the social nexus of the home and is able to be thermally zoned from all other spaces. It borrows light, views and ventilation from adjacent closable porches, which act as thermal buffer zones and shade the central space.	Turkish Sofa Room (Ertug 1980)

Direct cooling of occupant	In many locations great care is given to the relationship between the occupant and the building with regard to cooling. In some cases in-built furniture locates the occupant adjacent to air movement opportunities and cooling materials. For example, in summer rooms in Middle Eastern courtyard houses one siestas adjacent to a vent introducing evaporative cooled air directly onto the occupant.	Middle East Egypt Turkey Pakistan India (King 1984)
Linking to outdoor spaces	Outdoor spaces of different orientations and shading appropriate to different times and seasons are often linked living spaces, each thermaly and functionally dependent on the other. For example, the verandah, provides shade to exterior walls at the same time as creating shaded external spaces for household activities. The potential to enclose verandah spaces with vertical membranes (eg wetted screens) enables further conditioning of exterior and interior space. American and Australian 'Bungalow' houses of the 19th and 20th centuries included screened sleeping porches.	Indian verandah (King 1984) Middle Eastern courtyard (Rabbat 2010) American porch (Comstock 1990)
Spatial Design Strategies: Urban Scale		
Urban Shading	Many urban courtyard houses effectively self-shade, reducing solar exposure to the roof only with all external walls and windows oriented into courtyards or shared with neighbours. The urban form generated by courtyard houses in Saudi Arabia highlights the benefits of houses clustering to achieve thermal comfort internally and also the ability of the buildings to shade both streets and public spaces defined by the building form, increasing outdoor activity.	Middle East Egypt Baghdad Saudi Arabia Greece

2.2 Present – Existing housing stock

In Australia the main type of dwelling is the separate house (78%), the proportion of which has only decreased 1% in the decade since 1997 (ABS 2010). In 2009-2010 the most common dwelling was a 3-bedroom house (41%) and 28% of dwellings had 4 or more bedrooms (ABS 2010. In 2007 more than three quarters of dwellings in Australia had more bedrooms than were needed to accommodate the occupants (ABS 2007). Since the 1990s the density of new housing development in Australia has increased (Hall 2009). Lot sizes in many new housing estates are only about a third the size that they were fifty years ago, whilst at the same time the average floor area of new homes has increased, recently to the point of being the largest in the world (James 2009).

Australia's typical single storey freestanding suburban homes seldom employ the traditional cooling or comfort techniques shown in Table 1 and provide many challenges to thermal adaptation in heat waves. Built with minimal internal mass and with relatively low, consistent ceiling heights throughout, they seldom have the benefit of extensive urban shading and reliance upon mechanical cooling has become accepted. Current building designs usually include large, open living areas without potential for thermal zoning, increasing demand on cooling systems. Houses are closer together, privacy is often an issue and the perceived need for increased security has all but eliminated the tradition of throwing homes open to naturally cooling breezes.

It has been suggested that new buildings in Australia that comply with the energy efficiency requirements of the National Construction Code, Building Code of Australia (BCA) are reasonably resilient to the *average* changes expected with climate change although they may not be sufficiently resilient to extremes such as heat waves (AGO 2007). Dwellings constructed prior to the introduction of energy efficiency requirements, the vast bulk of the current building stock, have far less adaptive capacity.

Whilst the statistics provide an insight into recent trends, the context and quality of existing Australian building stock is extremely diverse and replacement of housing stock is slow – "over the past decade Sydney and Melbourne have added on average 1.4% and 2.1% overall stock each year" (Kelly et al. 2011: p. 37).

2.3 Present – Current mechanisms for dealing with effects of heat waves

In response to the National Climate Change Adaptation Framework (NCCAF) endorsed in 2007 and the heat waves of 2008-9 many states and councils developed heat wave response plans (see for example DFC 2010; SA SES 2010; Dept of Health 2011). These plans include strategies for issuing warnings and alerts about forthcoming heat waves, provision of information about what to do in a heat wave and mobilization plans for various government agencies and, in some cases some general recommendations about aspects of building design such as shading and ventilation.

The NCCAF specifically refers to the need for building codes, standards and guides to increase resilience to climate change and the need for the Australian Building Codes Board (ABCB) to consider climate change as part of their periodic reviews of the BCA (AGO 2007). A subsequent ABCB study of possible adaptation measures for climate change states:

> *the BCA does not currently address issues of thermal comfort directly. Rather, energy efficiency requirements effecting material selection, passive solar design and minimum levels of insulation serve to regulate a buildings internal temperature and therefore reduce risks during heatwaves* (ABCB 2010: 61).

The ABCB 2010 report also found that "by and large, the bulk of the BCA's energy provisions will contribute to positive adaptation outcomes" (ABCB 2010: 24)

2.4 Future – Predicted climatic conditions

It is predicted that one impact of climate change will be an increase in the number of days over 35 °C with more hot nights, hotter weather in spring and autumn and more heat events (CSIRO 2007; PwC 2011). Nguyen et al. (2010) investigated the likelihood of increased hot days and hot spells for different locations in Australia and the impact on building thermal performance and found that the longer the hot spell the more cooling required. A 3-bedroom house required 32% more cooling energy during a 4-day hot spell than for 4 individual hot days.

2.5 Future – Dwelling Needs

Australia's population is increasing and it is aging, with the proportion of people aged over 65 predicted to increase from 13% (in 2010) to more than 23% in 2050 (Commonwealth of Australia 2010). Recent Government policy aims to support older people staying in their own homes (Department of Health and Ageing 2012) and the vulnerability of the elderly the heat waves must be considered. It is also predicted that the proportion of lone person households will continue to grow and estimates are that, in Melbourne for example, one or two occupants per dwelling will account for 90% of all new households by 2030 (Dept of Sustainability and Environment 2005).

2.6 Future –Policy requirements

The recent Productivity Commission draft report, *Barriers to effective climate change adaptation* (PC 2012), notes that the BCA is based on historical weather and climate data which needs to be reviewed and updated and that although there have been numerous requests that climate change be addressed in the BCA, to date this has not happened. On the other hand, the Commission observes that the BCA deals with new buildings and that existing buildings pose a greater problem as they are not required to keep abreast of requirements of BCA, and there are issues regarding lack of information, the costs associated with adaptation measures, and 'split incentives'.

The ABCB 2010 study of possible adaptation measures for climate change in relation to the BCA suggests the existing focus on building energy requirements rather than occupant comfort in heat waves is likely to continue:

> *despite heat waves posing a clear health and life safety risk, it remains unclear the role buildings have played; relative to other factors such as age and health of those persons affected. Clearly a building's ability to maintain stable internal temperatures will reduce some of the health risks associated with heat waves;* (ABCB 2010: 61).

This assumed correlation between total annual energy demand and thermal behaviour of a building in heat wave conditions has been studied by Woolcock et al. (2007). The study compared National House Energy Rating Scheme (NatHERS) ratings and performance on a peak load day for twelve dwelling types of various construction materials and orientations. A relatively strong and significant linear relationship was found between the peak load and star rating of the cases, however for a given star rating there was a ±30% variation in peak load values. Hence, the thermal performance of houses with a given star rating does not directly relate to performance under peak load conditions caused by heat waves.

There have been suggestions that the current NatHERS should be supplemented by a measure of a dwelling's performance during days of peak electricity demand (generally days of extreme heat). Saman and Halawa (2010) investigated a different approach based on heating and cooling appliances.

Future land-use planning needs to work in conjunction with standards and codes (PC 2012; BRANZ 2010). Many States have released plans to guide growth in the coming decades (Dept of Sustainability and Environment 2005; Dept of Planning and Local Government 2010). The proposed location of new development, dwelling types, open space, landscaping provision and density will affect the thermal performance of new dwellings. The documents refer to mitigation and adaptation with references to passive design strategies related to cooling; ventilation, shading, insulation and thermal mass. Many publications about building design and climate change list similar passive design strategies without going into more detail or referring to specific examples (see for example Snow and Prasad 2011).

Much of the current information about designing for heatwaves and the existing and proposed policy can be characterised in one of two ways: either it is building-focussed and concentrates on energy use with little mention of the occupants, comfort or health or it is people-focussed and the references to dwellings and building design are in the form of broad generalisations of passive design principles. At this time none of the existing or proposed policies relevant to residential design positively promotes the use of adaptive strategies as identified in the historic cases (see sections 2.1.1 and 2.1.2 of this paper).

3. FURTHER INVESTIGATION

The literature review summarised above presents the initial stages of the research project and determines the scope of further investigations required to adequately address the adaptation of Australian residences (and occupants) to future heat wave conditions. Critical findings from the literature include the following:

Promoting Adaptive Behaviours: Design solutions can offer opportunities for occupants to engage in adaptive behaviours on daily or seasonal timeframes. Dwellings that provide occupants with greater thermal variation have the potential to promote thermal knowledge, acceptance of thermal variation and flexibility of thermal expectations.

Cool Retreats: Integrated with the idea of promoting adaptive behaviours, cool retreats or 'summer rooms' encourage occupants to reduce active cooling loads through the occupation of smaller zones of the building during extreme heat. The 'spare bedroom' identified by housing data as ubiquitous to the Australian housing market may provide an ideal space to employ in this manner. In existing housing the conversion of garages, often located in the coolest location in the house with mass flooring, is also an option. Cool retreats may be located either below ground level, as seen in early Australian examples and Middle Eastern courtyard housing (Warren and Fethi 1982), or above ground in a sheltered position similar to the Turkish sofa room (Ertug 1980).

Earth Coupling: Design solutions for future Australian housing that make effective use of the benefits of earth-coupled construction may offer an economical means of providing thermal comfort during heat waves. Numerous construction techniques and spatial relationships are possible. The courtyard or atrium houses of Islamic cities, the terraced dwellings of Afghanistan (Samizay 2003), shaft dwellings of Tunisia (Talib 1984; Oliver 2003) , and the pit houses of Shanxi Province North Eastern China (Ho 2003), each utilize differing connections between interior and exterior spaces together with variable relationships to the natural ground plane.

Balancing Seasonal Needs: A significant challenge in the design of high mass houses for maximum summer thermal comfort is the trade-off this may require in winter performance. The combination of massive and light weight construction is recommended in various Australian locations (Reardon 2010) with design solutions typically demonstrated for low density suburbs. Historical construction techniques employed in Turkey provide a useful precedent for translating these practices to medium density environment. These techniques incorporated thermally massive ground floor construction with lightweight timber upper stories (Ertug 1980).

Interior/exterior spatial relationships are understood as an important component to the Australian lifestyle. Improving thermal conditions in external spaces reduces the time spent indoors and hence the duration of active thermal conditioning. Increasing connection with climatic variation also has the potential to increase occupants' thermal tolerances. Design examples such as the traditional houses of Zhejang, China which have a deep, shaded terrace for household activities under the main house roof provide moderated external conditions throughout the year (Knapp 1989). The paved courtyards of typical Middle Eastern houses provides an example of the use of mass in occupied external spaces and its relationship to achieving comfort condition both in interior and exterior zones that can be applied to Australian environments and lifestyles.

Policies and Building Codes: Current Australian rating systems for energy efficiency in dwellings provide a single score for predicted total annual heating and cooling energy load to consistently condition all habitable spaces throughout the year. It is evident from the literature that heating and cooling loads can have significantly different implications for individuals and society, more so in some regions than others. Additionally, the processes of heating and cooling occupants in extreme conditions are very different as various options exist for achieving adequate warmth whilst the expulsion of excessive heat has thermodynamic limitations.

The active promotion of adaptive behaviours to hot weather and heat waves, including the employment of cool retreats, could be integrated into building energy rating schemes through the use of separate heating and cooling ratings which reflect seasonal occupation patterns. As housing designs are directly informed by rating schemes and building codes this would encourage housing designs that effectively encourage adaptive occupant behaviours to reduce cooling loads. This would also represent reduced costs to occupants (financial and health), infrastructure and the environment: an effective combination of adaptation and mitigation.

Urban Policies: Future urban policies should address mitigation and adaptation at an urban scale rather than primarily from a building perspective. Policies might then take into consideration how streets and public spaces are affected by heat events and what role building form might play in mitigating these effects. This suggestion is in line with the World Health Organisation (2004) which suggests that in order to maximise the thermal comfort in urban areas, climatic aspects should be considered in all scales from the design of the individual building to regional planning.

A number of these findings will be further investigated in the subsequent stages of the project, whilst others may provide grounds for future research.

4. CONCLUSIONS

Several conclusions can be drawn from the critical review and synthesis of literature. The study acknowledges that, while different in aim, mitigation and adaptive strategies are inextricably linked and both are crucial in response to climate change. The stronger or more successful mitigation strategies are in stabilising or slowing climate change, and therefore the magnitude of the change in climate, the less reliant the community will need to be on adaptive measures allowing them to cope with climate-induced exposures. Equally there is overlap in the benefits delivered by both types of strategies. Some measures to mitigate against climate change will have an adaptive function; whilst reducing the building's overall energy consumption in maintaining thermal comfort (mitigation) they will also deliver adaptive benefits which allow the occupants to cope more successfully with hotter seasonal temperatures and during heatwave events.

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PROJECT PROGRESS

The concept of a cool retreat may offer a lower energy solution for maintaining comfort conditions during heatwaves for both new and existing housing. The incorporation of below or partially below grade basements and internal rooms for new housing designs requires further investigation as does the retrofitting of particular zones or rooms in existing housing. These options will be the focus for the future stages of the research project.

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