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The Australian Building Codes Board

An Investigation of Potential Health Benefits from Increasing Energy Efficiency Stringency Requirements

Building Code of Australia Volumes One & Two

Associate Professor Terry Williamson

Dr Elizabeth Grant

Alana Hansen

Associate Professor Dino Pisaniello

Dr Myla Andamon

The University of Adelaide

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Adelaide Research and Innovation Pty Ltd
The University of Adelaide, AUSTRALIA 5005

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EXECUTIVE SUMMARY

In 2009, the Council of Australian Governments announced that it would request the Australian Building Codes Board to increase the energy efficiency provisions in the 2010 edition of the Building Code of Australia (BCA). These changes comprise a 6 Star energy rating, or equivalent, for new residential buildings; and significant increases in the energy efficiency requirement for all new commercial buildings. This report, through literature review, explores the possible positive and negative health related effects as temperature and other conditions change within a building to satisfy the energy efficiency provisions resulting from the proposed Building Code of Australia changes. As all new buildings have been required to satisfy BCA energy efficiency provisions for several years and it is likely that the most severe building defects that may impact on health conditions have already been eliminated; this report therefore focuses on the incremental benefits that might flow from an increase in the standard of construction.

There is an association between weather and health. Weather refers to the ambient climatic conditions, not necessarily the conditions within buildings and temperature is generally taken as the main indicator of climate severity. Low or high temperatures may lead to human stress situations and result in increased morbidity and mortality. At a population level, heat-related health issues generally are at their lowest at moderate temperatures and increase with elevated or reduced temperature conditions. Populations in colder cities are more affected by warmer temperatures, whilst those in warmer cities notice a greater effect of colder temperatures. While both cold and hot temperatures increase the risk of mortality, hot temperatures are likely to have greater effects. The effects of extreme heat are more immediate, occurring within one or two days of a hot weather event. Periods of hot weather generally exacerbate underlying health conditions in vulnerable populations resulting in an increase in hospital admissions, emergency department visits and ambulance transports. Heat-related fatalities generally occur at an individual's place of residence, which may be a private residence, an institution or the like. The incidences of heat-related mortality in other buildings appear to be low.

Certain populations are more prone to temperature-associated illness than others. Vulnerable populations include the elderly, those with chronic or underlying medical conditions (e.g. kidney disease, respiratory or heart disease), mental illness, and the social disadvantaged. Many drugs can affect the thermoregulatory process and can contribute to heat stroke. The pharmacological effects of some medications may be a contributing factor to the increase in hospital admissions for renal and mental disorders observed during heat waves. Predictors of heat-related illness (including fatalities) are socioeconomic status (indicated by households without air conditioners or heaters), race and less educated individuals. Living in social isolation increases vulnerability.

It is likely that in a changing climate, future temperature-related health issues will be dependent on the adaptive capacity of populations, including improvements to building design. The presence of air conditioning does not always guarantee its use, particularly with elderly householders with mobility or cognitive problems and those with financial concerns relating to energy costs. Fuel poverty may also be an issue but is under researched in the Australian context.

No studies or field data were found that detail health benefits that might accrue from an incremental change in building energy-efficiency (eg a change in rating from 5 to 6 Stars for houses). In a New Zealand intervention study which upgraded the standard of housing by adding thermal insulation, health benefits were measured in terms of hospital admissions, days off school and days off work and the private cost saving per household of visits to general practitioners and mental health improvements. The study was limited to considering the winter time benefits. Applying a number of assumptions the findings have been extrapolated to the Australian context. An estimated health benefit value of $111.00 per household from moving to a 5 to 6 Stars can be calculated as a potential maximum. This figure however would most likely apply to only the most vulnerable households (eg low income and elderly). The actual value is likely to be significantly less because the majority of households would off-set minimum temperatures by some form of heating. Assuming the penetration of heaters in new houses to be the same as the whole population we estimate the benefit to be a maximum value of $9.50 per annum per household. No data exists to estimate similar health benefits associated with higher (summertime) temperatures.

With no appropriate data available the quantification of health benefits for the occupants of other buildings has not been attempted.

This work has shown that a knowledge gap exists in this area with almost no research having been undertaken in Australia to establish potential health benefits of energy-efficient building improvements. The minimisation of temperature extremes within buildings, noise-related health impacts and air pollution related morbidity and mortality in an enlarging vulnerable population may yield significant savings to Australia's health sector but as yet there is little evidence to back this proposition.

1.0 INTRODUCTION

On 30th April 2009, the Council of Australian Governments announced that it would request the Australian Building Codes Board (ABCB) increase the energy efficiency provisions in the 2010 edition of the Building Code of Australia (BCA).

To achieve this aim the changes proposed for the 2010 BCA, released for comment by the ABCB, include:

- A 6 star energy rating, or equivalent, for new residential buildings; and
- A significant increase in the energy efficiency requirement for all new commercial buildings.

These initiatives are to include provisions for national energy efficiency for hot water and lighting in new homes.

The provisions of the Building Code of Australia Volumes One and Two include a requirement for minimum energy performance standards with the 'objective of reducing green house gas emissions by efficiently using energy'. Whether BCA compliance is demonstrated by computer energy performance simulation or by satisfying specified elemental provisions of Acceptable Construction Practice the building elements manipulated to achieve an appropriate outcome will include:

- the building fabric & thermal insulation (roofs, external walls and floors),
- external glazing, type and distribution,
- shading,
- building sealing, reduced infiltration, controlling fresh air exchange rate (ACH),
- air movement and ventilation (both natural and assisted), and
- insulation of services.

This report explores the possible health related effects (both positive and negative) as temperature and other conditions change within a building to satisfy the energy efficiency provisions resulting from the most recently proposed BCA changes. All new buildings have been required to satisfy BCA energy efficiency provisions for several years and we can therefore assume that the most critical building defects with the potential to severely impact on health are likely to have been eliminated. It is assumed in this report that the proposed changes should continue this situation. The potential detrimental effect on indoor air quality resulting from increased air tightness, although unknown, is implied to be negligible.

Likewise we assume that design expertise and building practices are adequate to ensure the improved thermal performance is achieved and that no adverse effects are introduced by the improved standards. This report therefore concentrates on the benefits to health that may flow from an incremental improvement in the standard of construction following from the proposed changes.

2.0 WORK TASKS

The work undertaken in this consultancy is limited generally to a review of existing literature for both Australian and overseas conditions. It deals specifically with the following issues:

- Identifying health related illnesses due to heat stress and cold conditions,
- Identifying the people at greatest risk of such illness,
- Identifying possible reductions in the risk of health problems and potential occupant benefits due to improvements to indoor temperature conditions from proposed BCA changes (from 5 star rating to 6 star rating),
- Identifying the areas of possible savings for health services,
- Identifying the potential impacts of climate change on building performance and consequential health related issues,
- Identifying (and if possible quantifying) the effects on indoor temperatures of making houses more energy efficient (from 5 Star rating to 6 Star rating),
- Identifying people’s reactions (or potential reactions) to extreme weather conditions and health related matters.

2.1 Methodology

This report reviews the literature on the health benefits of energy efficiency measures for buildings. The majority of this literature is concerned with domestic housing and this report emphasises this area. The process of literature review required identifying, reading and evaluating relevant literature sourced by various means, using a collaborative, interdisciplinary approach.

Initially, research was conducted to define the effects on human health of exposure to temperature extremes. This was undertaken using a search of peer-reviewed scientific publications sourced mainly from the PubMed database. Various combinations of search terms including ‘heat’, ‘cold’, and ‘health’ were used, as well as other terms based on knowledge of the public health literature. Only the most relevant articles were accessed from the vast amount of publications identified using this methodology. Follow up searches were undertaken to source relevant references cited in these articles.

To investigate the public health impacts of air pollution (indoor and outdoor), and climate change, a similar process was used. Additionally, reports and publications from recognised government departments and national and international organisations such as the Intergovernmental Panel on Climate Change (IPCC) and the World Health Organisation (WHO), were accessed electronically. The Australian Bureau of Statistics website provided valuable information on heating, cooling, household energy usage, trends in building design and presence of insulation in Australian dwellings[1].

Publications relating to the association between buildings (predominately relating to housing) and health were sourced using various internet search engines and databases including the PubMed database. The majority of relevant publications identified were from Europe and the United States and related to energy efficient interventions to mitigate the effect of cold weather. Although not exhaustive, the search revealed investigations of housing and thermal stress in a hot environment were rare, with little evidence based research from the Southern Hemisphere, however, recent New Zealand work proved to be particularly useful. Several assumptions need to be considered in this assessment and these assumptions are outlined in Appendix A.

[1] (DEWHA, 2008) available for download at: http://www.environment.gov.au/settlements/energyefficiency/buildings/publications/energyuse.html contains similar information.

3.0 THE ASSOCIATION BETWEEN WEATHER AND HEALTH

A considerable body of literature has identified an association between weather and health. Weather refers to the ambient climatic conditions, not necessarily the conditions within buildings. In general, air temperature is taken as the main indicator of climate severity. Low or high temperatures may lead to human stress situations and result in increased morbidity and mortality. At a population level, the relationship between ambient temperature and mortality has been described as U, V (Ballester, Michelozzi, & Iniguez, 2003; McMichael et al., 2008; McMichael et al., 2003) or J-shaped (Basu & Samet, 2002; Braga, Zanobetti, & Schwartz, 2001; Curriero et al., 2002) with death rates generally lowest at moderate temperatures and increasing with both elevated or reduced temperature conditions. This relationship varies according to local temperature thresholds, latitude and climatic zone (McMichael, Woodruff, & Hales, 2006). Populations in colder cities are more affected by warmer temperatures, whilst those in warmer cities notice a greater effect of colder temperatures (Curriero et al., 2002; McMichael et al., 2006). At the individual level, severe health effects can occur when there is a failure in thermoregulation. The following sections describe the mechanisms of thermoregulation and the particular effects of hot and cold weather conditions.

3.1 Thermoregulation

The human body receives or loses heat from the surroundings by radiation, convection and/or conduction. A hypothetical environmental temperature provides a single measure of these heat flow mechanisms as received by a body. The adaptation of humans to environmental temperatures is dependent on their ability to balance the gain or loss of body heat accordingly. Thermoregulation is the process of maintaining a stable core body temperature around 37^{o}C (Bouchama & Knochel, 2002). Minor variations due to environmental conditions or changes in metabolic rates are detected by the body's thermoreceptors and involuntarily compensated for by physiological processes initiated in the hypothalamic region of the brain (Bouchama & Knochel, 2002; Vander, Sherman, & Luciano, 1975).

In response to cold, the major form of body heat generation occurs via changes in muscle activity. A gradual increase in skeletal muscle tone leads to shivering (Vander et al., 1975), the muscle tremors acting to increase internal heat in a similar manner to voluntary muscular activity. Non-shivering thermogenesis also occurs generating internal body heat, which is conserved with the aid of cutaneous vasoconstriction (Vander et al., 1975).

The opposite occurs in response to high environmental temperatures. Muscle tone is involuntarily decreased and voluntary movement is generally minimized (Vander et al., 1975). Cutaneous vasodilation occurs as a result of increased cardiac output and as a consequence heat is dissipated at the body surfaces (Simon, 1993) principally via radiation, convection and the evaporation of sweat (Vander et al., 1975).

Behavioural thermoregulation, the ability to respond physically (e.g. by wearing appropriate clothing, seeking shelter from the elements and being able to adapt for thermal comfort) is an important aspect of human temperature regulation in both the outdoor and indoor environment (Vandentorren et al., 2006).

Thermoregulatory failure due to age, illness or overload of the physiological mechanisms, can lead to poor health outcomes ranging from mild to severe. In extreme conditions these may include hypothermia due to cold exposure; or hyperthermia from heat exposure, excessive heat production, or diminished heat loss (Simon, 1993).

3.2 The health impact of cold weather

In temperate regions of the world, mortality rates are generally highest in the winter (Braga et al., 2001; Curriero et al., 2002), with the risk of death increasing as temperature decreases (Barnett et al., 2005). A study of cold exposure and winter mortality in Europe found that all-cause mortality was greatest as temperatures decreased in warmer regions, particularly in populations with cooler homes (The Eurowinter Group, 1997).

Cold related deaths often occur due to respiratory diseases or arterial thrombosis. Rates of coronary events have been found to increase during cold periods, particularly in warm climates (Barnett et al., 2005). A study in Greece found a 1°C decrease in mean air temperature was associated with a 5% increase in hospital admissions for acute coronary syndromes (Panagiotakos et al., 2004) and in the United States extreme cold has been also been linked to increases in deaths due to myocardial infarction and cardiac arrest (Medina-Ramon & Schwartz, 2007). The likely pathophysiology of the association between cold temperatures and cardiovascular effects relate to thermoregulatory adjustment mechanisms including vasoconstriction. Studies on seasonal variations in hypertension have found blood pressure to be higher in the winter (Rosenthal, 2004). Keating et al. (1984) found surface cooling increases platelet count, blood viscosity and arterial pressure, factors which may contribute to the higher incidence of thrombosis in cold weather. The risk of mortality for cardiovascular and respiratory diseases has been found to decrease as temperatures increase from the coldest days (Curriero et al., 2002).

3.3 The effect of heat on human health

A study of temperature extremes in the U.S. found that although both cold and hot temperatures increase the risk of mortality, the latter has greater effects (Medina-Ramon & Schwartz, 2007). The health impacts of heat exposure have been the subject of much research in recent years (Basu & Samet, 2002; Naughton et al., 2002; Semenza, McCullough, Flanders, McGeehin, & Lumpkin, 1999; Semenza et al., 1996; Vandentorren et al., 2006) due largely to the public health interest in climate change scenarios. Major heat waves occurring in recent years have alerted authorities to the severe impact exposure to extreme heat can have on human health. The 2003 European heatwave caused more than 30,000 excess deaths in Western Europe (Kosatsky, 2005) with the majority occurring in France (Vandentorren et al., 2006). The U.S. heatwaves in 1995 (Semenza et al., 1996), 1999 (Naughton et al., 2002) and 2006; (Ostro, Roth, Green, & Basu, 2009) also resulted in hundreds of excess deaths.

Whereas the effects of cold temperatures on mortality can persist for several days or weeks, the effects of extreme heat are more immediate, occurring within one or two days of a hot weather event (Braga et al., 2001; Curriero et al., 2002). In a hot environment, failure of the thermoregulatory system to adequately dissipate heat can lead to cell damage, exacerbation of underlying conditions and serious heat illnesses.

Heat stress can cause mild discomfort and physiological strain, however if body heating and dehydration progresses, heat exhaustion can occur, with symptoms that may include headache, dizziness, muscle cramps, nausea, weakness and fainting (Bouchama & Knochel, 2002; Centres for Disease Control and Prevention, 2006; Donaldson, Keatinge, & Saunders, 2003). Left untreated, heat exhaustion can progress to heat stroke, the most serious of heat illnesses. Heat stroke occurs when body temperature exceeding 40^{o}C is accompanied by central nervous system involvement (Bouchama & Knochel, 2002). Progression to liver or renal failure or possible multi-organ system dysfunction (Bouchama & Knochel, 2002; Centres for Disease Control and Prevention, 2006) may occur. Heat stroke is often fatal and those who survive may have residual damage to the brain or other organs (Bouchama & Knochel, 2002). Two forms of heat stroke can occur – classic and exertional. Classic heat stroke results from exposure to high ambient temperatures while exertional heat stroke is brought about by exercising in the heat (and most common among younger more active populations) (Bouchama & Knochel, 2002).

Most deaths during heatwaves occur in persons with underlying cardiovascular or respiratory diseases (McMichael et al., 2006) and are often not recorded as being due to the heat (Basu & Samet, 2002). The pathophysiology of heat loss requires an increase in cardiac output, placing strain on the circulatory system. Loss of body water and/or salt through sweating can lead to dehydration and haemoconcentration (Donaldson et al., 2003), and studies have shown that blood viscosity and plasma cholesterol levels increase with high temperatures (Keatinge et al., 1986), increasing the risk of cerebral or cardiac thrombosis.

As well as increases in mortality, increases in hospital admissions (Semenza et al., 1999; 1996) emergency department visits (Knowlton et al., 2009) and ambulance transports (Nitschke, Tucker, & Bi, 2007) have also been found to be increased during heatwaves.

It is of interest to note that heat-related deaths occur out of hospital more often than in hospital (Medina-Ramon, Zanobetti, Cavanagh, & Schwartz, 2006; O'Neill, Zanobetti, & Schwartz, 2003) and commonly before individuals are able to seek medical attention (Kovats, Hajat, & Wilkinson, 2004). Most deaths from thermal stress occur at the individual's place of residence (Woodruff, Hales, Butler, & McMichael, 2005). This places great public health importance on interventions to reduce the risk of the onset of heat illnesses occurring in the home.

4. 0 IDENTIFYING VULNERABLE POPULATIONS

Although humans are generally acclimatised to their local climates, temperature extremes can exceed tolerable limits (Kovats & Hajat, 2008) with certain individuals, due to age, disease or social disadvantage, likely to be more susceptible than others. Schwartz (Schwartz, 2005) found that persons with chronic obstructive pulmonary disease were at higher risk of dying on cold days and that the risk to the very elderly (defined as those aged over 84 years) and to women was greater on days of extreme cold than extreme heat. A United States study found the association between temperature extremes and mortality was particularly strong in those at relative social disadvantage and those less educated (O'Neill et al., 2003) Similarly, studies have found that the percentage of households with air conditioners or heaters, an indication of socioeconomic status, can be an inverse predictor of reduced temperature-associated mortality (Curriero et al., 2002).

Generally in Australia, extreme heat is more of a concern than extreme cold. International studies have found those most vulnerable to the effects of heat include the very young, the elderly, and persons with chronic or underlying medical conditions (Semenza et al., 1999; Vandentorren et al., 2006) such as diabetes (Medina-Ramon et al., 2006; Schwartz, 2005) mental illness, kidney disease, respiratory or heart disease (Basu & Samet, 2002; Semenza et al., 1996). As the body's response to heat stress depends largely on its ability to increase cardiac output and cutaneous blood flow (McGeehin & Mirabelli, 2001), those with cardiovascular deficiencies are at greater risk during the heat as are persons with any illness that may compromise thermoregulation (Kovats & Hajat, 2008).

Living in social isolation increases the risk of heat-related death (Naughton et al., 2002) whereas having local social contacts is protective (Semenza et al., 1996). Some studies have also suggested race (Medina-Ramon et al., 2006; O'Neill et al., 2003; Schwartz, 2005) and gender (Hajat, Kovats, & Lachowycz, 2007) may be predictors and that persons in thermally stressful occupations are also vulnerable (McMichael et al., 2006). Many drugs can affect the thermoregulatory process (Bouchama & Knochel, 2002) and can contribute to heat stroke (Vassallo & Delaney, 1989). The pharmacological effects of some medications may a contributing factor to the increase in hospital admissions for renal (Hansen et al., 2008) and mental disorders (Hansen et al., 2008) observed during heat waves.

4.1 Living environments and the weather-health relationship

Although in hot climates people are more adapted to heatwaves (Braga et al., 2001) due to spatial variability, residents in certain areas may have greater exposure to heat than others. In a study incorporating 50 U.S. cities, it was found that the greatest heat-health effects were observed in cities with mild summers and less air conditioning (Medina-Ramon & Schwartz, 2007). Densely populated urban locations often show greater effects compared to suburban and rural areas (Hajat et al., 2007; Kovats & Hajat, 2008; Medina-Ramon & Schwartz, 2007). In many cities, an urban heat island effect occurs whereby temperatures can be elevated compared to the surrounding areas (Kovats & Hajat, 2008; US Environmental Protection Agency, 2009) (Figure 1). Oke (1987) has shown a relationship between the heat island intensity and the population of a city (Figure 2).

Reasons for the differences between the city and the rural surroundings is complex and occurs on two distinct scales (Oke, 1976). The *urban canopy layer* consists of air contained between the urban roughness elements, typically buildings. The climate is dominated by the nature of the immediate surroundings, especially site materials and geometry, and the *urban boundary layer* which is that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lowest boundary, generally considered to be approximately at roof level, and is affected by processes occurring over a meso-scale area.

Field studies on the urban heat island confirm that it is generally a nocturnal phenomenon. With heat retained overnight by the high thermal mass of the urban infrastructure, together with energy generated by anthropogenic sources, there is little night-time relief from the heat (McGeehin & Mirabelli, 2001; Woodruff et al., 2005). This factor may contribute to higher heat-related mortality in urban areas during summer months. Within city variations also occur. In a study conducted in St. Louis, Missouri, researchers observed heat-related mortality rates to be higher in the disadvantaged and warmer areas of the city than in the more affluent and cooler areas (Smoyer, 1998).

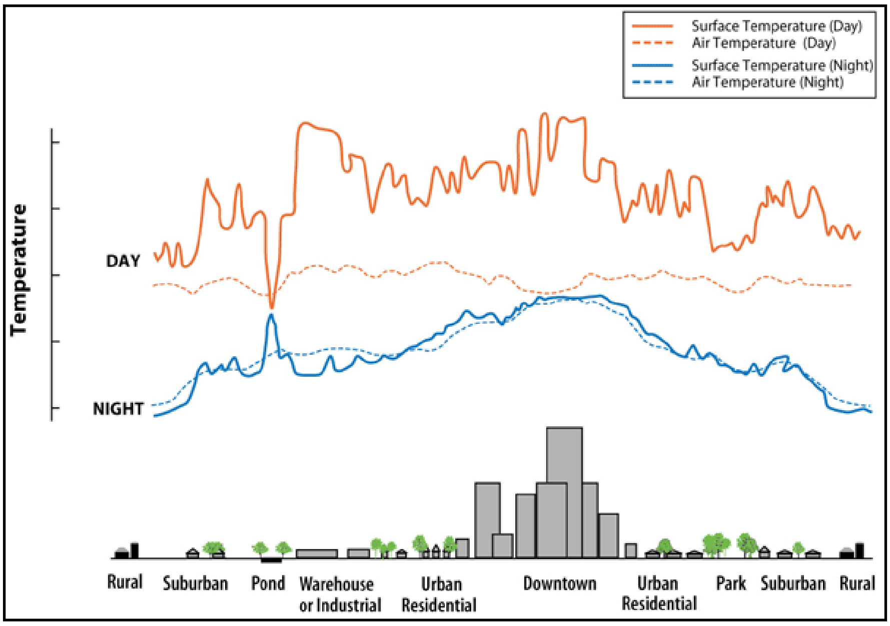

Figure 1: The urban heat island effect showing the temperature variation across a city and surrounds (Source: U.S. Environmental Protection Agency 2009).

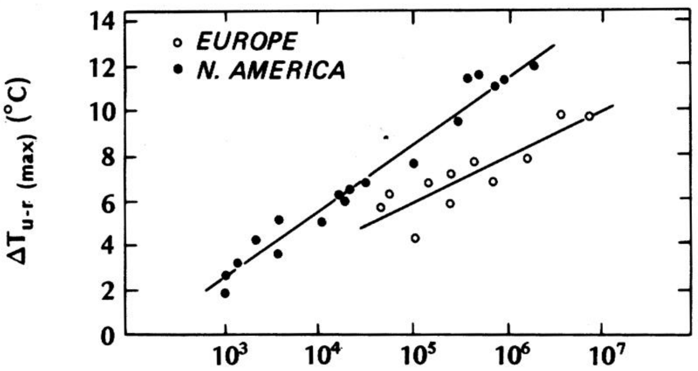

Figure 8.15 Relation between maximum observed heat island intensity ($\Delta T_{u-r(max)}$) and population (P) for North American and European settlements (modified after Oke, 1973).

Figure 2: Relation between maximum observed heat island intensity and population for North American and European settlements (Source: Oke, 1987, p. 291).

Measurements in urban situations also demonstrate that in addition to a distinct diurnal pattern, there is a clear seasonal pattern to the temperature difference. Adelaide data (figure 3) shows that during winter (May - September), the urban heat island is an almost continuous feature, both day and night, varying only in magnitude. During the rest of the year, and especially during the summer months, the nocturnal urban heat island alternates with a weak daytime cool island (Erell & Williamson, 2007). Similar results have been noted in a study of the urban microclimate in Vancouver, Canada (Runnalls & Oke, 2000).

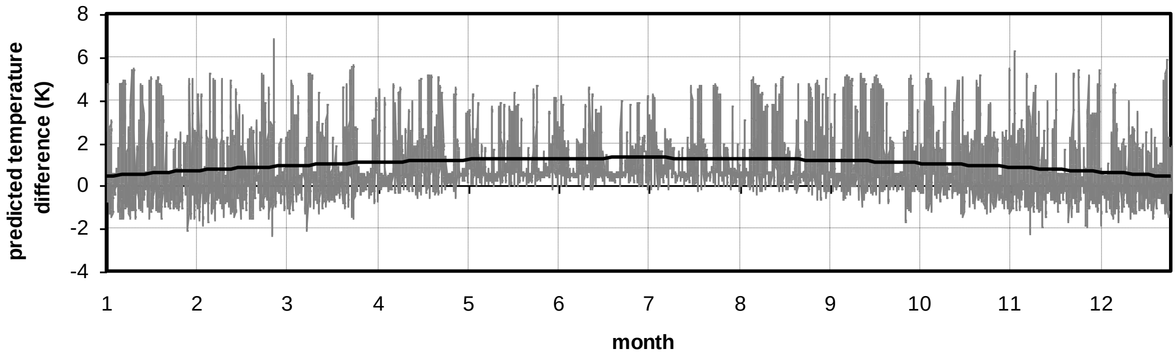

Figure 3: Seasonal pattern of the intra-urban heat island of Adelaide. Negative values indicate the street is cooler than Reference data. The time series trend is represented by a thick black line.

Studies have generally concentrated on the detrimental effects of higher temperatures in a summer period, and therefore little evidence has been collected on the potential positive outcomes of the urban heat island contributing to warmer winter temperatures and the consequential reduction in cold related health effects.

Housing appliances such as an air-conditioning and an adequate installed heater could play an important role in the prevention of thermal illnesses (Ballester et al., 2003). Several studies have shown the strongest protective factor against heat-related death to be a working air conditioner (Kaiser et al., 2001; McGeehin & Mirabelli, 2001; Naughton et al., 2002; Semenza et al., 1996). Major heatwaves however can effect this coping action particularly if residents rely solely on air conditioning to maintain thermal comfort. Electricity supply failures during times of peak demand, can have major public health implications (Kovats & Hajat, 2008)[2]. Apart from this, no directly relevant literature could be found regarding the potential for energy efficiency measures to keep a dwelling cooler during hot weather, and the consequential health benefits.

There is some evidence that certain types of thermal behaviour in terms of housing, increases vulnerability to heat (Kovats & Hajat, 2008). In a study into the 2003 French heatwave (which resulted in some 15,000 excess deaths), researchers found the major risk factor of death to be a lack of mobility along with some pre-existing medical conditions. The principal housing characteristic risk factor identified in the study was found to be associated with sleeping on the top floor, right under an uninsulated roof (Vandentorren et al., 2006). This finding relates to the styles of housing in France built prior to 1975. Other identified risk factors included the number of windows per 50 m^2, and the duration of entry of sunlight into the bedroom. Both these issues may point to a lack of appropriate shading. Closed windows and a lack of adequate ventilation were also found to be contributing factors (Vandentorren et al., 2006). This study concluded by suggesting that public health announcements should be issued prior to the onset of hot conditions. These announcements should be directed at the elderly suffering from chronic disease and lacking mobility and should contain advice concerning suggested behaviour changes: wearing light clothes, drinking more, increasing showers, opening windows at night, and avoiding housing in attic flats.

4.2 Health in Residential Buildings

Important links have been made between housing conditions and health, including mental health, noise nuisance, accidents, allergies and respiratory conditions (Bonnefoy, Braubach, Moissonnier, Monolbaev, & Robbel, 2003). Residential thermal comfort can have direct and indirect effects on health

[2] A report (Williamson & Bennetts, 2008) for the SA Department for Transport, Energy & Infrastructure found that for the climates and houses included in the study an increase in the Star Rating of a dwelling may result in a reduced peak load demand.

and the temperature differential between rooms may be more important than uniform indoor temperature (Lloyd, McCormack, McKeever, & Syme, 2008). A large review of housing conducted in eight European cities found that self-reported bad or very bad health was associated with perceived temperature problems and that asthma, hypertension and cold/throat illnesses were linked with temperature, mould or dampness within dwellings (Ezratty, Duburcq, Emery, & Lambrozo, 2006). Ventilation and weather tightness problems were also linked with poor health. The study made several recommendations including building improvements such as double-glazed windows, thermal insulation and a balance between natural ventilation, energy economy and thermal comfort (Ezratty et al., 2006).

A study comparing winter mortality rates in Ireland and Norway showed cardiovascular and respiratory deaths were 2.1 times and 1.4 times higher in Ireland than in Norway despite the milder winter temperatures (Clinch & Healy, 2000). The authors suggested an association with housing standards in terms of thermal efficiency which differed considerably between the two countries. Norwegian houses had substantially better wall, floor and ceiling insulation than in Irish houses with average internal temperatures some 6°C higher.

Chau et al (Chau, Hui, & Tse, 2008) have attempted to quantify the health benefits of improved indoor air quality for houses in Hong Kong. The interventions studied included installing portable air cleaners and keeping windows closed more often. They found that a 5-year accumulative benefit for an adult may be as high as HK$2072 (AU$318). A significant effect was found if people stayed home more often rather than venturing outside, but they suggested this finding may not have popular appeal.

4.3 Intervention studies

Several studies have been conducted to assess the health benefits of retrofitting houses with thermal insulation. While reported here for completeness, their relevance to this present report is marginal because in each case the intervention started from a construction standard well below the present BCA requirements. These have included those undertaken in Germany (Braubach, Heinen, & Dame, 2008) Scotland (Lloyd et al., 2008), and New Zealand (Chapman, Howden-Chapman, Viggers, O'Dea, & Kennedy, 2009; Howden-Chapman et al., 2007). Although their major focus has been the ability of insulation to create a warmer, drier indoor environment in winter, the hypothesis remains that insulation may act as a modifier of ambient temperature in both winter and summer. This can theoretically reduce exposure to temperature extremes whilst also reducing energy usage of heating and cooling devices respectively.

An intervention study in Frankfurt, Germany involved insulating 131 dwellings and surveying residents before and after renovation, together with a control group of residents in 104 non-insulated dwellings. Findings showed thermal insulation had a positive impact on thermal comfort but that direct association with self-evaluated health effects was weak and related mainly to respiratory diseases and common cold (Braubach et al., 2008). The perception of cold and exposure to noise were reduced in the intervention dwellings and a higher proportion of those in the renovated dwellings scored their health as improved, however differences were modest. Asthmatic persons showed a slight increase in asthma attacks, possibly related to reduced air exchange (Braubach et al., 2008).

In Glasgow, Scotland, two blocks of 36 flats were upgraded to improve thermal quality by double skinning walls, insulation, draught proofing, double glazing, solar panels, gas central heating, dual-purpose heat-recovery system, and the addition of front and back verandas. Two similar blocks of flats were used as controls (Lloyd et al., 2008). In the intervention group there was a significant fall in blood pressure of residents, respiratory health improved, medication usage for asthma and arthritis decreased, and heating costs were reduced (Lloyd et al., 2008).

The Housing Insulation and Health Study was a cluster randomised trial study undertaken in New Zealand (Chapman et al., 2009; Howden-Chapman et al., 2007). The intervention involved the installation of a retrofit insulation package to some 1350 households in seven low income communities. Within each household at least one person had a reported respiratory disease (Chapman et al., 2009). The intervention led to a drier, warmer indoor environment, improved self-rated health and a decrease in energy consumption. The total benefits of health gains, energy and carbon dioxide emissions savings were calculated to be approximately one and a half to two times the cost of retrofitting the houses (Chapman et al., 2009).

The reported differences between the intervention and control groups in the New Zealand Housing Insulation and Health Study included a slight increase in reported visits to general practitioners (Chapman et al., 2009), but a reduction in respiratory hospital admissions, days off school and days off work (Chapman et al., 2009) and reduced odds of fair or poor self-rated health (Howden-Chapman et al., 2007). Additionally typical households demonstrated net energy savings of 13%. In monetary terms, total health and energy savings per household were calculated to be NZ$3374. The deduction of total costs (NZ$1800) left a net benefit of NZ$1574 per household (the majority of which was due to the estimated reduction in hospital admissions), amounting to a benefit-cost ratio of 1.87:1 (Chapman et al., 2009).

4.4 Trends in household energy use in Australia

In Australia, households are responsible for 11% of the nation's total energy usage (Australian Bureau of Statistics, 2008c). Domestic energy consumption is increasing in Australia by an average of 2.6% per year, (Australian Bureau of Statistics, 2009) with electricity being the main form of energy used (Australian Bureau of Statistics, 2009). Heating and cooling contributes some 39% to household energy usage and 14% of the residential sector greenhouse gas emissions (Australian Bureau of Statistics, 2008c). In 2008, 77% of all households used a heater and 67% a cooler, with the percentage of dwellings with coolers more than doubling since 1994 (32%) (Australian Bureau of Statistics, 2008b).

Household floor space determines heating and cooling related energy usage (Australian Bureau of Statistics, 2009). In the 21 years to 2007, the average floor area of new residential dwellings in Australia increased by 30.8% (Australian Bureau of Statistics, 2008a) (Figure 4) and in 2008, 37% of separate houses had four or more bedrooms (Australian Bureau of Statistics, 2009).

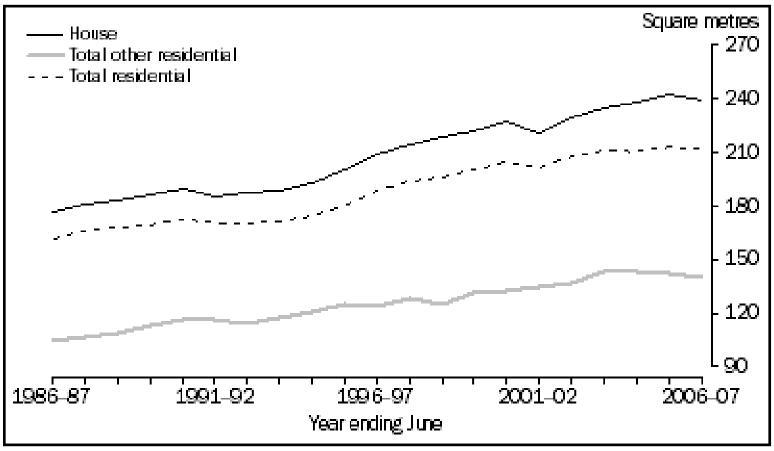

Figure 4: Average floor area of new residential dwellings in Australia from 1986-87 to 2006-07 (Source: Australian Bureau of Statistics (Australian Bureau of Statistics, 2008a).

It has been estimated that insulation in walls and ceilings can reduce energy use for heating and cooling by up to 45%, as well as contributing to year round thermal comfort (Australian Bureau of Statistics, 2008b). Although there has been an increase in insulation use in households, only 61% of dwellings in 2008 were insulated, compared to 52% in 1994. Usage varies by state and climate as seen in Figure 5. Interestingly, householders install insulation mainly to improve comfort, with only a small proportion doing so for energy savings (Australian Bureau of Statistics, 2008b). The present Government rebate for insulation to existing dwellings will most likely result in a significant overall increase of houses insulated.

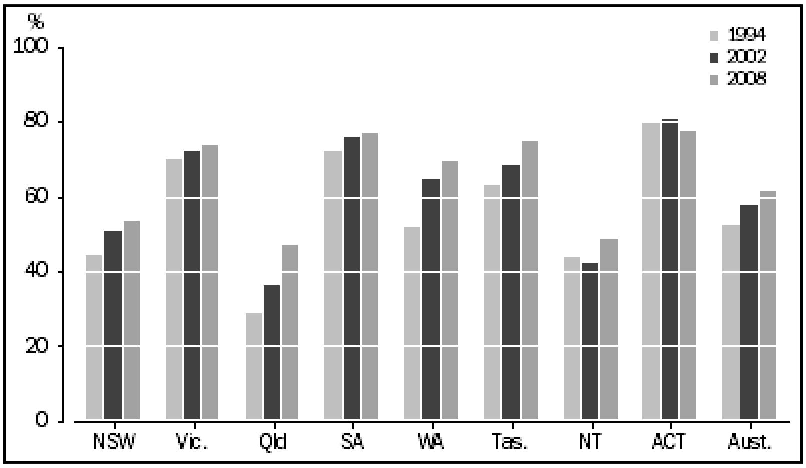

Figure 5: Dwellings with insulation in Australia (Source: Australian Bureau of Statistics (Australian Bureau of Statistics, 2008b).

4.5 Buildings other than Residential Buildings

Unlike residential premises, the indoor temperatures and air quality of commercial buildings are usually more controlled and less prone to human behavioural changes. The indoor conditions are often controlled by air-conditioning and occupation of these buildings can generally be characterised as discretionary. Occupation of, and activities within, these buildings is usually within occupational health and safety standards. If administered correctly, occupant exposure to temperature and noise conditions likely to cause health problems should be avoided.

Leaman and Bordass (Leaman & Bordass, 1999) have argued that investing in energy efficiency can lead to a healthier, more comfortable and more productive workforce, lower occupancy costs and reduced anthropogenic climate change. Scrase (2001) suggests that for institutional investors and commercial property developers, investment in energy-efficiency may lead to savings in insurance costs.

Much of the literature regarding health effects and commercial (office) buildings deals with the so-called 'sick building syndrome'. Here epidemiological studies often show that occupants' complaints are more prevalent in office buildings with more complex HVAC systems and technological devices to control and regulate the indoor environment (Leyten & Kurvers, 2006). Bluyssen (Bluyssen, 2008) provides a good summary of the present state of knowledge on health, thermal comfort and related health issues. She points out that standards to control indoor air quality related to energy-efficiency requirements may be falling short. Emissions, mainly VOCs, from building materials and anthropogenic activities, which could have an effect on comfort (odour, irritation) and/or health (cancer, asthma, etc.) are meant to be covered by these standards, however, the indoor air comprises of a complex mixture of compounds of which the source and effects are often incompletely known. Vitel (2001) points out that poor indoor air quality can arise from deficiencies in the design of the building or the HVAC system, but more often than not, problems arise because of poor inspection and maintenance practices in the operation of the building HVAC.

A post occupancy study of the Melbourne City Council CH2 building reported perceived health and productivity increases compared with the previous building occupied by the same staff, although these were not quantified (Paevere & Brown, 2008). While much of the literature points to cost savings from "healthier" buildings little data are available to quantify this claim.

5.0 POTENTIAL HEALTH BENEFITS OF ENERGY SAVINGS DUE TO BUILDING IMPROVEMENTS

The use and production of energy can generate greenhouse gas emissions and contribute to air pollution (Australian Bureau of Statistics, 2008c). Numerous studies have affirmed that exposure to air pollution can have adverse health effects which include mild to severe acute and chronic respiratory illnesses (American Thoracic Society, 2000) and cardiovascular disease (Brook, 2008). The World Health Organization has claimed that globally urban air pollution contributes to the premature deaths of 0.8 million people annually (World Health Organization, 2002). The main air pollutants are: particulate matter including $PM_{2.5}$ (fine particles) and PM_{10} (course particles), and the gaseous components - ozone, nitrogen dioxide, carbon monoxide and sulphur dioxide.

Based on the premise that reduction in residential energy consumption equates to reduced greenhouse gas emissions and air pollutant concentrations, complex modelling studies in the U.S. have identified substantial health benefits of installing insulation in new (Nishioka et al., 2002) and existing (Levy, Nishioka, & Spengler, 2003) dwellings. Supported by the North American Insulation Manufacturers Association, these studies quantified the health benefits using a combination of life cycle assessment and risk assessment (Nishioka et al., 2002).

Nishioka et al (Nishioka et al., 2002) modelled energy (natural gas, fuel oil and electricity) savings as a result of increasing residential insulation for new houses, and estimated that over a ten year period $PM_{2.5}$ emissions would be reduced by 1,000 tons, nitrous oxides emissions by 30,000 tons and sulphur dioxide emissions by 40,000 tons. Applying published concentration-response functions for premature mortality, the authors estimated there would be, out of the total U.S. population of 250 million, a rather insignificant 60 fewer premature deaths over the ten year period as a result of the reduction in air pollution, as well as 2,000 fewer asthma attacks and 30,000 fewer restricted activity days. The public health impacts of emissions in the manufacture of extra insulation, and associated occupational hazards of manufacturing and installation also need to be considered (Nishioka et al., 2002) although these should be far outweighed by the public health benefits of reduced energy consumption over time (Levy et al., 2003).

As new houses represent only a small fraction of total dwellings, a second study by these researchers (Levy et al., 2003) was undertaken using a hypothetical case study of insulation retrofits in 46 million existing dwellings in the U.S. at an estimated cost of US$37 billion. It was estimated the resultant annual reductions in emissions would total 3,100 fewer tons of $PM_{2.5}$, 100,000 fewer tons of nitrous oxides and 190,000 fewer tons sulphur dioxide. This translated to 240 fewer deaths, 6,500 fewer asthma attacks and 110,000 fewer restricted activity days annually across the U.S. Health economics calculations were undertaken and costs of retrofits considered. Energy savings were approximated to be equivalent to "$5.9 billion per year, indicating a payback period of slightly over 6 years," a net saving of approximately $80 billion over the lifetime of the homes. The health benefits corresponded to "$1.3 billion per year in externalities averted" (with over 99% related to premature mortality) "compared with $5.9 billion per year in economic savings" (Levy et al., 2003).

6.0 THE POTENTIAL IMPACT OF CLIMATE CHANGE

The earth's climate is naturally dependent on greenhouse gases including carbon dioxide, methane and nitrous oxide, which assist in keeping the atmosphere at an inhabitable temperature. A substantial body of literature suggests that observed rises in global temperatures are due, at least in part, to the growth of industrialisation and associated increasing concentration of greenhouse gases in the atmosphere (World Health Organization, 2005). Over the past century, average global surface temperatures have risen by approximately 0.6°C (IPCC, 2001; World Health Organization, 2005) to 0.74°C (IPCC, 2007) with the greatest warming trend over the past 50 years. Temperatures are projected to increase a further 0.2°C per decade in the next twenty years, with a 1.8°C to 4.0°C increase by 2099 compared to the beginning of the century. Unabated or increased greenhouse gas emissions may cause further warming (IPCC, 2007). It is very likely the number of heatwaves and extreme heat days and nights will increase (IPCC, 2007) (Figure 6), and in all Australian cities the average number of days per year with temperatures exceeding 35°C is expected to rise considerably (Research Australia, 2007). While the extent of anthropogenic climate change is one of the most contentious scientific issues of our time variations in temperature from long term averages will have implications for population health, both directly and indirectly.

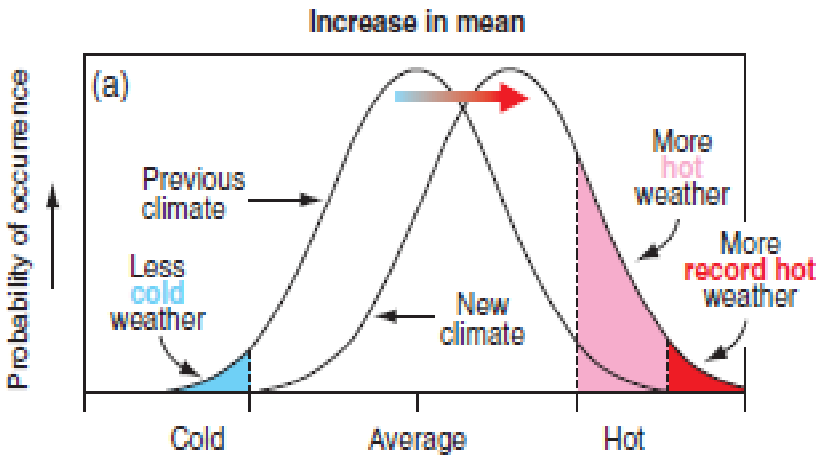

Figure 6: The effect of increasing mean temperatures on temperature extremes (Source: (IPCC, 2001).

Predicted global warming may lead to an increase in the incidence of thermal stress and temperature-related deaths (Pittock, 2003). Some 1500 deaths occur each year in Australian cities due to temperature extremes and with an ageing population, these figures are expected to double or treble by the middle of the century (Research Australia, 2007). As previously mentioned, susceptible groups will be the elderly and the very young, the infirm, the socially disadvantaged and those without access to a cool environment. A warmer climate may result in reduced numbers of cold-related deaths (McGeehin & Mirabelli, 2001; Pittock, 2003), however by later in the century these are expected to be outnumbered by the increase in heat-related mortality (Bambrick, Dear, Woodruff, Hanigan, & McMichael, 2008).

Exacerbated by higher humidity, higher temperatures, aridity, and increased urban air pollution and aeroallergen levels in many parts of Australia, rates of cardiorespiratory disease are likely to increase

(Hansen, Bi, & Nitschke, 2009), Other health risks from climate change include impacts of weather disasters; influences on mental health and water-borne, food-borne and mosquito-borne infectious diseases; and effects of food yields and water supplies (Bambrick et al., 2008; McMichael et al., 2006).

Climate change may modify lifestyles as populations acclimatise. Uncertainties in this area make predictions of health impacts purely speculative. In a warmer environment, people may spend more time outdoors or with windows open, thus increasing exposure to ambient air pollutants and reducing exposure to indoor air pollutants. The incidence of cardiorespiratory disease may vary accordingly. Increased exposure to solar radiation may lead to higher rates of skin cancer and eye disorders (McMichael et al., 2003; Pittock, 2003). Shaded outdoor areas in residential homes, recreational and community sites will be important. Greater time spent outdoors during the days and evenings in certain locations may also increase the need for personal protection against mosquitoes with the potential for vector borne disease transmission.

Alternatively, individuals may spend more time indoors to avoid extreme heat, thus increasing exposure to indoor air pollutants and allergens (Patz et al., 2000). Staying indoors may also affect levels of physical activity, particularly in children (Patz et al., 2000).

It is likely that in a changing climate, future temperature-related mortality will be dependent on the adaptive capacity of populations, including improvements to building design (Woodruff et al., 2005). The presence of air conditioning does not always guarantee its use, particularly with elderly householders with mobility or cognitive problems or those with financial concerns relating to energy costs. The issue of fuel poverty i.e. having a low income and living in housing that is difficult to heat or cool, has been addressed in UK studies (Rudge & Gilchrist, 2006) but rarely in Australian studies. Passive cooling techniques should also be investigated (Woodruff et al., 2005). Energy efficient housing modifications such as improved insulation and ventilation can reduce energy costs, and by reducing greenhouse gas emissions, can be a mitigation strategy for climate change (Braubach et al., 2008; Research Australia, 2007).

7.0 IDENTIFYING THE EFFECTS ON INDOOR TEMPERATURES OF MAKING HOUSES MORE ENERGY EFFICIENT (FROM 5 STAR RATING TO 6 STAR RATING)

No field data are available to determine the incremental changes in indoor temperatures that might accord with a move from 5 to 6 Stars. It should be noted that for a dwelling with air-conditioning operating the majority of the time there will no or very little change in temperature (only potentially less energy to achieve the set thermostat temperature). Maximum benefit would only be achieved when no heating or cooling is used. For a population of houses the actual effect in indoor temperatures will be in the range between zero and what may be achieved in a continuously free running building.

Computer modelling using a special research version of the AccuRate engine was used to investigate this issue. Scratch files for running the AccuRate program were supplied by the ABCB. These consisted of variations of 8 houses configured to provide Star Ratings between 5 and 7 Stars. The variations included concrete slab-on-ground and suspended floor constructions, although only the slab-on-ground results are used in this analysis. For key locations in each BCA climate zone the simulations were conducted for the houses operating in free running mode (i.e. no heating or cooling). The 95%ile maximum indoor summer temperature and the 5%ile[3] minimum winter temperatures were calculated from the simulations. Figures 7 to 16 show the results for selected locations. In general the results indicated a small increase in winter time minimum temperatures when moving from 5 to 6 Stars. While there were variations between locations the improvement for most climate zones was generally in the range 0.4 - 0.5^{o}C. As a general observation the summer results showed no decrease in maximum temperatures and some locations the result was a slight increase. The exception to these observations was Darwin, climate zone 1 (see Figures 15 & 16), where the change from 5 to 6 Stars results in no significant changes in maximum or minimum free running temperatures. While it is beyond the scope of this work to fully explain this finding, it is most likely the result of a domination of ventilation heat exchange in the free running mode.

[3] 95%ile maximum temperature – 95% of calculated indoor temperatures are less than this value. 5%ile minimum temperature – 5% of calculated indoor temperatures are less then this value.

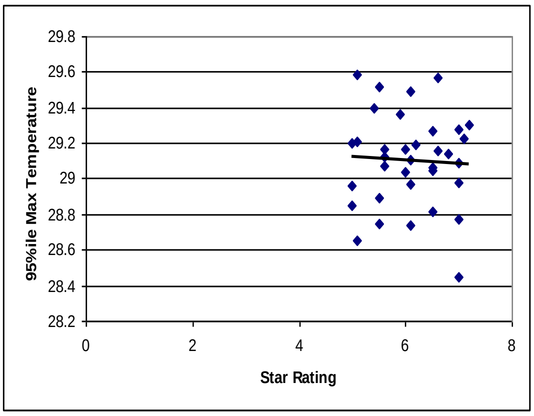

Figure 7: Summer Adelaide 95%ile Maximum Temperature

Figure 8: Winter Adelaide 5%ile Minimum Temperature

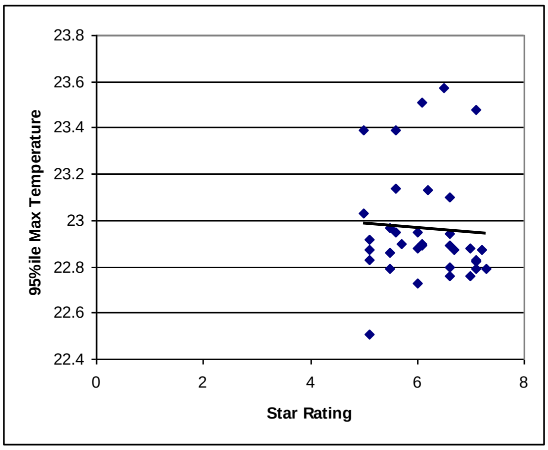

Figure 9: Summer Hobart 95%ile Maximum Temperature

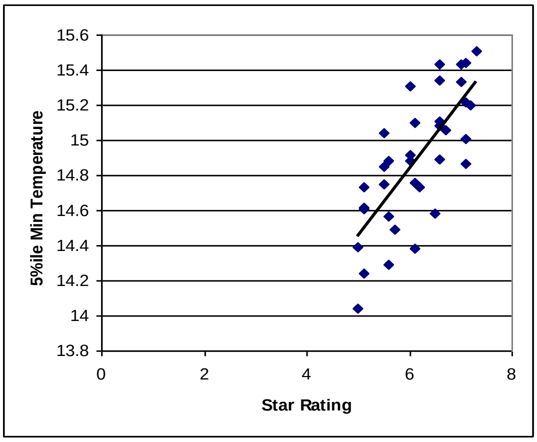

Figure 10: Winter Hobart 5%ile Minimum Temperature

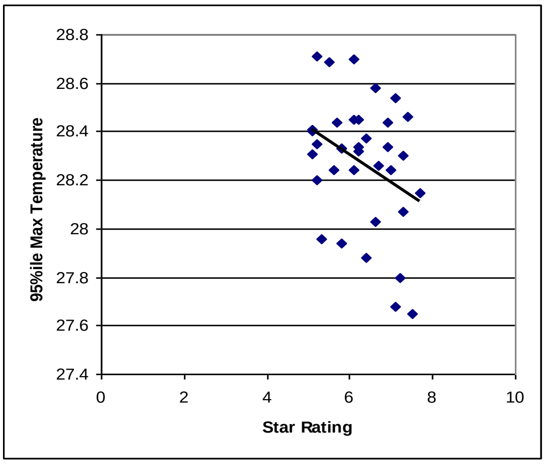

Figure 11: Summer Brisbane 95%ile Maximum Temperature

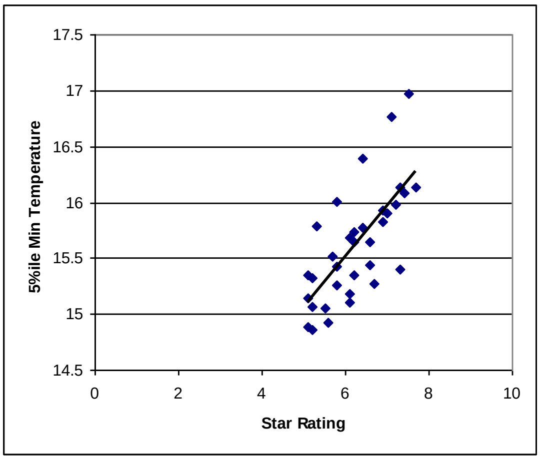

Figure 12: Winter Brisbane 5%ile Minimum Temperature

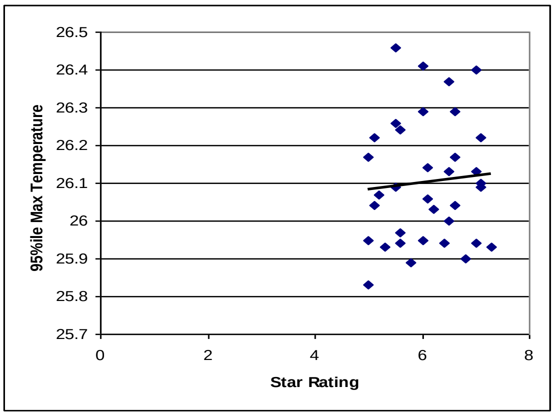

Figure 13: Summer Melbourne 95%ile Maximum Temperature

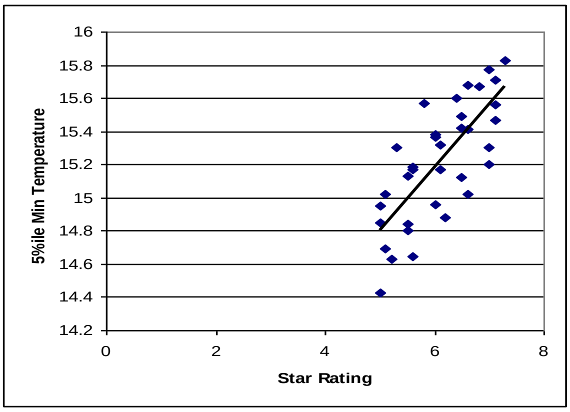

Figure 14: Winter Melbourne 5%ile Minimum Temperature

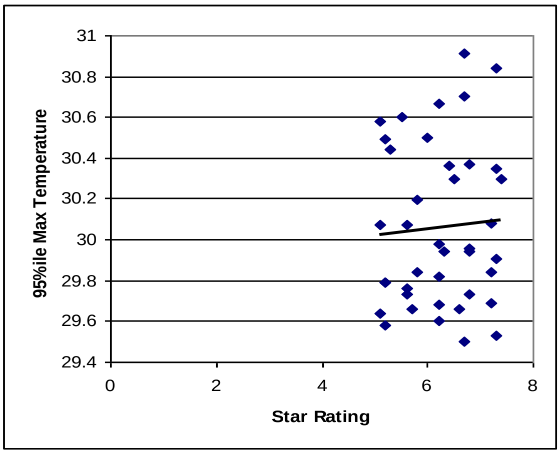

Figure 15: Wet Season Darwin 95%ile Maximum Temperature

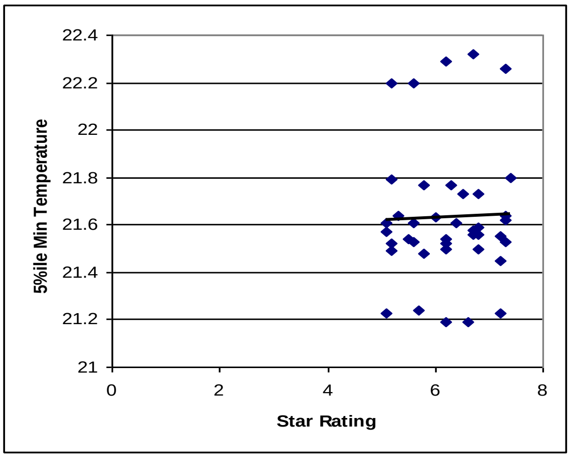

Figure 16: Dry Season Darwin 5%ile Minimum Temperature

For each BCA climate zone we can derive the slope of the Star Rating vs. Min Temperature relationship as shown in Table 1 below.

BCA Climate Zone	Standard Location	Slope (degC/Star)
1	Darwin	--
2	Brisbane	0.45
3	Longreach	0.54
4	Mildura	0.37
5	Sydney	0.35
6	Melbourne	0.37
7	Hobart	0.38
8	Canberra	0.54

Table 1: Slope of the Star Rating versus Minimum Temperature relationship for BCA Climate Zones

8.0 POSSIBLE SAVINGS FOR HEALTH SERVICES - COST BENEFIT ANALYSIS

Despite the limited literature, a quantitative appraisal of costs and benefits is possible. Table 2 lists a selection of costs and benefits of energy efficiency measures in residential housing compared to no energy efficiency measures. Table 3 addresses health costs and benefits only. Although detailed health economic estimates are beyond the scope of this review, it would seem that despite the initial outlay costs, the benefits of thermal efficient housing modifications have, over time, the potential to offset some or all of the costs. The data from a New Zealand housing intervention study involving around 1280 households (Chapman et al, 2009) probably represent the best available information for this review, and suggest that reduced hospital admissions for respiratory illness in winter constitute the greatest area of health cost saving. They showed that modelled with a 30-year horizon (5-7% discount rate) the health benefits outweighed the energy savings at least two-fold. It must be emphasised however that the New Zealand studies started from a situation where the houses where un-insulated and relatively energy inefficient.

By way of comparison the 2007/8 Australia average cost per case mix-adjusted public hospital separation was AU$4,232 excluding depreciation and AU$4,376 including depreciation.[4] Thus, in the case of vulnerable subpopulations, it is likely that societal benefits could be significant. The New Zealand data show a small increase in the number of GP visits, the significance of which is unclear. Braubach and co-workers (Braubach et al., 2008) also noted a slight increase in asthma attacks, possibly related to reduced air exchange. The New Zealand authors argue that some net benefit will accrue even when partially insulated houses are upgraded. However, it is difficult to extrapolate the NZ findings to Australian conditions with any certainty, and even more difficult in the case of European data where cold conditions are common. In Australia, the health benefits, in terms of reduced heat-induced mortality may only eventuate if cooling systems are actually used (Oreszczyn et al, 2006). Otherwise, extended heatwaves may simply lead to hot box conditions in insulated homes.

Climate change is likely to reduce population health impacts via an increase in winter minima, but this would be offset by health impacts associated with an increase in summer minima/maxima. Importantly, an ageing population will lead to an increased strain on the health system, and in general the elderly, particularly those living alone, are at greatest risk. In consideration of thermal lag, and where air

[4] Australian Institute of Health and Welfare. Australian hospital statistics 2007-08. Health Services Series Number 33. Canberra: AIHW cat. no. HSE 71, 2009. Ch 4, p.47. Available from http://www.aihw.gov.au/publications/hse/hse-71-10776/hse-71-10776.pdf

conditioning is absent, there may be a tendency for people to spend more time outdoors in the evenings. This could conceivably lead to an increase in vector-borne disease and food-borne disease.

Costs	Benefits
Costs of insulation: Manufacturing costs Energy usage Air pollution Greenhouse gas emissions Transport costs Installation costs Occupational injuries to manufacturers and installers	Reduced health care costs of heat-related, cold-related and air pollution-related illnesses: Reduced: - Ambulance usage - Hospital admissions - Mortalities - Medication usage - Days off work and school Increased quality and length of life in vulnerable populations Other: - Reduced energy costs and (mental) stress to meet payments - Reduced greenhouse gas emissions - Benefits to industry, employment sector and local economy

Table 2: Unquantified Costs and benefits of energy efficiency measures in residential housing compared to no energy efficiency measures.

Health Costs	Health Benefits
Private Costs	**Private Benefits**
Direct healthcare costs - Medical/healthcare co-payments - medication Indirect healthcare costs - attendance/transport costs - lost productivity and foregone income **Supplier Costs** Direct and indirect healthcare costs, relating to injured manufacturing and building workers, including workers compensation costs **Government Costs** Provision of healthcare services and payment subsidies	Reduced risk of disease and death arising from thermal conditions in homes. Potential increased quality and length of life. Reduced acute healthcare costs (including medication, ambulance, hospital, rehabilitation etc.) due to disease attributable to thermal conditions in homes. Reduced costs associated with absence from work and school due to disease and death attributable to thermal conditions in homes Potentially reduced chronic healthcare costs (including medication, ambulance, hospital, rehabilitation etc.) due to disease, including mental disorders and psycho-somatic health issues, attributable to thermal conditions in homes. Potential reduction in healthcare costs for persons affected by mould-related air pollutants[5]. Reduced costs from external noise-related health effects, including learning deficits, cardiovascular effects and annoyance[6]. **Societal Benefits** Reduced morbidity and mortality during weather extremes (impacting on available hospital beds, ambulances etc.). Potential reduction in morbidity associated with mould-related air pollutants.

Table 3: Health only costs and benefits of energy efficiency measures in residential housing compared to no energy efficiency measures.

[5] In the Frankfurt study, Braubach et al (2008) measure exhaled nitric oxide, as a marker for respiratory allergic reaction, for 117 occupants of intervention and control homes. No significant differences were found, but this was a small sample size.

[6] A variety of studies have explored external noise-related health effects, e.g. Stansfeld et al., Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet 2005; 365: 1942–49

8.1 An Approach to Health Benefits in Housing

As noted above extrapolating overseas data to the Australian context is difficult. However, in order to apply some quantitative estimate (however tenuous) to the potential health benefits of improved energy efficient housing the following logic is suggested. An approach, based on the New Zealand data (Chapman, Howden-Chapman, & O'Dea, 2004) and information from the AccuRate thermal modelling, is suggested as a way to attribute a health impact value to the incremental improvement from 5 to 6 Stars. The approach can only be applied to residential housing.

Chapman, et al (2004) take the aggregate health related benefits for a household to consist of three elements,

- reduced hospital admissions, reduced days off school and reduced days off work,
- private cost saving per household from reduced visits to a GP.
- mental health improvements.

Days off school and days off work are assumed to relate to health issues. This study was concerned more with improvements in cold housing and associated winter effects. Because of the relatively mild climate in the study area changes in health benefits from a reduction in higher temperatures were found to be too low to significantly impact on the model outputs. A recent publication for the NZ Energy Efficiency Conservation Authority (EnergyConsult Pty Ltd, 2009) summarises the net (winter) health benefits of improved thermal efficiency (the installation of thermal insulation) as shown in Table 4.

By making the following assumptions we have attempted to translate the New Zealand results to estimate the potential health benefits of improved housing energy-efficiency,

- that the New Zealand data converts directly to the Australian context
- that the New Zealand study which involved installing insulation in previously uninsulated houses relates to an improvement in the housing standard of 2.7 Stars (see Appendix B),
- that a proportional benefit from 5 to 6 Stars can be estimated by assuming that the health benefits are directly related to this change in Star Rating[7].

[7] As seen in Figures 9, 11, 13 & 15 the Star Rating is significantly correlated to the 5%ile minimum temperature. Health benefits will likely accrue from this improvement in temperature; we might also hypothesize that overall the changes in Star Rating would correlate to a reduction in heating and cooling degree hours below or above a "comfort" temperature (and therefore a reduction in heat related stress). Such a calculation was beyond the scope of this report
The following relationship would therefore hold;

$$\frac{\Delta H_{(5-6)}}{\Delta H_{(U-I)}} = \frac{\Delta SR_{(5-6)}}{\Delta SR_{(U-I)}} = \frac{\Delta T_{\min 5\%ile(5-6)}}{\Delta T_{\min 5\%ile(U-I)}} = \frac{\Delta HDH_{(5-6)}}{\Delta HDH_{(U-I)}}$$

Where:

Health Impact of Improved Thermal Efficiency	Current per Annum Value	Reference	Current estimated Max Value of Incremental Change Per Annum per Household
Estimated public cost saving per household from physical improvements	$NZ146.19 ($AU120)	Derived from Chapman et al (2004) Original values escalated by 10% to account for CPI	$AU44
Estimated private cost saving from mental health improvements – reduced GP visits	$NZ20.00 ($AU16)	EnergyConsult Pty Ltd (2009) Note: The Original NZ study showed a small increase in visits to GPs, that is a cost.	$AU6
Estimated cost saving from mental health improvements	$NZ200 ($AU164)	(Howden-Chapman & Chapman, 2009)	$AU61
TOTAL			$111.00

Table 4: Value of Health Impacts – New Zealand Study and Estimated Australian Maximum

The estimated health benefit value of $111.00 is a potential maximum per household per annum and would most likely apply to only to the most vulnerable households. The actual value is likely to be significantly less because the majority of households would off-set minimum temperatures by some form of heating. The 2008 ABS survey (Australian Bureau of Statistics, 2008b) showed that only 0.5% of households across Australia did not have at least one form of heater. Across Australia however, 14.1% of Australian households used a heater for less than one month in a year, and this figure is 8.6% in the States where heating would be expected. Taken together these data suggest that on average the present value of the health benefit achieved by an increase from 5 to 6 Stars could be $9.50 per household per annum, or a total of $1.425M assuming 150,000 dwellings to be constructed in one year.

(5-6) denotes change from 5 to 6 Star Rating
(U-I) denotes change from un-insulated to BCA min insulation
ΔH – change in health benefits ($)
ΔSR – change in Star Rating, $\Delta SR_{(5\text{-}6)} = 1$
$\Delta T_{min\ 5\%ile}$ – change in 5%ile min temperature
ΔHDH – change in HDH from comfort temperature

CONCLUSION

The Council of Australian Governments request to the Australian Building Codes Board to increase the energy efficiency provisions in the 2010 edition of the Building Code of Australia (BCA) comprises of a 6 Star energy rating, or equivalent, for new residential buildings; and significant increases in the energy efficiency requirement for all new commercial buildings. Through literature review it is possible to explore the incremental health related effects as temperature and other conditions change within a building to satisfy the energy efficiency provisions resulting from the proposed Building Code of Australia changes.

There is a strong association between weather and health. Weather refers to the ambient climatic conditions, not necessarily the conditions within buildings and air temperature is generally taken as the main indicator of climate severity. Low or high temperatures may lead to human stress situations and result in increased morbidity and mortality. At a population level, death rates generally are at their lowest at moderate temperatures and increasing with elevated or reduced temperature conditions. Populations in colder cities are more affected by warmer temperatures, whilst those in warmer cities notice a greater effect of colder temperatures. While both cold and hot temperatures increase the risk of mortality, hot temperatures have greater effects. The effects of extreme heat are more immediate, occurring within one or two days of a hot weather event. In a hot environment, such as a hot building the failure of the thermoregulatory system to adequately dissipate heat can lead to cell damage, exacerbation of underlying conditions and serious heat illnesses and during heat waves there are increases in hospital admissions, emergency department visits and ambulance transports. As heat-related deaths commonly occur before individuals are able to seek medical attention and generally occur at the individual's place of residence, great public health importance should be placed on interventions to reduce the risk of the onset of heat illnesses occurring in the home. Certain populations are more prone to temperature-associated mortality than others. Vulnerable populations include the elderly, those with chronic or underlying medical conditions, mental illness, and the social disadvantaged. Many drugs can affect the thermoregulatory process and can contribute to heat stroke. Predictors of temperature-associated mortality include socioeconomic status (indicating households with air conditioners or heaters), race and education. Living in social isolation also increases the risk of heat-related death.

It is likely that in a changing climate, future temperature-related mortality will be dependent on the adaptive capacity of populations, including improvements to building design. However the presence of heating or cooling does guarantee its use, particularly with householders with mobility or cognitive problems or those with financial concerns relating to energy costs. Fuel poverty is an under researched issue in the Australian context.

No field data are available to determine the incremental changes in indoor temperatures that might accord with a move from 5 to 6 Stars. However despite the limited data and literature, a qualitative appraisal of costs and benefits is possible. There is a potential for the incremental changes to be measured against reduced hospital admissions, reduced days off school and work and the private cost saving per household from reduced visits to general practitioners. Using a number of assumptions it is possible to extrapolate the findings of an existing New Zealand study conducted during the winter, to the Australian context. The authors estimate a health benefit value of $111.00 from moving to a 5 to 6 Stars can be calculated as a potential maximum per household. This figure however would most likely apply to only to the most vulnerable households. The actual value is likely to be significantly less because the majority of households would off-set minimum temperatures by some form of heating. Taken together these data show that on average the present value of the health benefit achieved by an increase from 5 to 6 Stars per household could be at a minimum of $9.50 per annum.

At this point a knowledge gap exists in this area and little research has been undertaken to establish potential health benefits of energy-efficient housing modifications in hot environments. Minimising increases in temperature and air pollution related morbidity and mortality in an enlarging vulnerable population may yield further considerable savings to Australia's health sector. Extremes of temperature can have serious consequences on human health that are largely preventable. Individuals spend a great deal of their time at home, particularly those who are most vulnerable to thermal stress – the elderly, the frail and the chronically ill. As temperature-related deaths often occur prior to seeking medical attention, it is important that housing design adapts to changing weather patterns in order to improve residential thermal comfort and reduced indoor air pollution. However, a knowledge gap exists in this area as little research has been undertaken to establish potential health benefits of energy-efficient housing modifications particularly in hot environments.

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Appendix A: General assumptions and notes

HEALTH DATA

Only information relating to deaths, hospital admissions and ambulance usage was considered (no Australian information was available regarding GP visits, medication usage etc, and little information relating to chronic disease sequelea).

Health effects are based on a simplistic model of the impact of indoor air temperature (and possibly radiant heat) on clinically relevant and measurable health outcomes (i.e. no consideration of humidity, air movement).

Data pertains to cities only and specific meteorological sites.

There is no or minimal likelihood of disaggregation of occupational vs. non-occupational casualties. Hospital category (children's hospital vs. public hospital vs. other form of hospital) was not considered.

Some reference was given to secondary health effects (i.e. food borne disease which might affect those who are usually not susceptible to thermal extremes).

No information was available on subclinical effects (e.g. thermal comfort).

HOME ENVIRONMENT

No specific consideration was given to roofing materials (colour/type), or wall construction.

No specific consideration was given to window overhangs, shading by vegetation, house orientation, ceiling fans.

Thermal lag is averaged (there will be differential lag in walls, versus ceiling versus floor).

Hot/cold weather patterns are averaged (i.e. a 10-day hot spells may not be comparable with 5 x 2 days of hot weather separated in time).

Comparisons between New Zealand studies and Australian settings use generalisations that do not take into account differences in climatic conditions.

ACTIVITY and BEHAVIOUR

Adaptive responses, including the use of heating/cooling devices, fluid intake, appropriate clothing, opening windows were not taken into account.

There was no specific extrapolation of home occupancy (10, 20, 50 years) for those at risk.

AT RISK POPULATONS

There was no disaggregation of those at risk (i.e. we may not be able to assess the impact of the intervention on the elderly versus others).

No data were available on projected medication usage and proportional disease states, that might affect thermoregulation.

No consideration was given to degree of social disadvantage, and associated health impacts.

No consideration was given to social isolation versus dedicated care facilities.

No specific consideration was given to acclimatisation of individuals or communities to local climatic conditions.

Appendix B: Thermal Improvements – Un-insulated to Insulated

To allow a comparison with the NZ study (Chapman et al., 2004) star rating improvement achieved by adding ceiling insulation to an existing un-insulated dwelling was estimated for a range of houses in each BCA climate zone.

The houses are rated with AccuRate first without ceiling insulation and then with ceiling insulation set to the minimum required by the BCA – 2009.

Table B1 shows the results. The improvement taken as an average 2.7 Stars was assumed to be equivalent to the New Zealand study.

BCA Climate Zone	Star Rating Average Un-insulated	Star Rating Average Insulated to BCA Standard	Average Improvement Star Rating
2	0.6	2.4	1.8
3	0	2.1	2.1
4	1.4	4.6	3.2
5	1.4	4.5	3.1
6	1.5	4.4	2.9
7	1.4	4.1	2.7
8	1.6	4.5	2.9

Table B1: AccuRate Data for Estimating Average Thermal Improvements