Addressing the relationships between ageing, thermal comfort, house design and health: A study in South Australia

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List of abbreviations

ABCB	Australian Building Codes Board
ABS	Australian Bureau of Statistics
AIHW	Australian Institute of Health and Wellbeing
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BOM	Bureau of Meteorology
CEN	Comité Européen de Normalisation
DPTI	Department of Planning, Transport and Infrastructure
HVAC	Heating, ventilation and air-conditioning
kWh	kilo-Watt hour
PMV	Predicted Mean Vote
PPD	Predicted Percent Dissatisfied
NCC	National Construction Code
TSV	Thermal Sensation Vote
WHO	World Health Organization

Abstract

There is a large body of evidence linking extremes of outdoor temperature with morbidity and mortality amongst older people; less is known about the indoor conditions of the houses older people live in. This is despite the fact that it is well documented that older people spend most of their time inside their houses. As the overwhelming preference amongst Australian people aged 65 and over is to remain in their home as long as possible. it is thus important to understand the relationship between the indoor thermal conditions, the perception that occupants have of these conditions, and the reactions they have to these conditions, to allow them to stay healthy and comfortable as they age in place. The research presented in this thesis has been conducted to address the relationships between ageing, thermal comfort and health, and the housing conditions of a group of older South Australians.

As part of this study, a survey was undertaken to investigate the satisfaction amongst older people in regard to their housing, comfort and health. The survey found that most were satisfied with the level of year-round thermal comfort provided by their homes, and typically used their heating and cooling devices sparingly to achieve thermal comfort. Participants were more concerned about their health during heatwaves than they were during cold weather.

Following the survey, a field study of 18 houses was carried out to further understand the indoor thermal conditions and occupants' thermal comfort as well as the

relationship between these variables and self-reported symptoms. The results showed a consistent trend toward a preference for cooler conditions than predicted by current thermal comfort standards. All but one of the participants reported thermal satisfaction at lower temperatures than predicted, but expressed no preference toward warmer conditions. These preferences, however, may be problematic, as the study also showed that a relationship exists between indoor minimum and maximum temperatures and the presentation of heat- and cold-related symptoms. This relationship is binomial: symptoms are related to temperatures at both ends of the temperature spectrum. The frequency of the presentation of symptoms increased and temperatures for lower or higher, for both daily maximum and minimum temperatures.

Temperatures in the houses were lower than recommended by these field study results for 50% of the time, even when heating and cooling systems were used. Whilst there were some issues of overheating, the main concern that the study uncovered was the under-heating of houses.

A sample of houses from the field study were then included in a study of building improvement, using a building performance simulation technique, to investigate how retrofitting insulation and double glazing might improve conditions in the houses. Simulated results showed that basic building improvements would slightly increase the time during which the temperature of the house was in the optimal range; however, there was still a need for more heating than is currently utilised by this cohort.

Increasing heating use, however, increases the cost to the occupants, which some older people may not find affordable. This in turn could dissuade occupants from the recommended heating increases. For this reason, this study then examined the benefit of installing solar photovoltaic cells as a solution which offsets increased cost needed to adequately heat the building whilst being cost-neutral in a relatively short time span.

A home environment that is conducive to thermal comfort and good health has the potential to allow older people to age in place, to prevent hospitalisations and to delay entry into residential aged care. It is thus in the best interest of home owners, policy makers and governments to consider building improvements as an investment in health. These stakeholders must work together to make a healthy thermal environment achievable and affordable, both for older people now and for the increasing numbers of older people in the future.

Statement of originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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CHAPTER 1

Introduction

1.1 Overview

Australia has an increasingly ageing population. Longer life expectancy, coupled with a decrease in the national fertility rate, means that those over 65 years old are representing a larger proportion of the population than ever before. The Australian Bureau of Statistics (ABS) predicts that by 2066, 21% of Australia's population will be aged over 65 (ABS 2018a), and this is set to reach 25% by 2101 (ABS 2013e). Despite currently only representing 15% of the population (ABS 2018a), older people are over-represented in the health and hospital system, making up 41% of hospital admissions and 49% of patient days spent in hospital (AIHW 2016, p. 19). Because of the body of evidence linking housing, thermal conditions and health, this thesis will examine the thermal experiences of older people in their own homes, and how these may be linked to their health. This chapter will briefly explore the history of ageing policy in Australia and the relationships between ageing, temperature, health and housing. It will then outline the research questions and aims of the research, and summarise the research methods used in the study.

1.2 A history of ageing policy in Australia

It is the desire and intention of most older people to remain living in their current private residence, whether rented, mortgaged or owned (AIHW 2013, Faulkner 2017, Kendig et al. 2017). Only a very small proportion of older people (4%) live in non-private accommodation such as aged care homes, although this number increases with advancing age: 26% of people aged 85 or older live in a non-private residence, and people in this age group make up more than half of all residents in aged care facilities (ABS 2017b). The ability to stay in one's own home is supported by government programs which provide low levels of care in the home, until the needs of the individual grow beyond that which is able to be supplied there.

Governmental support of the ageing has a relatively short history in Australia. Prior to the 1950s, it was generally assumed that older people would remain with their families, and that the very sick would enter hospitals. In this era, life expectancy was shorter, and as a rule women did not work outside the home, meaning that their role as a caregiver could transition from that of mother of their own children to nurse of their older family members. Those without immediate family help were generally cared for by voluntary and religious organisations, which became the models for the first nursing homes (Kendig, Duckett & Institute 2001).

During the 1950s and 1960s, the main focus on funding for older people was the increase in the amount and availability of the old age pension (now called the Age Pension), previously available to less than a third of older people, to the point that by the late 1960s, the terms 'pensioner' and 'elderly' were essentially interchangeable (Kendig, Duckett & Institute 2001). Meanwhile government amendments to the *National Health Act*

1953 provided benefits to private and voluntary organisations to give care to older people in nursing homes. This led to a distinctly three-tiered approach to housing for older people that persisted until the 1990s—private housing for most older people, public housing and hostels for frail but otherwise healthy older people, and nursing homes for sick older people. These different approaches had different funding models, meaning that those living in hostels received less financial assistance than those in higher-care nursing facilities. The 1980s saw the introduction of the Home and Community Care (HACC) Program, which brought together disparate Commonwealth services into a more streamlined care package, both for older people and people with significant disability (Kendig, Duckett & Institute 2001).

Between 1997 and 1998, the entire aged care system was overhauled (Kendig, Duckett & Institute 2001). This overhaul saw the development of the modern residential nursing home, a facility in which older residents can receive all health and welfare needs in one place. The government then introduced its 'Staying at Home' package, expanding the level of support available in home for carers and those with dementia. The expanded at-home care package alongside the residential care homes comprise the aged care system today (Kendig, Duckett & Institute 2001).

The name and structure of components of the system may have changed, but the two-tiered system which encourages home living for as long as possible remains. It has led to the low proportions of older people living in a residential aged care facility, as well as greater numbers of older people remaining independent rather than living with extended family, as was historically the case. The challenge now, which this research attempts to address, is how to keep the environmental conditions in people's own homes optimal for health and comfort.

1.3 Ageing, temperature and health

Exactly what does it mean to create homes which provide optimal health and comfort for older people? Why are their housing needs any different to that of a younger demographic?

It is well established that with advancing age come a range of health problems. High blood pressure, high cholesterol levels and impaired glucose tolerance are all prevalent in people over 65. Disability and activity limitations worsen with age, and the incidence of stroke and diseases such as Parkinson's disease and dementia increases (ABS 2015a, AIHW 2007). Many of these health conditions bring with them changes to how the body perceives and responds to changes in the thermal environment. They can also pose a challenge when it comes to a person experiencing such conditions remaining in the home, with both accessibility and care requirements being a barrier.

Even without considering disease and disability, healthy older people typically respond differently to changes in the thermal environment than younger people do (Kenney & Munce 2003). As a general rule, the body's metabolism slows with age, which can make it harder to keep warm in cooler conditions. Older people typically have decreased sensitivity to changes in temperature (Anderson, Meneilly & Mekjavic 1996, Yochihara et al. 1993). This may lead to them displaying delayed *behavioural* responses, such as changing their clothes or turning on heating and cooling devices, which are typically seen as a result of changing temperatures, or avoiding such behaviours at all.

Ageing has also been shown to lead to delayed *physiological* responses such as sweating or shivering (Dufour & Candas 2007, Foster et al. 1976, Inoue et al. 1999, Yochihara et al. 1993), which may delay behavioural adaptation to the environment and further heighten the risk of heat- and cold-related illnesses.

Both within Australia and globally, the health of older people and its relationship to climate is of interest to researchers. Extreme heat, in particular, has been the focus of much research, due to the very strong links that can be found between high temperatures and illness and death (Nitschke, Tucker & Bi 2007, Rocklöv, Ebi & Forsberg 2011, Tong et al. 2014). This is especially true in Australia, historically known for its high temperatures and very hot summers in many parts of the country. Claims that 'heatwaves kill more people than any other natural disaster' are common in the media (Phillips 2014) , and are based in fact. The rate of death and illness related to heat can be easily measured, owing to the acute and severe nature of the conditions related to high temperatures. Hospitalisations, ambulance call-outs and emergency department visits all increase during periods of extreme heat (Nitschke, Tucker & Bi 2007, Nitschke et al. 2011). 'Heat stress' and 'heat stroke' are conditions that can be tracked with relative ease within medical records and correlated with high temperatures.

Cold weather and health have a more insidious connection. Conditions that are created or worsened by cold weather have a tendency to be chronic, and they are not always attributed to low temperatures in medical records. Cold weather also tends to cause longer-term ailments, so that the lag between becoming ill or injured and the mortality that may ensue is not always attributed to the cold temperatures. Despite illnesses such as influenza and asthma being associated with the winter months

(Greenburg et al. 1964, Lowen et al. 2007, Thompson et al. 2003), and despite the fact that there is evidence of cold temperatures increasing the risk from falls (Lindemann et al. 2014), these conditions are not necessarily tracked specifically as illnesses and deaths caused by cold when retrospective medical record analysis is conducted.

However, there is increasing concern about people's health during the colder months in Australia, especially the health of older people. For instance, hypothermia, a cause of death directly related to the cold that can be easily traced over time, has been shown to kill more people per capita in South Australia than it does in Sweden and other places in Europe (Bright et al. 2014, Gasparrini et al. 2015). The demographics of these deaths are very different. In Sweden, a victim of hypothermia is most likely to be a middle-aged homeless man; in South Australia, the victim is most likely to be an older woman who lives on her own (Bright et al. 2014).

A mounting body of evidence thus suggests that a relationship exists between outdoor temperatures and the health of older people. The link between extremes in these outdoor conditions and the risk of illness or death for older people clearly needs to be addressed. The current body of evidence does not, however, indicate what the indoor thermal conditions are, nor how they are perceived by the occupants. How a building is designed, what materials are used, and how heating, cooling and ventilation are used can mean that conditions indoors are quite different from those outside. Typically, older people spend significant amounts of time inside their own homes. The home should be a place that provides comfort for its occupants and protects them from the elements. If, despite being inside, older people are exposed to environmental extremes, an examination of these conditions and the houses themselves is required in order to see what steps need to be taken to improve the indoor environment.

1.4 Housing and health

The indoor environment of a house is determined not only by the outdoor conditions, but also by how the house itself performs as a barrier to the environment. It is thus not surprising to discover that housing quality and health have similar links to each other as do outdoor conditions and health.

There are a number of different aspects of housing quality. When housing quality is considered 'poor', this can indicate a range of problems, including (but by no means limited to) cold, damp, toxins such as lead or asbestos, the presence of mould, a lack of ventilation, overcrowding, the presence of vermin, or structural defects (Krieger & Higgins 2002). Each of these issues is associated with health conditions, some of which can be fatal on their own. The chances of fatality increase when there is a combination of such factors present (Baker et al. 2016).

The houses included in this study were for the most part in good condition, as is typically seen in Australian homes (Baker & Lester 2017). The problems of the majority of houses in Australia are relatively minor when compared to other parts of the world, but in combination they can still result in a home that poses health risks to its occupants. Most of these problems relate to the internal temperatures of the houses.

One of the major factors to be considered is the age of a property. Whilst an old house is not in and of itself a health risk, certain features that help to create a healthy environment may not have been included when it was built. Minimum insulation standards were only included in the Building Code of Australia from 2004 (ABCB 2004). Whilst some houses built before this standard was adopted will have some insulation in the walls or ceiling or both, many will not. Double brick houses, for instance, rarely had cavity insulation installed at the time of construction, whereas brick veneer houses, which comprised nearly 70% of new construction in the 1990s, usually have wall and ceiling insulation.

Older houses are less likely to have centralised heating or cooling systems (Palmer 2012). If they have been installed either at the time of construction or as a later retrofit, issues relating to age and maintenance may mean that they are inefficient or non-functional. Old heating and cooling systems can be a hazard in themselves, as they can be a cause of poor air quality and can occasionally emit various toxins, such as carbon monoxide. High ceilings, which are more common in older houses in Australia, can also limit the effectiveness of heating systems and make them more expensive to run, which may discourage their use.

This acknowledged link between housing quality and health has led to a number of housing improvement plans being implemented in various parts of the world. These typically have two aims—to improve occupant health and to improve energy efficiency through the use of specific improvements. These have typically included improved insulation and draught-proofing of windows. In some instances, especially in those places with a very cold climate and very old buildings, housing interventions have also included the improving of heating facilities, through replacement or enhancement of existing systems.

Subsequent evaluation of these improvement programs has seen positive health outcomes for residents (Thomson et al. 2009) as well as decreases in energy bills. Lower energy bills decrease the cost of living, which is also significant; older people, especially those solely reliant on government pensions for their income, are among the most likely to struggle to pay their energy bills. Affordability of both housing and other living costs also has an impact on the health of occupants, and although such costs are largely outside the scope of this study they are worth noting, due to their association with housing quality and improvement.

1.5 Research questions and aims

There is ample evidence within the literature to demonstrate clear links between ageing, housing and health. Despite a tendency for governments and welfare bodies to treat them as such in the past, the provision of quality housing and the provision of health are not separate measures. Thus the provision of quality housing has the potential to act as a preventive health care measure, allowing older people to maintain comfortable healthy lives whilst remaining in their own dwelling.

What remains to be seen is what constitutes a comfortable and healthy environment. Comfort is something of a subjective experience, although building scientists have long sought ways in which to quantify and standardise it. Because the human body changes physically with age, it is possible that the existing standards may fall short in providing comfort for people of all ages. What is needed is a thorough understanding of how older people experience their houses from day to day, how this experience affects their health, and what their preference is in terms of thermal comfort.

There are thus, for the purposes of this research, four main research questions to be explored:

1. What is already known about the thermal comfort and experiences of older people?
2. What is the current understanding of housing and health within a sample of older South Australian people?
3. What thermal conditions exist in the houses occupied by older people in Adelaide, and what impact do these conditions have on the health and wellbeing of the occupants?
4. Can greater comfort be achieved by simple building improvements?

With these questions in mind, the stated research aims are

a. to investigate the relationship between the indoor thermal environment of the home, the comfort perception of older people, and their health

b. to investigate ways to create a more thermally comfortable, healthy and low-energy environment to accommodate older people in their homes.

It is expected that this research can thus inform future decisions regarding housing policy, especially in regard to housing improvements for older people remaining in their own homes.

In order to achieve these aims, this research has been conducted in several parts:

I. a literature review to determine what is already known about thermal comfort, health and older people

II. an investigation into the current state of the housing and health of a sample of older South Australians, as expressed by the occupants:

a. What level of thermal comfort do these houses provide?
b. What utilities are available to the occupants, and how are they utilised?
c. What is the self-assessed health of the occupants?

III. an investigation of the thermal conditions of a sample of houses occupied by older people in Adelaide, and what impact these conditions have on the health and wellbeing of the occupants:

a. Do ageing and perception affect the thermal comfort of these occupants?
b. How easy or difficult is it for these occupants to manage their heating and cooling requirements?

IV. an examination of whether greater thermal comfort can be achieved by simple building improvements through the use of building simulation software:

a. Can comfort be achieved through design intervention alone?
b. What is the best way to use heating and cooling in conjunction with design to create comfortable thermal environments?

1.6 Research methods

This study utilised mostly quantitative methods of data collection. There were some instances where qualitative information was of interest, but the use and analysis of this are minimal. Because of the diverse aims of this study, a number of different research approaches were undertaken. A survey of housing and health was first conducted, followed by a field study into the thermal comfort and health of a sample of older South Australians. Finally, a building improvement study was carried out to assess the effectiveness of simple retrofits in improving thermal conditions in houses and how this may relate to the presence of symptoms amongst the occupants. These methods are discussed in detail in Chapter 3. A chart showing how each methodological approach was used to answer each research question, and where in the thesis the results are presented, can be found in Figure 1-1 on on Page 13.

1.6.1 **Housing and health survey**

The Housing and Health survey was designed to gather information about housing and health from a large number of people. It was distributed by groups who work with older people, such as the Home and Community Care branches of various local councils, and University of the Third Age groups in Adelaide. It included questions about housing, comfort in summer and winter, and cooling and heating facilities, as well as questions about medications, health conditions and some basic demographic information. The survey also included a page detailing the field study and inviting participants in the survey to opt in to join this next part of the study.

1.6.2 **Field study**

A field study can assist in the evaluation of the effectiveness of occupied designed environments from the point of view of human users (Zimring & Reizenstein 1980). This field study sought to examine both the thermal conditions in the house, measurable by temperature and humidity, and the reactions of its occupants to these conditions. This combination of indoor climate measurements and survey allows the occupants' perceptions about the space to be matched to the measured conditions in the space, creating an accurate picture of their thermal comfort over time. Whilst a standard 'right

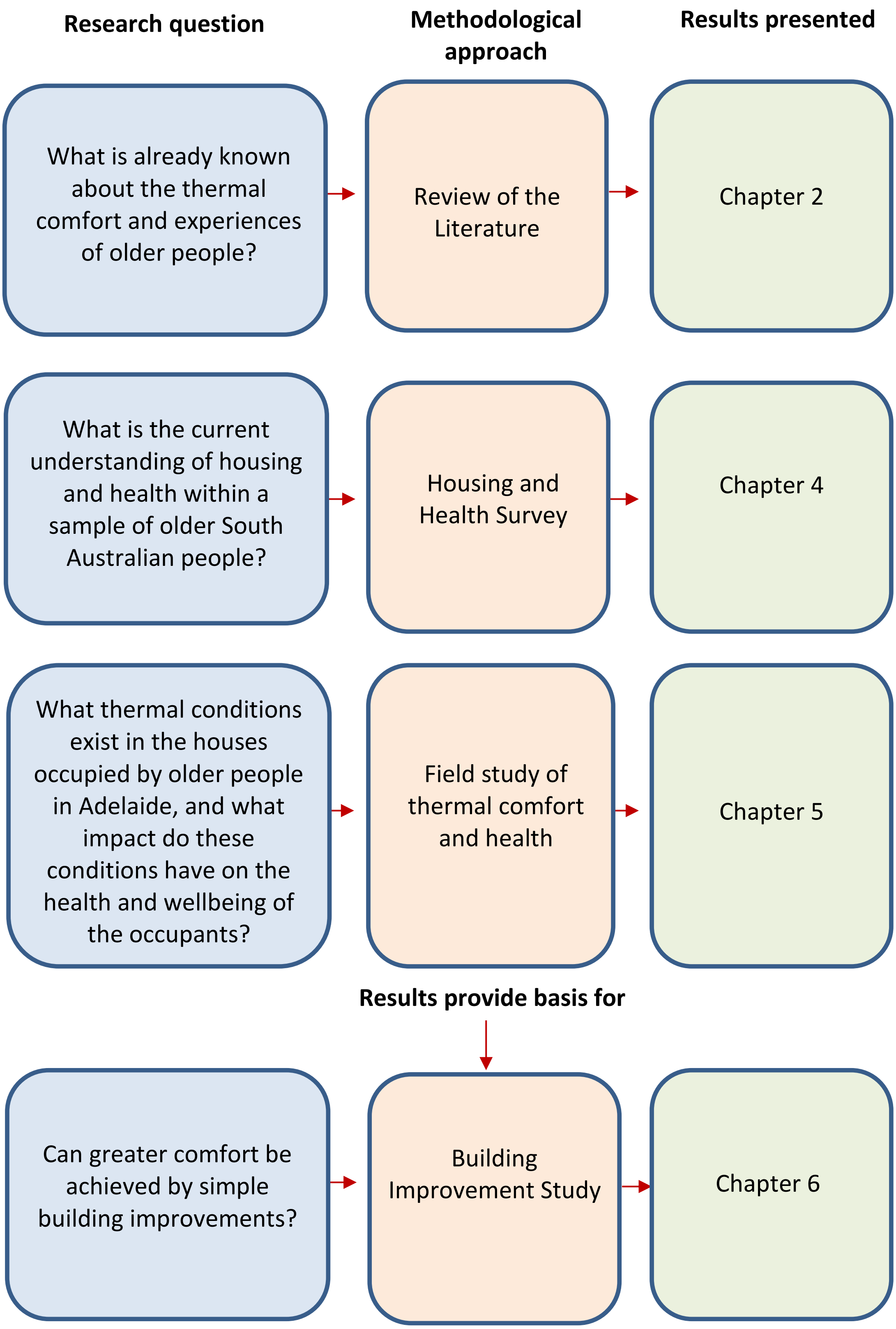


Figure 1-1: Flow chart of methodological approaches

here, right now' thermal comfort survey approach was employed (ASHRAE 2013), this particular survey was customised to include questions relating to any symptoms that the occupants had experienced in the previous 24 hours.

1.6.3 **Building performance analysis**

Some of the participants in the field study were able to provide copies of the original construction drawings of their houses. This enabled building improvement experiments to be carried out using a building performance simulation package (IES Virtual Environment software) (Integrated Environmental Solutions Limited 2017). Use of building performance simulation allows for the analysis both of the building as it exists and of the effects that any theoretical changes to the building fabric might have on its performance. It allows the user to see, for instance, what changes to temperature and energy use might be seen, should insulation be installed in the ceiling or in the cavity of a double brick home. This allows the effects of building improvements to be modelled and analysed without the cost and time implications of physically changing existing buildings.

1.7 Summary

This chapter has introduced the basic concepts discussed in this research. In the following chapters a review of the existing literature on the topic will provide more details of the current knowledge in these fields. A detailed description of the methods employed, and the results of the three stages of information gathering will follow. It concludes with a discussion of the results and how they could be translated into practical interventions for the benefit of older people through education and policy changes.

CHAPTER 2

Review of the literature

2.1 Overview

This chapter contains a review of the literature in regard to ageing, thermal comfort, and health. By examining what is already known about the experiences of older people in regard to thermal comfort, a clearer understanding of those areas yet to be explored can be obtained. This review is cross-disciplinary: it covers research in housing, physiology and public health, as well as research in thermal comfort and housing improvement policy.

2.2 Ageing in Australia

Australia, like most countries in the developed world, has an increasing population of people aged 65 or over. It is predicted by the Australian Bureau of Statistics (ABS) that by 2066, 21% of Australia's population will be aged over 65 (ABS 2018a).This is set to increase to 25% by 2101 (ABS 2013e), a significant increase from the 15% of the population they currently represent. In fact, it equates to more than double the current numbers of older people: 7 million people aged over 65 compared to 3.6 million in 2016 (ABS 2017b). It is suggested by the Australian Bureau of Statistics that in South Australia there will be over half a million people aged over 65 by 2066, and nearly 130,000 of these will be aged over 85, a more than threefold increase on numbers in 2016 (ABS 2017a, ABS 2018a).

An increased number of older people presents a number of challenges. One of these challenges is how to provide access to services which cater for the specific health and wellbeing needs of older people. According to the Australian Government Productivity Commission inquiry in 2011, over 1 million Australians aged 65 or over access government-subsidised services, at a cost of $11 billion (Commonwealth of Australia 2015). It is expected that the number of people accessing these services will increase to 3.5 million by 2050 (Commonwealth of Australia 2015). The majority of older people who need care receive it informally, relying on partners, family, friends and neighbours for support. Most of the $11 billion goes to government-funded aged care, with two-thirds of that being allocated to residential aged care facilities (Commonwealth of Australia 2015), despite fewer than 5% of people over the age of 65 being in permanent residential care facilities (AIHW 2017c).

This model essentially provides care to older people after they have deteriorated to a certain level of health or disability, with a limited scope for preventive health care. It offers very little to those over 65 who do not need care, but who could put measures into place to prevent themselves from needing such care in the future. Such preventive measures may help people stay healthier for longer, thus allowing older people to remain in their current residence for longer. Indeed, current policies strongly encourage older people to remain in their own home and receive care there if necessary; however, they do little to ensure that the home and the environment it provides are for the best health and wellbeing of the occupants.

With that in mind, this study examines the thermal environment of homes of older people and assesses their thermal comfort and its potential relationship to health. This review of the literature aims to examine the specific needs of older people in regard to their thermal comfort and health. This review will

- provide background information on thermal comfort research so far. It will then give an overview of the ways in which ageing may influence the thermal comfort needs of older people
- report on findings within the scholarly literature which relate to the physiological changes that occur with ageing, which influence the way older people experience thermal comfort, and how their experience of thermal comfort can impact on their health, especially during periods of heat and cold
- discuss research into why older people may fail to achieve a healthy thermal environment in their home
- review literature relating to housing improvement programs aimed at creating healthier and more comfortable homes in order to assess the success of this literature and its applicability to the residences of older South Australians.

This review will create an overall picture of what is known about the thermal experiences of older people, what still needs to be determined, and what can potentially be applied in Australia from international knowledge once the local contextual factors have been more rigorously examined.

2.3 Thermal comfort

The term thermal comfort refers to the combination of physiological, environmental and behavioural variables which produces a feeling of comfort or satisfaction with the environment. As defined by ANSI/ASHRAE: 'Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation'. (ANSI/ASHRAE Standard 55-2013, p. 3).

The *environmental* factors that influence the thermal comfort equation are air temperature, mean radiant temperature, humidity and air movement. The *human physiological and behavioural* factors included in the equation are metabolic rate and clothing insulation. Since the early 1900s, thermal comfort research has largely been driven by the need to specify the requirements of heating, ventilation and air-conditioning (HVAC) systems (Cooper 2002). Thermal comfort standards, therefore, are often to be found linked with HVAC standards such as the ASHRAE Standard 55 (ASHRAE 2013) or the CEN Standard EN 15251 (CEN 2007).

2.3.1 **Thermal comfort models**

Since the early 20th century, various researchers have attempted to standardise the variables pertaining to thermal comfort into predictive equations. A key contribution to the field was that of Povl Ole Fanger in the 1970s (Fanger 1970, Fanger 1973). Through experiments in climate chambers with college-aged males, Fanger developed an equation which, when given the above variables, will predict the number of people who will find the conditions comfortable, called the Predicted Mean Vote (PMV), and the percentage of people who are dissatisfied with the conditions, called the Predicted Percentage Dissatisfied (PPD).

The equation states:

$$PMV = (0.303\, e^{-0.036M} + 0.028)\, L$$

where

PMV = Predicted Mean Vote Index

M = metabolic rate

L = thermal load—defined as 'the difference between the internal heat production and the heat loss to the actual environment for a man hypothetically kept at the comfort values of the mean skin temperature and the sweat secretion at the actual activity level' (Fanger 1970, p. 111).

As conditions move away from a neutral PMV of zero, the Predicted Percentage of Dissatisfied (PPD) will increase, as shown in Figure 2-1 (Fanger 1970). The equation for this prediction is:

$$PPD = 100 - 95e^{-0.03353\ \mathrm{PMV}^4 + 0.2179\mathrm{PMV}^2}$$

Satisfaction with the thermal environment is indicated with a Thermal Sensation Vote (TSV). The TSV is indicated on a 7-point thermal point thermal sensation scale. This scale has been incorporated into the ASHRAE Standard 55. It allows a person to rate their current thermal sensation on a scale from –3 to +3. The seven points on the scale are: –3 Cold, –2 Cool, –1 Slightly cool, 0 Neutral, +1 Slightly warm, +2 Warm, +3 Hot.

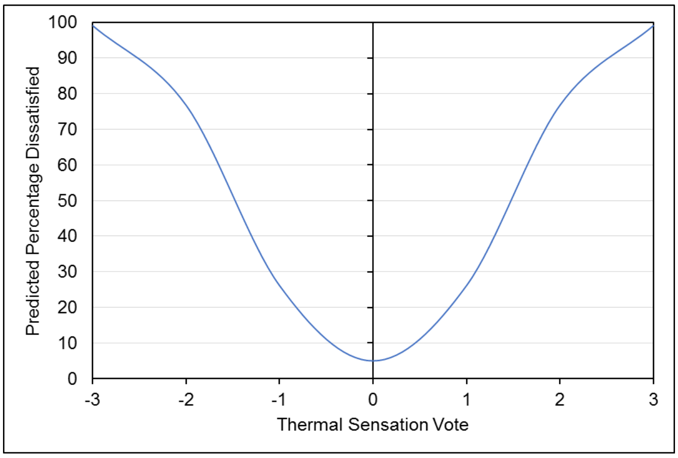


Figure 2-1: Fanger's PPD equation

The PMV/PPD model has been shown to be accurate in situations where the thermal comfort of a large number of people is being considered—for instance, large air-conditioned office buildings. It was, however, noted early in the history of thermal comfort research that the research done by Fanger, conducted in a controlled climate chamber setting, might not be ideally suited as a means of predicting human thermal comfort in all settings. Researchers such as Rohles and McIntyre began to emphasise the importance of environmental psychology as a further factor that influenced human thermal comfort (McIntyre 1982, Rohles 1971, Rohles 1980). It was, they argued, much more complicated than the six measurable variables which could be inserted into the PMV equation.

In his experiments in 1980, Rohles showed that visual environmental factors, such as dressing a climate chamber that otherwise looked much like a cold storage unit with timber panels, carpet and furniture, changed how participants perceived their thermal comfort. They typically reported being more comfortable in the dressed chamber than in the undressed chamber, despite the same conditions (Rohles 1980). The presence of a thermometer rigged to show a constant temperature also influenced the participants (Rohles 1980).

Furthermore, in experiments with heating units, participants who were told that their space was being heated reacted differently to a group who were not told this, despite the same heating conditions being in place for both these groups. Both groups felt warmer than the group who had no heating installed; however, those who were not told that the heating was installed reported feeling colder than those who knew that the heating appliance was in place (Rohles 1980).

According to Heijs and Stringer (1988), discussion which followed Rohles's 1980 article suggests that Rohles and Fanger came into conflict over their differences in approach to thermal comfort. Fanger, as an environmental engineer, doubted that thermal comfort could be altered by 'psychological tricks' (Heijs & Stringer 1988, p. 241). Despite the thoroughness of Rohles's research, and regardless of how compelling his evidence was, Fanger's definition and variables are still used more than 35 years later by the regulatory body ASHRAE to determine thermal comfort standards.

That is not to say that there has been no change in any of the standards since the 1970s. Fanger himself acknowledged this, suggesting that an 'expectancy factor' should be added into the PMV model when used in non-air-conditioned buildings, to account for those who accept warmer conditions as part of life or, as Fanger put it, as their 'destiny' (Fanger & Toftum 2002, p. 534).

It is now well acknowledged both by researchers and within the ASHRAE standard itself that in buildings in which there is no mechanical heating or cooling, occupants have different experiences of thermal comfort. The Adaptive Thermal Comfort standard was developed during the 1990s and included in ASHRAE Standard 55 in 2002 (de Dear & Brager 2002). Through extensive analysis of field study data from several naturally ventilated office buildings in different countries and climactic zones, de Dear and Brager (1998) devised revisions to the standard, which accounted for outdoor conditions and the fact that in occupant-controlled, naturally ventilated buildings the outdoor conditions will impact both the comfort of the occupants inside and whether or not they find the thermal conditions acceptable. This model also utilises a measurement known as the prevailing mean outdoor air temperature—a weighted mean of the temperatures that have occurred over the last 7–30 days depending on the equation used (de Dear & Brager 2002).

2.3.2 **Thermal comfort in the residential environment**

The difficulties posed by the rejection of psychological factors in the ASHRAE standard are perhaps seen most acutely when applying thermal comfort standards to the residential environment. Here, the aim is ensuring the comfort of a few occupants, rather than, as is the case in a non-residential setting, creating conditions that will be 'satisfactory' to a majority. Thus, the preferences and idiosyncrasies of the individuals come into play when considering or determining the occupants' comfort.

In the home environment, occupants typically have more control over their environment than they would in a commercial building, where HVAC systems are likely to be centrally controlled. Thus, the adaptations to the indoor temperature that can be made within a home are greater than that which can be made in an office building. This has been confirmed in a Finnish study, which found greater levels of thermal comfort in the home setting than in offices (Karjalainen 2009).

There have been a number of studies of residential thermal comfort, in a range of climates and in both naturally ventilated homes and air-conditioned homes. These are discussed below. The common feature in these studies is that the actual average thermal sensation vote differs from that predicted by Fanger's standard. However, the results are not consistent; sometimes the conditions people report as neutral are colder than the neutral predicted by PMV, and sometimes they are warmer.

A 2009 study involving homes in Haifa, Israel, found that thermal comfort responses differed from the ASHRAE Standard 55 significantly. In 189 dwellings in summer and 205 in winter, indoor conditions were logged, and participants completed regular surveys. The calculated PMV from Fanger's model underestimated the actual participant TSVs, with participants typically reporting feeling warmer than predicted (Becker & Paciuk 2009). This study also showed that the actual percentage of dissatisfied participants was distributed asymmetrically around the neutral sensation vote, with greater dissatisfaction at the 'slightly warm' and 'warm' votes on the scale than predicted, and lower dissatisfaction with cooler sensations, as opposed to the symmetrical distribution predicted by Fanger's PPD model.

A series of thermal comfort studies involving over 100 subjects in residential apartments in Hyderabad, India, utilising data logging and participant surveys (Indraganti 2010a, Indraganti 2010b, Indraganti 2010c, Indraganti 2011, Indraganti & Rao 2010), found that PMV was overestimated by Fanger's model, with a neutral temperature of 29.23 °C. This was true in both naturally ventilated and mechanically ventilated buildings. In these studies, residents often reported being uncomfortably hot, and there was often a lack of adaptive opportunities, with residents also having concerns about privacy, noise and economics.

Thermal comfort studies in residential buildings also show different ranges of comfort depending on climate and urban context and the degree to which mechanical air-conditioning and heating systems are used. Residents in naturally ventilated apartments in India reported a wider band of comfortable temperatures than Indian heating and cooling standards predicted (Indraganti 2010c). In China, a study involving 28 houses in an urban area and 30 houses in a rural area of the Hunan Province found that the participants who lived in the remote areas consistently had a higher tolerance for cold than those who lived in the city (Han et al. 2009) .

Another Chinese study by Cao et al. (2016) studied people across three areas of China: 206 people in the cities of Harbin, 304 people in Beijing and 230 people in Shanghai. Harbin is considered a severe cold zone, Beijing a cold zone and Shanghai a hot summer/cold winter zone. The findings show that people living in Shanghai accept and feel comfortable both when indoor temperatures are lower than predicted by standard models of thermal comfort and when compared to other colder regions of China. The authors suggest that an overuse of heating has led to decreased cold resilience in people in the colder regions.

Australian residential thermal comfort studies have typically focused on specific populations or housing types, or else on behaviour such as HVAC usage or adaptation. There are, to this author’s knowledge, no published data on the neutral temperature or thermal comfort of Australians in general or in comparisons of different climactic zones. Residential studies which have examined various aspects of thermal comfort in the Australian context, as cited below, rely on the standards from ASHRAE and CEN as the baselines for comparison, as in the Indian and Chinese studies.

In the hot–humid climate of Darwin, there are a variety of different housing types, and each provides different thermal comfort. In a study which compared PMV and PPD in houses with and without air-conditioning (Williamson, Coldicutt & Penny 1991), these tools were found to be inaccurate at predicting the thermal comfort of the occupants. The occupants were more comfortable and less dissatisfied than the available tools predicted. Daniel et al. (2015) found that the occupants of atypically constructed, naturally ventilated houses in the same city were comfortable outside the limits of the Adaptive Thermal Comfort model, recording being comfortable at warmer conditions than would otherwise have been predicted. When these two studies were compared (Williamson & Daniel 2018), it was determined that after 25 years—and despite changes in the housing stock available, as well as the proliferation of air-conditioning in both homes and businesses—the comfort expectations of those who live in naturally ventilated buildings have remained the same.

This study of people living in atypically constructed houses was conducted not only in Darwin but also examined the thermal comfort of people living in atypically constructed buildings in the colder Australian climate of Melbourne (Daniel et al. 2015). Here, people were more likely than they were elsewhere in Australia to report comfort at lower temperatures. The neutral temperature (determined by linear regression) of the 20 households in Melbourne was 19.3 °C, compared to 27.4 °C in the 20 Darwin households. Comfort across Australian climate zones is thus not universal, and it can be affected by both the type of climate and the type of construction in which a person is living.

In South Australia, a thermal comfort study during a summer season (Soebarto & Bennetts 2014) of 10 houses, using thermal monitoring and comfort vote surveys, suggested a neutral temperature for these occupants of between 21.7 °C and 26.1 °C. These occupants lived in apartments in a model ‘green village’ which had been designed specifically for low- to middle-income earners, with a higher energy efficiency standard (7.5

stars) than required by state regulations (6 stars). To keep cool in warm conditions, these occupants preferred adaptive behaviours (such as opening windows) to turning on air-conditioning, typically because of the perceived running cost of the mechanical cooling system.

In many of these studies, the greater level of comfort that people feel in the home is attributed to the greater possibility they have for adapting the environment or their behaviours than they would have in an office setting. These adaptive behaviours are, however, taken into account by the equation which predicts PMV. Thus, in the studies where PMV has been shown to be different to the TSV of participants, other factors must be in play.

Becker and Paciuk's (2009) Israeli study suggests that the difference may be due to 'contextual variables such as local climate, occupants' expectations, and available control over the environment' (p. 659). Indraganti (2011) attributes the difference to 'adaptation and acclimatisation of the occupants' in the Indian studies (Indraganti 2011, p. 1134). Indraganti (2010c) does however note a significant difference between the assumed thermal acceptability of conditions and the actual acceptability as indicated by participants. Thermal acceptance was found amongst participants even at times when 'hot' and 'cold' votes were cast; and those voting within the comfort band of 'slightly cool' to 'slightly warm' noted that conditions were unacceptable 22% of the time. Indraganti (2010c) attributed this 'fuzziness' of acceptability to 'lower expectations in some user groups; overall satisfaction with oneself and his/her immediate environment; gender; tenure; age; health; availability/access to controls; time of the day; season and psychological attitudes etc' (Indraganti 2010c, p. 880).

Indraganti also suggests that, as seen in other studies, the ability to control the indoor environment and the perceived effect of their adaptations or control strongly influences residents' satisfaction with the thermal conditions (Hwang, Lin & Kuo 2006, Indraganti 2010c, Wagner et al. 2007).

2.3.3 **Thermal comfort for older people**

In addition to the complicated matter of how humans experience thermal comfort in the home compared to how they experience it in office-type environments, it is not fully understood whether the thermal comfort requirements change with age. Whilst the thermal comfort of older people has been widely studied (Indraganti & Rao 2010, Natsume et al. 1992, Turnquist & Volmer 1980), there are conflicting answers to the question of changing thermal preference with age.

Thermal comfort research is carried out in two distinct ways: using a climate chamber to control conditions, or through field study measurements and surveys. The results of these differing methods vary and are discussed separately below.

2.3.3.1 *Climate chamber studies*

Climate chamber studies allow climactic conditions to be tightly controlled by researchers, allowing participants responses to be captured according to specific variables. Whilst not always accurately representing a 'real world' scenario, there is much insight to be gained when conditions can be regulated in a specific fashion.

Fanger's original studies were conducted on 128 college-aged students (Fabbri 2015), whose responses formed the basis of his PMV/PPD equation and the ASHRAE Standard 55 (ASHRAE 2013, Fanger 1970). Fanger (1973) repeated the climate chamber research with 128 older subjects (mean age 68 years) but did not find any difference between the neutral temperature of the two groups and therefore assumed there was no difference in their thermal preferences.

Within 10 years of these original experiments, new studies began to emerge to suggest that Fanger's conclusion may have been incorrect. In studies in the UK, focusing primarily on determining which conditions minimise the risk of hypothermia in older people, researchers found decreased ability to discriminate between differences in temperature in older subjects (Collins & Hoinville 1980) and surmised that whilst neutral temperatures were the same between the older and younger groups, older people in general prefer warmer conditions, attributed in this study as being due to the slowing of their metabolism. Collins (1981) further found that whilst the neutral temperatures of two groups of participants of different ages were the same, the older cohort were less able to control the ambient temperature than the younger group. For some of the older participants, this was due to the previously discerned (Collins & Hoinville 1980) decrease in their temperature discrimination threshold.

Throughout the 1990s and 2000s, a number of studies showed altered responses to thermal stimuli in older people compared to younger adults. For example, a study in Japan (Natsume et al. 1992) was conducted in which a group of six older men and six younger men were allowed to control the ambient temperature in a climate chamber. This study showed that the older men manipulated the ambient temperature differently to the younger men, depending on the starting temperature. When temperatures started at 20 °C, the subjects' average preferred ambient temperature was lower than when they started at 40 °C, but this disparity was much wider amongst the older people than the younger people participating in the same experiment. When the experiment was repeated, the ambient temperatures of the older cohort differed more widely from the first trial than those of the younger participants.

A study by physiologists in the USA examined the response to cold stress in 46 older people (aged 65–89) compared to 36 younger people (aged 18–30) (DeGroot & Kenney 2007). The researchers found that the older people were less able to maintain their core temperature during cold stress than the younger people. The older participants had a delayed vasoconstriction response (vasoconstriction being the tightening of peripheral blood vessels in response to cold, keeping blood away from the cold external environment as one of the measures to maintain a constant core temperature). Conversely, a climate chamber study of 10 older women and 10 younger women in Japan (Yochihara et al. 1993) showed a lesser degree of vasodilation in the older cohort during warm temperatures to assist heat loss from the body.

Other studies have also shown similar delays to the body's thermoregulatory responses—such as shivering (Anderson, Meneilly & Mekjavic 1996), sweating (Anderson, Meneilly & Mekjavic 1996, Dufour & Candas 2007) and thirst (Phillips et al. 1991)—in older people compared to younger adults during both increases and decreases in temperature.

Given the body of evidence for differences in thermoregulation and thermal sensitivity in older people, newer studies have looked again at the thermal comfort of older people compared to younger adults. These more recent studies have varied results, with some showing that older people have a preference for warmer conditions and others for cooler conditions. For example, Schellen et al. (2010) found in a climate chamber study that the optimum conditions for older adults were different to younger adults. This study also determined that the thermal sensation vote of these older adults was 0.5 units lower on the PMV scale than that of the younger people, showing overall that at a given temperature older people are likely to feel cooler than their younger counterparts and thus have an overall preference for warmer conditions.

Soebarto, Zhang and Schiavon (2019) conducted further climate chamber research which showed no significant difference between the TSVs of older people and younger people. The authors of this paper note a trend emerging in thermal comfort research, that climate chamber studies often show little or no difference between older people and younger people, but that greater differences tend to be found in field studies. This is despite the physiological differences that have been measured in climate chamber studies.

2.3.3.2 *Field studies*

An alternative to climate chamber studies examines the thermal preferences of people in a field study, whether in an office or residential setting. These studies measure the climactic conditions rather than controlling them, and compare the sensations of participants with the measured data.

One of the earliest field studies to look at the preferences of older people was conducted by Turnquist and Volmer (1980), who found that the preferred temperature of older adults fell within the PMV range. Other than this early study, field studies typically show more of a difference between the thermal experiences of older people when compared to younger people.

In a field study of 71 people aged 60 or over conducted by Hwang and Chen (2010), the preferred temperature (that is, the temperature at which the largest number of people would vote 'no change') was found to be 0.4 °C lower for older adults than for younger adults (based on a previous study), and that the range of conditions they would find comfortable was narrower (23.2 °C to 27.1 °C) when compared to a previously studied cohort of younger people (23.0 °C to 28.6 °C).

More recently, due to an increasingly ageing population, Chinese research has focused on thermal comfort in older people in residential settings. Older people who live in Shanghai also accept lower temperatures compared to older people in other regions of China (Jiao et al. 2017). These people were also shown to have lower sensitivity to changes in temperature, potentially due to changes in physiology due to age (Jiao et al. 2017). During the summer months they do not show this same difference in thermal preference, with results similar to other younger people in the area. Older people are more likely to draw upon adaptive behaviours during summer, such as changing clothes and opening windows, than they are in colder weather, when increasing activity levels seems to the most effective means of improving thermal comfort (Jiao et al. 2017).

In Beijing, however, the results are somewhat different. Older people who live in urban areas have similar neutral temperatures to younger people, but older people in more rural areas accept a colder environment (Fan et al. 2017).

There are currently no known studies looking at the thermal comfort of older people in their houses in Australia. There is some field evidence from studies in nursing home residents (Tartarini, Cooper & Fleming, 2018) but this is oustide the scope of the present study.

Overall, the general conclusion to be drawn from studies on the thermal experiences of older people is that there are differences in how they respond to conditions and in how they feel. These differences tend to lie in how older people perceive the environment, with differing TSVs and different neutral temperatures when compared to younger study participants or to the PMV/PPD standard. There are also different responses depending on climactic conditions, suggesting adaptation to the climate and lifelong experience may also play a part in changes in thermal comfort. The literature is mixed as to exactly what the thermal comfort requirements are for older people; however, the consensus is that they differ from those of younger people for a number of reasons, largely due to changes in sensation but also due to behavioural factors and expectations (van Hoof & Hensen 2006). Thus, when it comes to the thermal comfort of older people, the original conclusions drawn by Fanger about the requirements of older people appear to be erroneous.

2.4 Thermal conditions and health

The differences in the thermal experiences of older people when compared to that of younger adults raise the concern that changes in thermal perception may prevent adaptive behaviours during extremes in temperature, and thus have an effect on their health. It is well documented in the literature that excess mortality during extreme weather events, such as a heatwave or a prolonged period of intense cold, increases with age (Conti et al. 2005, Davie et al. 2007, Fouillet et al. 2006, Garssen, Harmsen & Beer 2005, Huynen et al. 2001). This is due to the decreased ability to regulate body temperature that comes with increased age, as well as to complicating factors such as disease and dementia. These studies focus on the outdoor climate and the impact it has on morbidity and mortality; they do not tell us about thermal comfort and health per se.

That said, there are guidelines for indoor temperatures aimed at maintaining health as well as comfort. A report produced by the WHO (Goromosov 1968) concluded that the human body could compensate for temperatures with minimal energy expenditure only between 15 °C and 25 °C; outside this range, larger amounts of metabolic energy are required to maintain homeostasis. A further WHO study (WHO Working Group 1982) showed minimal risk to the health of sedentary people, such as the elderly, when housing was kept at the slightly narrower temperature range of 18 °C and 24 °C. These recommendations have come under criticism for lacking basis in evidence, and focussing predominantly on protection from cold-related rather than heat-related illnesses (Ormandy & Ezratty 2012). There have however been studies which suggest these guidelines are appropriate, showing negative health outcomes in older people at cold indoor temperatures (Collins & Hoinville 1980, Osman et al. 2008). Thus whilst the WHO guidelines aim to promote good health through appropriate indoor temperatures, the evidence for these guidelines is old, Euro-centric and sparse. There is a need for more study into the relationship between indoor temperature and health, especially across broader climactic zones.

Heat and cold affect the body in different ways, and thus studies into each will be reviewed separately.

2.4.4 **Heat-related illness**

Heatwaves are a known source of illness and death, affecting older people disproportionately. A heatwave in Europe in 2003, for instance, caused an excess mortality of an estimated 70,000 deaths (Robine et al. 2008). The exact proportion of older people represented in this excess mortality is unclear; however, in France, 80% of excess deaths during the heatwave was in those aged 75 and over (Fouillet et al. 2006, Kravchenko et al. 2013). Heatwaves have also been associated with increased mortality amongst older people in the USA (Anderson & Bell 2009, Knowlton et al. 2008, Lin et al. 2009) and Asia (Hashizume et al. 2009, Huang, Kan & Kovats 2010, Son et al. 2012). In Australia, heatwaves have also been associated with an increase in mortality in Brisbane, Sydney and Melbourne, particularly affecting older people (Tong, Ren & Becker 2010, Tong et al. 2014).

As well as excess deaths, a number of studies have shown adverse effects during periods of extreme heat. These include an increase in hospitalisations, ambulance call-outs, and emergency department visits during heatwaves. One challenge in this area of study is that the definition of 'heatwave' varies in different studies and by location. In Adelaide studies, negative adverse health outcomes have been found during heatwaves, which were defined as a three-day period with outdoor maximum temperatures of or exceeding 35 °C (Hansen et al. 2008a, Hansen et al. 2008b, Mayner, Arbon & Usher 2010). In Brisbane, adverse health outcomes were found when there was a heatwave of two or more days when the outdoor temperature exceeded 34 °C (Toloo et al. 2014).

Some studies of extreme heat and its relationship with morbidity and mortality show that whilst there is, overall, an increase during periods of extreme heat, the maximum temperatures during the day are not what do the most harm. Excess deaths in Melbourne, Australia, during periods of extreme heat were correlated with warm overnight minimum temperatures of 24 °C (Nicholls et al. 2008), whereas no such simple correlation was found with the daily maximum temperature. This effect has also been observed in France, where a significant relationship was found between the excess deaths of those aged over 65 and night-time minimum temperatures, but not between their deaths and daytime maximum temperatures (Laaidi et al. 2012).

Loughnan, Nicholls and Tapper (2010) suggest that the daily minimum provides a more accurate predictor of excess mortality because it suggests extended exposure to heat; a daily maximum may expose people to high temperatures for only a short time. This extended exposure to extreme heat rather than to high daytime temperatures has the most impact on increased mortality amongst older people.

The city of Adelaide is prone to extreme heat events, and it may be for this reason that when the trends of morbidity and mortality were studied there was no excess mortality related to heatwaves between 1993 and 2004 (Nitschke, Tucker & Bi 2007), although there was an increase in some heat-related illnesses such as renal disease and ischaemic heart disease in older people. Long periods of hot weather may bring about some excess mortality; during a 15-day heatwave in 2008, a small increase in excess deaths was reported, with a steeper increase during the four consecutive days over 43 °C (Nitschke et al. 2011). During this period, the study reported that the nights were particularly hot, although the study did not investigate any direct correlation between night-time minimum temperatures and subsequent mortality increases. Whilst it takes prolonged days of high temperatures and potentially hot nights to see this increase in excess mortality, shorter heatwave events in previous years did create an increase in overall ambulance call-outs (Hansen et al. 2011b) and emergency department visits (Mayner, Arbon & Usher 2010).

Other studies have shown an increase in admissions related specifically to renal disease (Hansen et al. 2008b) and mental and behavioural illnesses such as schizophrenia and dementia (Hansen et al. 2008a) during hot weather. The latter study also found that during heatwaves an increased mortality was associated with mental illnesses in those aged 64–74, and that deaths related to dementia increased in those over the age of 65.

Given that much is known about the dangers of extreme heat in relation to human health, relatively little is known about the indoor conditions that might lead to these illnesses and deaths. Studies of excess morbidity and mortality during extreme heat events focus on retrospective analysis of the available epidemiological data compared with external climate data available from meteorological agencies. These studies show that heat and health are related, but that, considering that the majority of older people spend a majority of their time inside, the overall relevance of external weather conditions may not be as important as the thermal performance of houses during extreme heat events and the subsequent indoor conditions. Knowledge of what goes on inside the home and of the thermal comfort of the occupants during these events is, however, somewhat scarce, although some studies are beginning to emerge.

As part of a study into the adaptation of older people to heat, Loughnan, Carroll and Tapper (2015) examined the relationship between housing and heatwave resilience in an undisclosed regional town in Victoria, Australia. Results of this study indicated that daily maximum temperatures in the living room were not correlated with the outdoor temperature, and there was a weak but significant relationship between indoor minimum temperature and outdoor temperature. This may be due to the fact that all the houses had air-conditioning installed but residents preferred not to use it at night, which would keep the maximum indoor temperature steady during the day but would still allow indoor temperatures to drop overnight corresponding to the daily minimum outdoor temperature. The neutral temperature of this cohort was 26.6 °C, and thermal comfort decreased as indoor temperatures rose.

Interestingly, this study showed that houses with multiple air-conditioning units actually had warmer overnight temperatures than those without one or no air-conditioning units; the authors attribute this to the non-use of air-conditioning at night, with occupants not opening their windows. The study concluded that increased building age, flat roofs and an absence of wall insulation increase the risk of heat exposure amongst older people ageing in place. Brick veneer homes performed the best and maintained a more stable indoor environment than weatherboard or cement sheeting homes (Loughnan, Carroll & Tapper 2015). It may seem counterintuitive to say that increasing insulation makes homes cooler than uninsulated homes, as insulation has a tendency to prevent night-time heat loss; however, given the lack of correlation with indoor temperature and maximum outdoor temperature, it is likely that houses with less insulation maintain the conditioned air temperature for a short amount of time compared with insulated houses, with hot air infiltrating the building sooner than in a house with insulated walls.

From the literature presented above, a clear pattern emerges of a relationship between heat and both morbidity and mortality amongst older people. This pattern suggests a stronger relationship between morbidity and mortality and outdoor minimum temperatures that remain high overnight during heatwave conditions, than with daytime outdoor maximum temperatures, due to a lack of night-time relief to shed excess heat. In extreme cases, which are predicted to increase in frequency and severity in the future , high maximum temperatures over an extended period are associated with increased morbidity and mortality, especially amongst the older population Suppiah et al. 2007

(Suppiah et al. 2007). The evidence for indoor temperatures contributing to these health problems is limited but this is an emerging field (Hansen & Soebarto 2019), and the design of houses may thus play a significant part in the future, limiting exposure to extremes in temperature and thus acting as a preventive health measure.

2.4.5 **Cold-related illness**

The study of the association of cold outdoor temperatures with sickness and death goes back to at least the 1920s, with a study confirming a relationship between meteorological conditions and deaths from respiratory diseases amongst children between 1891 and 1910 (Young 1924). During the 1920s, studies also provided the first reports of a seasonal pattern of the occurrence of cardiac thrombosis, with increased attacks in the winter months (Wolff & White 1926). From these earliest studies has grown a wealth of research from all over the world on the effects of exposure to cold on human health.

The majority of cold-related health problems are related to the heart and lungs (Crawford, McCann & Stout 2003). Upon exposure to the cold, the body responds to preserve body heat and maintain a regular core temperature. The primary thermoregulatory response to cold is vasoconstriction, drawing blood away from the skin to keep the blood warmer and maintain the body's core temperature. This response leads to a cascade of other events, resulting in an increase in blood viscosity and blood pressure. High blood pressure is linked with the incidence of stroke and heart failure, which are significant causes of death and disability in older people (Ezzati et al. 2002). This is evidenced by the fact that the incidence of congestive heart failure in South Australia is highest in the coldest months of the year, despite the relatively mild winter temperatures (Inglis et al. 2008).

Other cardiovascular conditions also increase in the relatively mild winters in other parts of Australia: coronary artery mortality has been shown to increase during cold weather in New South Wales (NSW) (Weerasinghe, MacIntyre & Rubin 2002), and a study of myocardial infarction trends in Melbourne, Victoria, has shown peaks during July (Loughnan, Nicholls & Tapper 2008).

In a physiological study of thermal perception conducted by DeGroot and Kenney (2007), an increase in blood pressure was seen in both the younger adults and the older adults as temperatures decreased. This same blood pressure increase at lower temperatures was seen in a study of older males when subjected to different types of heating (Hashiguchi et al. 2004). Whilst both the older and the younger groups in DeGroot and Kenney's study showed the same increase in blood pressure, the older adults' blood pressure was higher at the base temperature, meaning that under cold conditions their blood pressure was still higher than that of younger people.

There is also a seasonal variation in the frequency of respiratory disease and infections across all age groups. The causes for this are unclear, but it appears that changes in the airway as a reaction to cold air may make individuals more susceptible to infection by the cold virus (Eccles 2002). Other research indicates that the viruses which cause respiratory infection tend to spread more easily and remain more stable outside of the human host during colder weather (Lowen et al. 2007). Whilst respiratory infections occur across all age groups with the same seasonal pattern, up to 90% of the mortality associated with influenza and respiratory syncytial virus is in those aged over 65 (Thompson et al. 2003). Those aged 85 and over are 32 times more likely to die from influenza than those aged 65–69 (Thompson et al. 2003). There is thus an increased risk of ill health and death in the colder months amongst older people due to the higher frequency of influenza during the colder weather.

Beyond these well-studied and documented causes of morbidity and mortality in the cold, there are other causes for concern regarding a cold indoor environment. In a study by the World Health Organization, older people who lived in dwellings they felt were too cold reported higher rates of arthritis than other participants, as well as increased respiratory problems (WHO 2007). Joint pain in those diagnosed with various forms of arthritis is often attributed by sufferers to the weather: up to two-thirds of osteoarthritis patients believe that the weather (both hot and cold) worsens their pain (von Mackensen et al. 2005). Whilst there is some evidence of a link between joint pain and temperature (McAlindon et al. 2007, Patberg & Rasker 2004) it typically varies from study to study, and a causal relationship remains unproven.

A further concern in cold temperatures is falls, especially amongst older women. In the 1980s it was discovered that there was a correlation between the incidence of femur fractures and cold weather (Bastow, Rawlings & Allison 1983). Further research by Campbell et al. (1988) found that the incidence of falls amongst women aged over 70 increased in colder weather, with falls increasing as outdoor temperature dropped. Early suggestions were that undernutrition led to a greater susceptibility to cold and hypothermia, and such undernutrition might also lead to falls, with fractures as a consequence (Bastow, Rawlings & Allison 1983).

Despite this observed relationship, there are not much data on whether indoor temperature is associated with an increase in falls amongst older people. However, there is recent evidence that shows a significant decrease in muscle power associated with cold ambient temperatures (Lindemann et al. 2014). The muscle power of older people is related to their mobility, and poor explosive muscle power has been shown to be a fall predictor (Skelton, Kennedy & Rutherford 2002). In their study of the effect of cold indoor temperatures on the physical performance of older women, Lindemann et al. (2014) showed that in temperatures of 15 °C muscle performance was significantly diminished compared with performance at 25 °C.

These findings are significant to the search for conditions that provide healthy conditions for older people: whilst falls are traumatic on their own, they are also the cause of approximately 90% of all hip fractures (Cumming, Nevitt & Cummings 1997). A hip fracture in an older person can be deadly—approximately 20% of those who suffer a hip fracture will die within 12 months (Jacobsen et al. 1992) and very few older people return to full pre-fracture function. In those who live alone, there is an added risk, as 50% of older people will be unable to get up after a fall without assistance, and this lack of mobility in cold weather can cause them to become hypothermic. This risk is in addition to other serious concerns attendant with immobility (Voermans et al. 2007).

As seen in the previous section discussing the relationship between heat and health, there is limited direct evidence about indoor conditions, with most studies focusing on correlations between disease or death and outdoor conditions. The study into muscle power amongst older women (Lindemann et al. 2014), conducted in a climate chamber, gives some insight into ambient conditions and their effects, but it was not conducted in a residential setting. Since there is such an obvious connection with cold outdoor conditions and health, there is a need for a greater understanding of how indoor environments, too, affect health, and why they fail to protect people from the effects of cold.

2.5 Barriers to achieving a healthy indoor thermal environment

Since there are proven relationships between poor indoor conditions and ill health, and these links remain despite what is now known about the dangers of excess heat and cold, the suggestion is that barriers exist for older people that prevent the creation of a healthy thermal environment. These barriers are beginning to be understood through social science research and epidemiology, as well as through research into the physiology of ageing, and the challenges that ageing brings.

What is becoming apparent through this research is that clear distinctions between behaviour, psychology, socioeconomics and physiology do not exist. Rather, a complicated web of factors determines the thermal comfort of the individual older person. Whilst it is unreasonable to assume that all older people experience thermal comfort in the same way (Day 2015), there are common themes to be found within much of the literature which can contribute to an understanding of these barriers.

2.5.6 **Measurable barriers**

Despite the complex relationships that exist between the different types of barriers to comfort and health amongst older people, some measurable and more easily defined factors must be taken into account.

Earlier in this chapter, the thermal comfort of older people was reviewed in terms of age-related changes in physiology. As these changes alter the way a person experiences thermal comfort, they may also present a barrier to achieving thermal comfort in the residential environment. Changes to thermal perception and thermoregulation may cause over- and under-heating of the home environment, which may further lead to some of the health challenges mentioned in this chapter. As the research stands, however, little is known about the effects of indoor temperature and the health of the occupants, or about the current heating and cooling practices of older people in Australia.

Other measurable factors lie in the field of economics. Older people, especially those on a low fixed income, may experience what is known as 'fuel poverty' or 'energy poverty'. Technical definitions of these terms vary. In the UK, a person is deemed by the *Warm Homes and Energy Conservation Act 2000* to be in fuel poverty if they are 'a member of a household living on a lower income in a home which cannot be kept warm at reasonable cost' (Moore 2012, p. 25).

In a country with warmer climates, like Australia, there is the added dimension of cooling, which complicates this definition. Whilst percentage-driven definitions are problematic (Moore 2012), typically those who spend more than 10% of their income on their energy bills can be considered to be in energy poverty (Simshauser, Nelson & Doan 2011), depending on their overall income and other housing costs. In the decade to 2017, Australian retail energy prices rose by 97% according to the Consumer Price Index, and this rise was not matched by growth in wages or in other economic sectors (Australian Competition and Consumer Commission 2017). Given that heating and cooling devices account for up to 40% of household energy use (ABS 2009), the reality of affordability and energy poverty cannot be overlooked.

There have until recently been very few studies into how energy poverty might be affecting Australians, with most studies focusing on winter warmth in the UK and in other parts of Europe. Energy poverty has, however, been a part of some Australian thermal comfort and adaptation studies. A study of low- to middle-income households (all ages) in

South Australia (Soebarto & Bennetts 2014) found that amongst the adaptive strategies available in the home, turning on air-conditioning was the least favoured strategy that a person might use in order to make themselves feel comfortable in hot weather. The reason people in the study gave for choosing other strategies was their concern about the cost of electricity needed to run the air-conditioning systems. Some occupants did not use their air conditioner at all, despite indoor temperatures reaching up to 37 °C. In fact, the study reported that one occupant went to stay with relatives rather than bear the cost of air-conditioning their own home. Whether a household meets the percentage-defined threshold for energy poverty or not, clearly there is a cost concern amongst lower-income households in regard to cooling their homes.

To the author's knowledge, there is currently no published scholarly research into whether energy poverty specifically poses a barrier to winter warmth in Australia. There are some studies emerging which show there is concern amongst older people particularly that electricity costs are a concern to them (Daniel, Baker & Lester 2018, Daniel, Baker & Williamson 2019, Soebarto et al. 2019) however these studies have not yet shown energy poverty as a specific issue, although issues such as thrift and frugality certainly inform the warming practices of many older people. The body of evidence regarding energy poverty in Australia is likely to grow in the coming years, as many organisations providing social services are beginning to express concern about the impact of rising energy prices on the ability of people to keep warm in winter (Australian Council of Social Service 2018).

Of further concern in regard to housing for older people is the maintenance and repair work that may be required to keep conditions comfortable and healthy. A report from New Zealand (Saville-Smith, James & Fraser 2008) assessed the condition of the houses of 1600 older residents as well as their attitudes towards maintenance. Many residents overestimated the good condition of their house, feeling that it was sufficient for their needs, and thus failed to adequately invest in repairs and maintenance. Much of this failure to enter into renovations and repairs was reportedly due to the perceived expense involved.

This is not a problem unique to New Zealand; it has also been reported in Australia (Bridge & Flynn 2003), in the USA (Fausset et al. 2011) and in the UK (Hillcoat-Nallétamby & Ogg 2013). Living in poorly maintained homes has also been shown to be a significant factor in the decision to move out of the home and community and into residential care facilities (Saville-Smith, James & Fraser 2008). Since it is largely the preference of older people to remain in their home as they age (AIHW 2013), and since the ability to stay at home is also the target of most aged care policies, this inability to do so due to maintenance issues poses a further problem that needs to be taken into account in any future policy decisions surrounding housing and health.

These known and measurable factors which may affect the creation of a comfortable thermal environment are not the specific focus of this research per se; however, an understanding of them is required when analysing the thermal sensations of older people in the home. Should older people fail to achieve thermal comfort, costs and physiological challenges may go some way to providing an explanation. Should they achieve thermal comfort despite such barriers, this information is also of interest when considering their housing and health needs. If older people consider their thermal conditions comfortable in a situation where those conditions are outside of recommended parameters, then understanding the physiology of why such a result is possible is essential.

Such measurable barriers provide a framework on which future policy and housing performance can be built and quantitatively evaluated, and thus they are vital for determining the success of any interventions implemented.

2.5.7 Psychological, socioeconomic and behavioural barriers

A number of barriers exist beyond those that can be measured. Generational attitudes, behavioural factors that may be related to life experiences, and a personal view of ageing and vulnerability may all influence the way a person responds to, and copes with, extremes in temperature in the home.

A study by Hansen et al. (2011) examined the perceived barriers to adaptation affecting older South Australians during hot weather. This study of some of the key stakeholders in aged care, such as medical practitioners, aged care workers and policy makers, found that they believed there were physiological, psychological, socioeconomic and behavioural factors that made older people more vulnerable during hot weather.

Whilst this study focused on the stakeholders rather than on the older people themselves, it provides valuable insight into what barriers are preventing thermal comfort and creating health problems in hot conditions. For instance, the study reported that a medical practitioner suggested that some older people do not drink a lot of water because they fear falling in the night when they need to use the toilet. Some are on restricted water intake due to various medications and do not increase their water intake even during hot weather.

In the same study, stakeholders also reported finding air-conditioning units set to ‘heat’ in summer, due to a lack of understanding on the part of the older people on how to use the units. Furthermore, some council officers reported older people avoiding using their air conditioners due to concerns about cost. Others noted generational attitudes as well as past experience as a barrier to adaptation: people who have always coped in the past may not utilise new and different ways to stay cool, and may not understand that they have different needs now that they are older.

A further study by the same research group conducted a telephone interview with older people to determine their behaviour and adaptive strategies during hot weather, and any health effects they had experienced. Nitschke et al. (2013) found that overall there was good heat resilience amongst older people, but that there were risks associated with social isolation, and there were also increasing health concerns amongst those who were on multiple medications and had more than one chronic health complaint. Typically, older people would keep cool via behavioural mechanisms such as reducing clothing levels and taking cool showers. Most participants had air-conditioning installed, but over 40% indicated concerns about the running costs. Despite 75% of participants considering their health to be good to excellent, 74% took medication for chronic health conditions.

The authors surmised that this may indicate a tendency for this population to underestimate both the effect that heat may have on their health and their own vulnerability during such extreme heat events. This—alongside the stakeholders' concerns, which older people do not themselves share—leads to a question that remains unanswered about the health of older South Australians: What are the conditions in their houses and how do these correspond to extreme heat events?

Studies in the UK have shown that similar barriers exist, both in the heat and in the cold. Some of these studies have analysed the tendency of older people to dissociate from the descriptor of 'old': though older people acknowledge that they as a group are more vulnerable during periods of heat and cold, they do not see themselves individually as particularly vulnerable (Abrahamson et al. 2009, Day & Hitchings 2011, Tod et al. 2012).

In a study into policy failures regarding fuel poverty, Wright (2004) found that, beyond simple issues of affordability, attitudes to the cold were a barrier to achieving warm indoor temperatures. Similarly to the Hansen et al. (2011) study discussed above, many of the participants in this UK study (Wright 2004) retained the comfort practices they had used throughout their life, such as opening windows at night, even in winter. Central heating was seen as a luxury, as many had grown up in houses without it. A third of the participants had no heating in their bedrooms.

Beyond the simple economics of being unable to afford to heat their homes, some of these respondents saw reducing their heating bill as a virtue and a sign of thrift. These notions about cost, affordability and thrift are a common theme in many studies which have examined the thermal practices of older people (Hitchings & Day 2011, Nunes et al. 2015, Tod et al. 2012). These are complicated issues, intertwined with personal values such as stoicism and hardiness, and thus they pose a challenge for those attempting to assist people who are vulnerable during extremes in weather, whether such assistance is through policy or through direct care work (Tod et al. 2012).

These attitudes also affect the ways in which older people think about energy efficiency measures and low-carbon initiatives. In a paper regarding the 'tyrannies of thrift', Waitt et al. (2016, p. 37) discuss the effects of these attitudes on the actual use and uptake of energy-efficient policy and devices. The paper discusses the ideas that older, low-income people may have about making do with less, which are counterintuitively problematic in regard to energy consumption.

For example, current energy efficiency policies encourage the purchase of newer appliances with good energy star-ratings to save electricity. This goes against the thriftiness and the abhorrence of waste which many of their interviewed participants expressed. Waitt et al. (2016) analysed the ways in which older people talk and think about energy efficiency: many think of the thrift and hardiness of their generation as a point of difference when compared to younger people, whom they see as wasteful and consumer-driven. Thus, energy efficiency becomes a narrative of thrift and economy rather than of good global citizenship.

Further to these attitudes of thrift and economy, more likely to be seen amongst older people than younger people, there is a more common attitude that extensive winter heating in Australia is unnecessary in most parts, due to Australia's relatively mild winters (Hitchings et al. 2015). Attitudes towards winter in a relatively temperate climate mean that the winter warming practices, or lack thereof, may actually place people at risk. In a study in the Australian coastal city of Wollongong examining the warming practices of eight households, conditions in the house were measured, and then a qualitative interview process examined participants' attitudes towards the cold, heating and winter in general (Hitchings et al. 2015).

The differing attitudes between households towards heating meant that there were a wide range of house conditions; however, the houses were recorded as being below 18 °C between 10% and 80% of the time. This threshold temperature was chosen in the study due to the WHO guidelines for healthy indoor conditions (WHO 2007). The participants were all over 50 years of age, and whilst they do not necessarily fit the description of 'older' Australian for the purposes of this thesis, their attitudes are still relevant as an indicator of the attitudes of Australians as a whole. The study cohort was typically in denial of winter cold, deeming it largely irrelevant due to a cultural focus on summer.

Whether this is true in South Australia, which has slightly colder winters, remains to be seen, as no research currently exists in the area.

2.6 International evidence for housing improvement as an investment in health

There is a long-established link between housing quality and the health of the occupants. Studies from a range of countries show that poorer-quality housing leads to long-term poor health (Bonnefoy 2007, Evans et al. 2000, Krieger & Higgins 2002). This is due to a range of different factors, including sanitation, mould growth, toxins, overcrowding and ventilation, just to name a few.

In Australia, studies of housing quality and health have been largely related to the Indigenous population (Bailie & Wayte 2006, Torzillo et al. 2008), and data are scarce about the health of non-Indigenous Australians and how their health is influenced by the physical aspects of their housing. This is largely due to the fact that, compared to many parts of the world, Australia has good-quality housing (Baker et al. 2016). The housing in Australia is relatively new by international standards and is largely clustered in the mild climactic zones (Baker et al. 2016). Because of this, there is little research related specifically to housing quality, with much of the housing research dedicated to the less direct relationships that housing has to health, such as through housing affordability stress and the precariousness of tenure (Baker, Bentley & Mason 2013, Bentley, Baker & Mason 2012).

However, a recent examination of housing quality in Australia has recognised that approximately 1 million Australians are living in housing of poor to derelict quality, and that this was correlated with poorer health (Baker et al. 2016). Whilst the study indicated that the number of older people living in these poorer-quality houses was low, the fact remains that the quality of the house does seem to have an impact on the health of the occupant, even in a country with perceived high-quality housing.

In countries other than Australia, where there is a longer history of housing construction, one of the biggest contributors to poor housing condition is simply housing age. A study of building thermal performance in the south-western American cities of Los Angeles, California, and Phoenix, Arizona, has shown through building simulation (Nahlik et al. 2016) that older buildings tend to warm up most quickly, due to poorer construction methods and materials. An English study also found (again through building simulation) that house age was a predictor of high summer temperatures: houses built between 1914–45 had predicted temperatures significantly higher than houses built after 1980 (Mavrogianni et al. 2012).

Both of these studies found that building age typically correlated with building quality, and that retrofitting measures such as insulation and double glazing were vital for providing thermal comfort, especially in regard to summer, as overheating becomes more of a health concern.

Further to the fact that poor housing conditions are associated with poor health is the fact that housing improvement schemes have, perhaps unsurprisingly, been shown to be associated with health improvements. Systematic reviews of a range of housing intervention schemes has shown overall improvements in residents' health when the warmth and energy efficiency of houses is improved in countries with cold climates (Gibson et al. 2011, Thomson, Petticrew & Morrison 2001, Thomson et al. 2009).

Whilst it has been noted above that Australian houses are generally of good quality, many people think of Australia as a 'summer place' (Hitchings et al. 2015, p. 162), and therefore many Australian houses have been designed to mitigate heat, with little consideration in the design having been given to winter cold. The result is that more deaths in Australia are associated with cold weather than with hot weather (Vardoulakis et al. 2014), despite the relatively mild winters.

Thus, even a house in good condition that is not designed to mitigate cold temperatures can be associated with poorer health outcomes. A report (Williamson et al. 2009) into the benefit of improving the star-rating of a house through increasing energy efficiency found only a small overall increase in health of the occupants and therefore a minimal cost benefit to the health system in terms of the cost of retrofitting a typical house.

Given these links between housing and illness, and given that older people have increasing issues regarding health and disability regardless of their housing, it is important to ensure that the houses of older people are not detrimental to their health. Where possible, it is best to provide housing which encourages good health and comfort rather than housing that simply prevents poor health.

Whilst it is the preference of older people to remain in their own homes when possible (AIHW 2013), there are a number of factors that can make this difficult or unsuitable. For instance, the Australian Housing survey conducted by the ABS in 1999 revealed that around 57% of houses in Australia were over 20 years old, with somewhere between 15 and 20% of those houses being 50 years old or older (ABS 1999). Whilst the age of a property itself is not necessarily a problem for older people, older houses can represent challenges to the occupants. For instance, houses built before 2003 were not subject to energy efficiency guidelines enforced by the Building Code of Australia (BCA) (ABCB 2010). The energy efficiency guidelines put in place by the BCA aim largely to reduce the energy needed to heat and cool houses and other buildings, as heating and cooling account for up to 40% of a building’s energy costs (ABS 2009).

In addition, if not effectively maintained, older houses can have other issues, including cracks and shifts in floors and door frames, which can lead to warm air escaping in the winter and infiltrating in summer. Such issues relating to heating and cooling are of most concern for ageing Australians with regard to energy efficiency and affordability.

Because of the large body of evidence supporting a link between housing and health, a number of initiatives have sought to improve housing conditions as a means of creating a healthier population. Given the above evidence about the known links between housing and health, a number of governments worldwide have begun to implement state-sponsored housing improvement programs (Thomson et al. 2009). Typically, these programs are designed not only to improve the comfort of the home but also to increase energy efficiency and therefore decrease running costs and carbon emissions.

The following sections will review government schemes carried out in the UK (Section 2.6.8) and New Zealand (Section 2.6.9), using them as a guide to determine whether housing improvement schemes are worthwhile as an investment in preventive health and energy policy.

2.6.8 **Warm Front – UK**

The Warm Front initiative was begun by the UK Government in 2000 with the aim to eliminate fuel poverty by the year 2010 (Hong et al. 2009). In this scheme, low-income households with at least one 'vulnerable' person (aged <16 or >60, chronically ill or disabled) were provided with between £1500 and £2500 to install cavity wall insulation, ceiling insulation, draught proofing and either gas wall heaters or gas central heating (Hong et al. 2009). This scheme recognised poor energy efficiency as one of the drivers of fuel poverty, and thus, by creating more efficient homes, it aimed to increase the warmth of occupants whilst decreasing their energy bills.

An early evaluation of the Warm Front initiative showed that, overall, living room temperatures increased by 1.6 °C and bedroom temperatures increased by 2.8 °C in houses which received the retrofitted upgrades (Oreszczyn et al. 2006). Further research (Hong et al. 2009) also showed that the average comfort vote of the participants increased by approximately one scale point, and the number of votes that indicated temperatures were neutral or warmer increased substantially from 36.4% to 78.7%.

Initially, fuel poverty appeared to decrease, from 5.1 million households in 1996 to 1.2 million households in 2003 during the first years of the program, although some of this was due to falling energy prices at the time, in combination with the program's interventions (Sovacool 2015). Qualitative evidence seems to indicate that overall health also improved amongst recipients of the intervention program—many in the form of reported improvements in mental health, reduced or improved symptoms of chronic illness, feeling less stress and having better nutrition (Gilbertson et al. 2006). In terms of measurable outcomes, mental health was the only factor to be shown to be quantifiably improved by the program (Gilbertson, Grimsley & Green 2012).

Although people felt warmer and happier in their homes, the improvements overall did not translate to substantially lower energy bills over time, as energy prices rose again and householders took advantage of greater energy efficiency to increase their heating (Gilbertson, Grimsley & Green 2012), a phenomenon known as 'energy rebound'.

Whilst these initiatives started out promisingly and more than halved energy poverty initially, there are still rising levels of fuel poverty in the UK, as electricity prices have once again increased. As of 2012, 4 million UK households were in fuel poverty, and 80% of these households are considered 'vulnerable' (Sovacool 2015). Whilst this is not necessarily entirely a failure of the program itself, increasing fuel prices mean that the benefits of no longer being in fuel poverty have not been seen, despite increased energy efficiency.

At the same time, the funding available for the scheme and the number of households eligible were cut substantially. The program therefore did not deliver its aim to eliminate fuel poverty. However, nearly 2.4 million homes were improved (Sovacool 2015) and are now more energy-efficient. They are thus warmer for a lower cost than they would have been without the intervention. Improvements in mental health were noted and it is possible that had fuel poverty been further decreased in the long term, other health benefits may have been seen.

2.6.9 **Warm Up New Zealand: Heat Smart – New Zealand**

A similar program to Warm Front began in New Zealand in 2009 under the name Warm Up New Zealand: Heat Smart. This program provided installation of insulation and/or the provision of clean heating to houses built prior to the year 2000. The program's stated aims according to Grimes et al. (2012) were to

- help New Zealanders to have warm, dry, more comfortable homes
- improve the health of New Zealanders
- save energy
- improve New Zealand's housing infrastructure through the uptake of cost-effective energy efficiency measures
- stimulate employment and develop capability in the insulation and construction industries.

This program comes on the heels of extensive work by the *He Kainga Oranga* program in consultation with community and government agencies earlier in the 2000s. The first of these community studies saw insulation retrofitted in 1350 houses, some prior to winter and others (a control group) insulated after winter. The result of this study was a general improvement in self-reported health, along with warmer and drier indoor environments (Howden-Chapman et al. 2005). This study also showed a 19% reduction in energy bills when compared to uninsulated houses during the cold weather, and a 5% reduction in annual energy expenditure (Chapman et al. 2009).

A second community trial in New Zealand, focusing on child health, involved more effective heating installed in insulated houses that were relying on inefficient bar heaters or unflued gas heaters (Howden-Chapman et al. 2008). As a result, small increases in the average temperature in the bedrooms and living rooms of the houses were reported, although with no accompanying significant drop in energy expenditure. Notably, there were decreases in respiratory symptoms, fewer days off school and reduced reports, overall, of poor child health.

Cost-benefit analysis was carried out on both of these studies. In the study into the effects of insulating a house, a benefit-to-cost ratio of 1.87:1 was found when taking into account factors such as the cost of electricity, visits to the doctor, greenhouse gas emissions and days off school or work (Chapman et al. 2009), meaning that the savings to the householders were nearly twice as much as the cost of the improvements.

There was a poor benefit-to-cost ratio (0.31:1) in the study in which heaters were installed, unless the family had a child who suffered from asthma (Preval et al. 2010). Given that one in five children in New Zealand suffer from this respiratory disorder, the benefits may be economically valuable for some people. Furthermore, warmth also improves a number of health conditions that were not covered in the study, and people place a value on warmth and comfort that cannot be easily measured in monetary terms. It is thus the opinion of the researchers that there is a case for investment in improved heating (Howden-Chapman et al. 2012).

These studies provide the evidence base for New Zealand's government housing program (Howden-Chapman et al. 2012). Evaluation of this wider program has shown similar results to the pilot studies in terms of benefit-to-cost ratio and energy savings. What has become evident is an 'energy take-back' or 'rebound' effect (Grimes et al. 2012, p. 4), whereby houses which are now more energy-efficient—whether because of more efficient heating appliances or improved insulation—now used heating and cooling devices more often, leading to smaller reductions in energy bills than if use of appliances remained the same (Berkhout, Muskens & Velthuijsen 2000). Whilst the scheme may not have produced the energy savings originally anticipated, it has succeeded in terms of health effects. The calculated benefit-to-cost ratio of the overall scheme is between 2.9 and 5.2 to 1 (Grimes et al. 2012), with 99% of this being attributed to savings in the health sector.

2.6.10 **Limitations of housing improvement studies**

The limitations of considering these studies from New Zealand and comparing them to the Australian context is that these programs have focused solely on warmth in winter. In Adelaide, South Australia, a balance must be struck between making houses warm in winter without trapping excess heat in the house during summer. In other parts of Australia, heating is not required at all, whilst some of the climate zones require no cooling.

There is not a one-size-fits-all solution, given the range of climactic conditions in this county. For example, the New Zealand study has shown improved winter health outcomes due to more warmth in winter, but it has been argued that the installation of the more energy-efficient reverse cycle units for heating may actually be contributing to greater energy use during the summer (Byrd & Matthewman 2012). These houses previously would not have relied on cooling during the summer, and thus the credibility of the scheme to reduce electricity use is called into question.

A review by Willand, Maller and Ridley (2017b) made several recommendations as to the interpretation of past studies and the implementation of new policies. These include the fact that policies should be tailored to meet the specific needs of the population, taking into account local and sociocultural factors. Intervention strategies need to take into account the preferences of the community: top-down approaches that assume a ‘we know best’ approach are less successful than those which include the householders in the improvement process. Furthermore, the current heating and cooling practices of the target population need to be understood before any intervention can be designed. There is little use in installing complicated and expensive heating systems if it is the preference of the consumer not to use such systems.

Finally, this review calls for an interdisciplinary approach to further research in the area, involving building scientists, social scientists and epidemiologists, to get a more holistic view of the problems and their suggested solutions (Willand, Maller & Ridley 2017b). It would be folly to simply apply the same improvement strategies from other countries to the Australian context without a deeper understanding of the needs and desires of Australians in regard to their housing and heating and cooling practices.

2.7 Summary

Between the various disciplines of building science, physiology, public health, epidemiology and social sciences, there is a wealth of information about the thermal experiences of older people. Their thermal comfort requirements have been measured and analysed in climate chambers; their health has been tracked and correlated with outdoor temperatures; and their specific needs and attitudes toward heat and cold have been examined for potential barriers to health and comfort.

What is lacking in the literature is any year-round, all-season examination of the thermal conditions in the residences of Australian older people, and of the occupants' perception of thermal comfort. Do the conditions that older people find comfortable in their homes match the assumed conditions that have been developed by studying younger people and by conducting research in climate chambers since the 1970s? And if not, what impact might this have on their health and comfort?

The research aims of this study begin to address some of these questions, examining residential thermal comfort in a group of older people in Adelaide, South Australia. The scope of this study is largely in the fields of building science and public health, investigating the thermal conditions in domestic settings and the response of occupants in terms of both comfort and health. In doing so, this research will link thermal comfort research with the field of housing research in order to suggest ways in which people's homes can contribute to better health in older age.

CHAPTER 3

Methodology

3.1 Overview

As outlined in Chapter 1, this research project aimed to address four main research questions.

1. What is already known about the thermal comfort and experiences of older people?
2. What is the current understanding of housing and health within a sample of older South Australian people?
3. What thermal conditions exist in the houses occupied by older people in Adelaide, and what impact do these conditions have on the health and wellbeing of the occupants?
4. Can greater comfort be achieved by simple building improvements?

The first of these questions has been explored through the literature review in Chapter 2. The remainder of the questions are the basis for the research component of this thesis. Because of the diversity of aims within these questions, no single methodological approach was appropriate. Thus a mixed methods approach was utilised to gain specific insights into different aspects of housing, health and ageing.

All research was conducted with the approval of The University of Adelaide's Human Research Ethics Committee, Project No. H-2014-199 (Appendix H).

3.2 Theoretical framework

Adaptive thermal comfort theory states that 'if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort' (Nicol & Humphreys 2002, p. 564). As well as altering the temperature conditions using heating or cooling appliances, people often choose other means, such as changing their clothing, or increasing the ventilation by opening a window or using fans, in order to produce a sensation of thermal comfort (Nicol & Humphreys 2002). It is thus sensible to assume that the Adaptive Thermal Comfort model would be applicable in a home environment.

The Adaptive Thermal Comfort Standard, included in the ASHRAE Standard 55 as of 2002, suggests that in naturally ventilated buildings, 90% of individuals should find conditions acceptable between 18.5 °C and 30.5 °C depending on the outdoor prevailing mean. When this is compared to the WHO recommendation for older people, which is an indoor temperature of 18 °C and 24 °C (WHO Working Group 1982), it becomes apparent that at the upper end of the temperature spectrum the acceptance of higher temperatures may not be beneficial to people's health, although the upper end of this range has been recently disputed as lacking in supporting evidence (Head et al. 2018).

This theory is supported by research that links hot conditions with increased morbidity and mortality amongst older people: older people may be comfortable at hotter conditions that are good for their health. It does not however explain the relationship between lower outdoor temperatures and increased morbidity and mortality. If conditions below 18.5 °C are indeed unacceptable to older people, then adaptive thermal comfort theory suggests they should act in such a way as to decrease their discomfort. If they are failing to do so, this may place their health at risk.

This research thus examines the indoor conditions of the houses of a sample of older people through both a survey of housing and health and a field study of thermal comfort and health. It is not just the conditions indoors that are of interest, but the perceptions and reactions to these conditions. For instance, the acceptance of conditions that are colder than those predicted by the Adaptive Thermal Comfort model could be linked to poor health outcomes, yet if these cold conditions are deemed acceptable, the behaviours which might be used to warm a house may not be utilised. Conversely if older people accept temperatures higher than the 25 °C suggested by the WHO, which the Adaptive Thermal Comfort standard suggests they might, then this too may need to be addressed.

This theoretical underpinning relies on recommendations from the WHO, which were last updated in 1982. Because of more recent research showing the links between housing, outdoor climate and health, this study will also examine whether this temperature range is indeed adequate for maintaining good health amongst older people, or whether the advice should be updated reflect changes in climate and understanding of its relationship to health and wellbeing.

3.3 Methodological Approach

To address Research Question 2 (that is, ‘What is the current understanding of housing and health within a sample of older South Australian people?’), a cross-sectional study design was employed with a survey method deemed most appropriate. There are a number of survey methods available including hard-copy (paper), telephone and online surveys. According to the ABS, only 51% of people over the age of 65 people use the internet (ABS 2016b), which would disqualify half of the population from participating. Other studies have shown good response rates from telephone surveys (Herzog & Rodgers 1988) such as a telephone survey conducted by Nitschke et al. (2013). Despite the success rate of such an approach, this method requires staffing and costs that were outside of the scope of this study.

For this research, it was decided that a paper survey was the most economical way to contact and get information from the largest possible range of older people. For the purposes of this thesis, this survey will be referred to as the 'housing and health survey' to distinguish it from the comfort vote surveys in the field study.

The housing and health survey covered a range of information about housing type and tenure, heating and cooling usage, and self-reported health. These questions were drawn in part from other surveys of a similar nature, such as the Australian Housing Survey (ABS 1999), a survey used to determine the risk factors, health effects and behaviours of older people during extreme heat (Nitschke et al. 2013). The author also developed questions to address specific housing questions about matters such as the availability and usage of blinds, fans, air-conditioning and heating. Where possible, questions were asked in a multiple choice format, to ensure that information remained consistent across participants; in addition, the survey included spaces on the paper where participants could add extra comments, in order to allow some subjective insight within an otherwise largely objective measurement tool.

The largest component of this study was the field study into the thermal conditions of a selected number of homes, which addressed Research Question 3: 'What thermal conditions exist in the houses occupied by older people in Adelaide, and what impact do these conditions have on the health and wellbeing of the occupants?'. A field study allows valuable information about a building to be obtained from those who are most affected by, and knowledgeable about, conditions in the building: the occupants. In this case, the study was used to measure both the thermal conditions of participants' houses and the comfort experienced by those occupants. It combined objective measurement via data logging equipment with subjective responses captured in a comfort vote survey to create an overall picture of the thermal comfort of the occupants of the building. This field study was tailored to the research questions and thus included an indication of symptoms as well as the more typical thermal comfort questions.

While Question 4—'Can greater comfort be achieved by simple building improvements?'—could be answered by making physical changes to a residence, and the improvement (or otherwise) objectively measured, constraints of time, budget and practicality meant that this was not possible to carry out within the limits of doctoral research. There are, however, tools available which can predict the outcome of building alterations on energy use and thermal conditions. Building performance simulation software was thus used to determine whether sometimes costly building alterations would be justifiable in terms of improved performance. For this study, such information has the potential to inform health policy by determining whether housing alterations can bring about conditions more conducive to good health, allowing older people to remain healthier and thereby preventing a move to residential aged care facilities.

3.4 Housing and health survey

In order to address the questions about the current state of the housing of older South Australians, a questionnaire survey was designed to gather information about the houses and the health of the target population, and to recruit participants for the field study. It was based partially on a survey conducted by the South Australian Department of Health and Wellbeing (formerly the South Australian Department of Health)and The University of Adelaide's School of Public Health (formerly the Discipline of Public Health) in 2010 (Nitschke et al. 2013), but included more detailed questions about housing design. These latter questions about the physical housing features and the use of the heating and cooling begin to build a profile of the houses in which older people live, and whether they are able to be utilised in a way that provides thermal comfort to the occupant.

The Housing and Health Survey included five sections with questions about:

a) house characteristics and running costs

b) comfort, cooling practices and behaviours in summer

c) comfort, heating practices and behaviour in winter

d) general health

e) household demographics

The design of each section is expanded upon below.

Attached to this survey was a form that invited those who filled it out to participate in the field study. They were able to add their name and address to this form so that further information could be provided, and thus this survey acted as a recruitment aid to the later parts of the study.

3.4.1 **Survey design**

3.4.1.1 *Overall design*

The questionnaire was designed to include multiple choice answers where possible. There were several reasons for this: first, multiple choice questions are answered quickly with a simple tick or cross, reducing the need for long answers. Given that the survey contained over 50 questions, it was important to provide a quick means of answering the questions to increase the likelihood that the participant would finish the survey. Second, multiple choice questions provide a more convenient data set for subsequent analysis.

Whilst open-ended questions were avoided, most of the questions offered space for participants to add qualifying information if they felt it necessary, and this information was considered separately to the quantitative multiple choice question answers. Where a multiple choice question was not appropriate, the question was designed so that answers were limited to one or two words unless the participants wished to provide more information. A copy of the Housing and Health survey in its entirety can be found in Appendix B.

3.4.1.2 *Section A—House characteristics and running costs*

Section A directly addressed the question 'What is the current state of the houses of older South Australians?'. Questions in this section related to the house and its operation. Questions were designed to get an overall picture of the age, type and quality of the houses of older people in Adelaide. Participants were asked about the physical characteristics of their home: whether it was detached or attached, what its approximate age was, what construction materials had been used, what the ceiling height was, and whether or not it was insulated. The reasons for asking the participants these characteristics are explained below.

Detached houses are likely to perform differently to those which are attached to a neighbouring house. They can have fewer external walls, due to shared walls between houses, which alters the surface area in contact with outdoors and alters the amount of solar radiation that a house receives. For instance, a unit with a neighbour attached to their northern wall may struggle to warm their house using north-facing sun exposure. Someone living in the top storey of a multistorey residence may have hotter conditions than someone on a lower floor. It is thus important to know what the living situation of the participants is, so that like can be compared with like.

Building materials and methods change over time, due to both the development of new techniques and technologies and to changing fashions within the building industry. An older house may also have structural issues as a result of age, and may not be insulated or well-sealed, leading to draughts and potential heat loss.

If participants have not been living in the home for long, they may not yet have experienced the full range of seasons, or the extremes of seasons, and therefore they may not be able to reliably indicate whether their house provides comfortable indoor conditions in all circumstances. Conversely, someone who has lived in the same place for a very long time can become accustomed to the particular conditions provided by their house, and the peculiarities of how it responds to various conditions.

Asking participants to indicate whether their house was double brick, brick veneer, concrete block and so on enabled the comfort provided by different construction types to be compared. This meant that when it came to suggesting design improvements and interventions, principles from the construction types which provide the best levels of thermal comfort could be applied to other types of construction. It was also important when it came to building simulation later in this project that the construction type was known, so that the house was correctly modelled.

The use of insulation is widely known as a method of preventing heat loss from buildings and therefore increasing their thermal comfort, particularly in colder conditions (Hong et al. 2009, Pacheco, Ordóñez & Martínez 2012). In warmer conditions, houses which are heavily insulated, however, may be more prone to overheating if air-conditioning is not used (Lomas & Kane 2013), although insulation has been shown to reduce the cooling load in a hot–humid climate (Aktacir, Büyükalaca & Yılmaz 2010). There is therefore a complicated relationship between insulation, energy efficiency and thermal comfort, and asking the level of insulation in people’s houses allowed these relationships to be examined.

Ceiling height plays a specific role in the thermal comfort of a building, as keeping conditioned air (whether cooled or heated) in the place where it is most needed for human comfort can be hindered by a very high ceiling. Participants were asked to provide information about the average ceiling height in their home via a diagram showing a person 1.6 m tall, compared with associated approximate ceiling heights, as shown in Figure 3-1 below. The diagrammatic format was chosen to try to eliminate the subjectivity of terms like ‘medium’ and ‘high’, by including both a person for scale and an approximate height in metres.

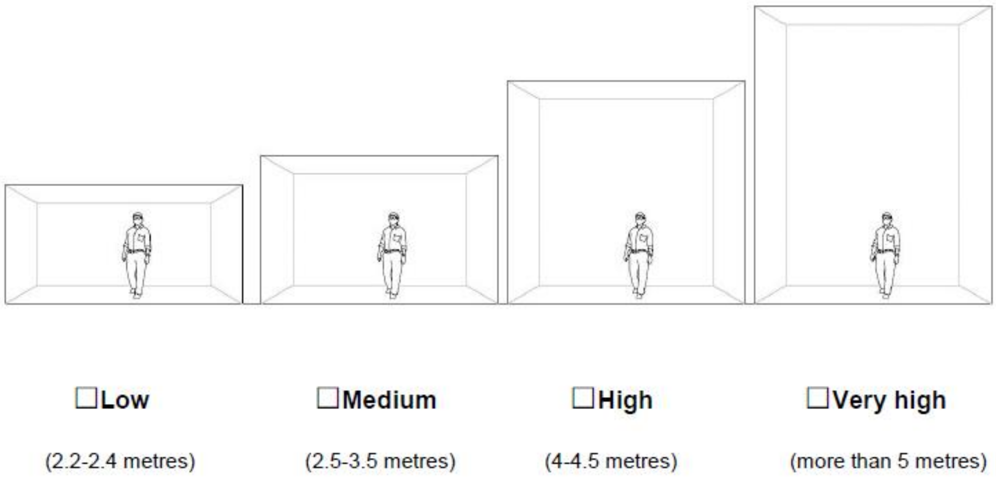


Figure 3-1: Diagram of ceiling heights included in the survey

Beyond the physical characteristics of the house, participants were also asked to list their annual spending on gas and electricity. Concerns have recently been raised about the cost of electricity and whether this may be preventing some Australians from keeping their houses comfortable and healthy (Chester 2014, Chester & Morris 2011, De Vries & Blane 2013). As this study examines people’s health, it is important to consider energy affordability as a factor that may influence health outcomes. Knowing the amount spent on gas and electricity also allows for comparisons to be made between different types of houses, insulation levels and the costs of energy.

Many of the factors that were determined by gathering general information about the houses could also in fact be related to each other—for instance, whether a house is insulated may affect how much money its resident spends on energy. Also of interest was whether factors such as energy expenditure showed any correlation to later questions about the comfort of the home and health of the occupant.

3.4.1.3 *Section B—Conditions and comfort in summer*

Questions in this section were designed to determine how people felt their homes performed during the hotter months, and what factors influenced the thermal comfort of the house. Participants were asked first to say what conditions were like in their home generally during summer, and then to indicate what thermal condition their home typically provided. By asking these questions, the research could determine whether older people typically find their homes comfortable during hot weather, but it could also determine the sorts of conditions that the participants classify as comfortable. Participants were asked the following questions about their home's comfort:

- In general, is your home comfortable in summer?
- In general, in summer is your home: hot, warm, slightly warm, just right, slightly cool, cool, cold?

Nitschke et al. (2013) showed that there was some indication that participants experienced difficulties using various cooling devices and appliances. For instance, older people may avoid using external window shades because they have trouble with them, or because they cannot be bothered (Nitschke et al. 2014). Because of this, participants were asked about the windows of their home and about any internal and external window treatments, and about their ability to use them.

Participants were then asked about their cooling practices. Most houses in SA (>90%) have some form of air-conditioning (ABS 2009), with 95% of older people reporting having air-conditioning installed (Nitschke et al. 2014). They may, however, avoid using it for various reasons, such as cost, noise or environmental concern (Nitschke et al. 2014).

Participants were thus asked about the kind of cooling that was available to them, whether they knew how to use it properly, and when they used it or avoided using it. If they avoided using their air-conditioning for any reason, they were asked to specify why.

Cooling is not limited to air-conditioning. Many homes also utilise fans to create air movement, which creates a cooling sensation. Participants were thus asked about the presence of any ceiling or pedestal fans and how frequently they used them.

Participants were also asked about their clothing level. The question was presented pictorially to participants, with accompanying check boxes, as seen in Figure 3-2 below. Clothing was depicted pictorially rather than by using descriptions such as 'light' 'medium' and 'heavy', due to the subjectiveness of such terms. The use of pictures also still allowed individuals to quickly tick a box rather than to have to list the type of clothing by item.

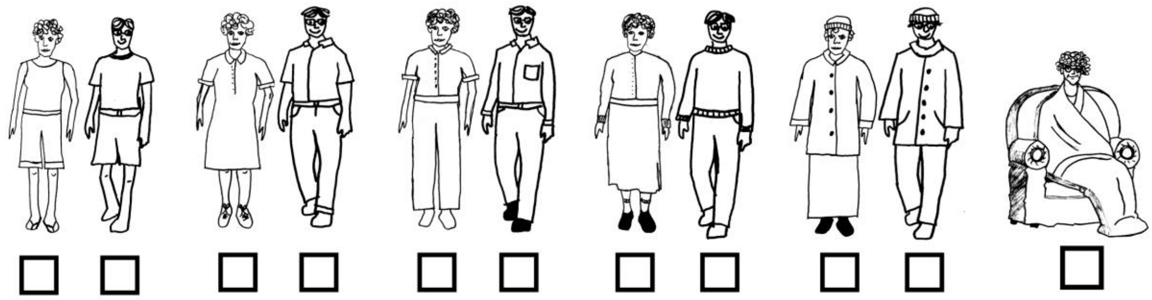


Figure 3-2: Pictorial representations of clothing typically worn as presented in the survey

3.4.1.4 *Section C—Conditions and comfort in winter*

This section was very similar to section B, except that questions related to winter conditions rather than to summer conditions, and to heater use rather than cooling use. The justifications are thus similar. Whilst the Nitschke et al. (2014) study examined extreme heat conditions only, this research deemed it important to ask about winter comfort as well, due to the increasing body of evidence suggesting that cold is as much a hazard to health (especially amongst older people) as extreme heat, even in the relatively mild Adelaide climate (Bright et al. 2014, Gasparrini et al. 2015). The questions asked of participants in this section were:

- In general, is your home comfortable in winter?
- In general, in summer is your home: hot, warm, slightly warm, just right, slightly cool, cool, cold?

The same questions were asked about heating as were asked about cooling. Participants were asked what kind of heater/s they had available, how they used them and so on, as well as being asked about the clothing they wore in winter, with the same pictorial answer as given above.

3.4.1.5 *Section D—General health*

These questions gave an indication of how the participant viewed their own general health, and what health conditions were most prevalent in the surveyed cohort. The section started with general health questions, using a self-rated 5-point scale. Such questions are frequently used in surveys and have been shown to be a reliable predictor of morbidity and mortality amongst their target populations (Chandola & Jenkinson 2000, Idler & Benyamini 1997). Participants were asked about their health in general and about whether they were taking medication for a specified list of conditions.

A list of conditions that was included in the Nitschke et al. (2014) study was included as a multiple choice answer set: diabetes, high blood pressure, heart problems, kidney problems, respiratory problems, depression or other mental illness, and multiple sclerosis. These conditions and the medications taken for them can cause changes to how the body experiences and adapts to the thermal environment (Davis et al. 2010, Epstein et al. 1997, Kenny, Sigal & McGinn 2016, Lomax & Schönbaum 1998). Additionally, Parkinson's disease was added to the original list used by Nitschke et al. (2014), due to its known impairment of heat tolerance (Sandyk, Iacono & Bamford 1987).

Participants were asked about any symptoms they experienced at home during hot and cold weather. Again, a list of the symptoms was provided, based on the Nitschke et al. (2014) study as a means of comparison to previous work. This list included anxiety, dizziness, a fall, headache, shortness of breath, heat stress, a heart condition and kidney problems. Added to the original list used by Nitschke et al. (2014) were asthma, joint pain, high and low blood pressure, and coughing. These were included due to their association with cold weather, whereas the referenced study (Nitschke et al. 2014) covered heat only. Increased joint pain from osteoarthritis is well documented as being associated with cold temperatures (Jamison, Anderson & Slater 1995, Ng et al. 2004, Timmermans et al. 2014). Similarly, coughing can occur by itself as a reaction to cold (Koskela 2007) or as a symptom of other cold-related conditions such as asthma or common cold and influenza viruses (Mäkinen et al. 2009). Cold weather has also long been associated with increased asthma symptoms (Greenburg et al. 1964, Greenburg, Reed & Erhardt 1966).

To reduce the influence of bias in answering, all symptoms were listed for both seasons, with the exception of heat stress (not listed in winter) and 'other respiratory disease' (not listed in summer), which covers things like cold and influenza, which again are generally more common in the colder months.

Participants were asked about how much they worried about their health in summer and in winter, and whether they had someone who checked in on them during extreme weather. Increased public health campaigns about the dangers of hot weather, especially following a particularly extreme heat event in 2009, have led to a greater understanding by the public of these risks (Akompab et al. 2013, Queensland University of Technology 2010). It was thus of interest to this research whether this translated to increased anxiety about health during hot weather as opposed to cold weather. This is especially true in light of research that suggests that vulnerable cohorts, such as older people, recognise that some individuals are more vulnerable during hot weather, but do not necessarily count themselves amongst them (Abrahamson et al. 2009).

3.4.1.6 *Section E—Demographics*

Participants were asked to provide basic demographic information about themselves and their household. This information allows for comparisons between national and state data. It also demonstrates any relationship between demographic factors such as age and income, and between other factors in the survey such as comfort and health. Participants were asked to provide their age range and sex. They were also asked their country of origin, and participants who were not born in Australia were asked to indicate how long they had lived here. This question was included because recent migrants from a very different climactic zone may not have had time to adjust to the Australian climate, and this could affect their response to questions about comfort and thermal conditions in their house. Participants were then asked for details about their household structure, income and tenure. Finally, they were given the chance to include any other relevant information the researcher should know about the participants' housing and/or health.

3.4.2 **Pilot surveys**

For the pilot survey, draft surveys were given to five people who fitted the inclusion criteria for the study, across both sexes and aged from the youngest age bracket (65–70 years) to the second oldest (86–90 years). These participants were asked to give feedback on whether they found questions to be ambiguous and whether the multiple choice options covered the correct range of options, as well as on anything else that was unclear. They were asked to give feedback either in written form, with notes being provided on the hard copies of the survey, or verbally in discussion following survey completion.

Once their feedback had been received, a number of changes were made before the final survey was distributed. This included the addition of the approximate measurement (in metres) of the ceiling height to accompany the pictorial examples; the addition of the option ‘none of the above’ to lists of medications and symptoms; the inclusion of pedestal fans in the questions about fan use; and the addition of more options about where fans were in use.

In addition, some questions referring to ‘winter’ were changed to ‘very cold weather’, in order to more adequately address the fact that the survey was referring to extremes in temperature and conditions rather than just to the ‘seasons’ (since the term ‘season’ can be ambiguous, referring to both a set of weather conditions but also to blocks of time as measured in months). Changes were also made to the description of the field study at the end of the survey, after the pilot study volunteers raised concerns about devices being attached to their walls and damaging paint or wallpaper. Answers from the pilot survey were not included in the results of the study.

3.4.3 **Recruitment and survey distribution**

Surveys were distributed initially to local city councils, which are accessible providers of low-level home and community care services. The targeted councils were selected by overlaying a map of the Adelaide metropolitan council boundaries on the Vulnerability Index maps created by Loughnan et al. (2013), shown in Figure 3-3 and Figure 3-4.

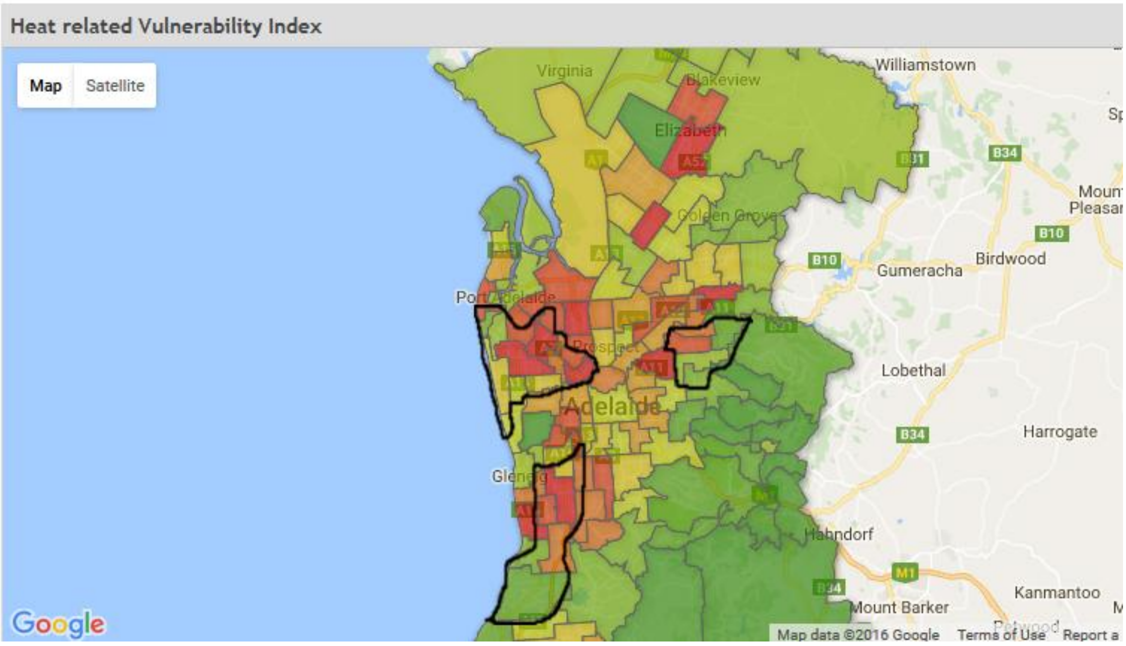


Figure 3-3: Heatwave-Related Vulnerability Index. Green indicates areas of low vulnerability through to red, which indicates the highest vulnerability. From http://www.mappingvulnerabilityindex.com/home/adelaidevi (accessed 01/04/2014) with the index described in the paper by Loughnan et al. (2013). Black lines, added by the author, show the city council districts targeted for research.

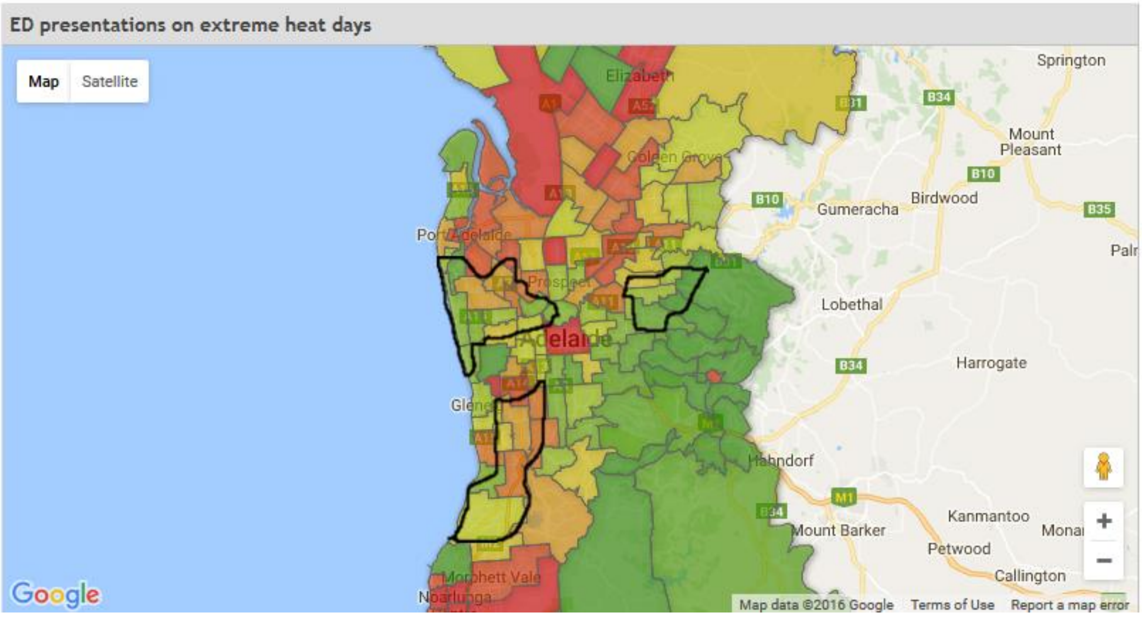


Figure 3-4: Emergency department presentation by area 2004–10. Green = low through to red = high. From http://www.mappingvulnerabilityindex.com/home/adelaidevi (accessed 01/04/2014) with the index described in the paper by Loughnan et al. (2013). Black lines, added by the author, show the city council districts targeted for research.

The heatwave vulnerability map (Figure 3-3) draws on temperature, demographics and local environments to determine the vulnerability of various areas to extreme heat events. Figure 3-4 shows the number of emergency department visits per area on extreme heat days. Both maps were used to determine which council areas to target for this study. Whilst the northernmost suburbs of metropolitan Adelaide contain large areas of vulnerability, the council structure of these areas made it logistically difficult to target specific groups of vulnerable individuals. Thus the smaller council regions that still had some areas of high vulnerability were chosen as initial targets for the survey. These councils were the Campbelltown City Council, the City of Marion and the City of Charles Sturt.

Representatives from each of these city councils were found via the council websites, where a contact was found within the 'community care' or 'home support programs' pages. These representatives were initially contacted via email, with a follow-up phone call if no response to the email was received. These individuals were then asked to distribute surveys to older people who participated in their home and community care services. A participant information sheet was attached when the surveys were distributed, along with a reply-paid envelope so that the surveys could be returned at no cost to the participant.

Each council was given 200 surveys to distribute in the ways they saw fit, with suggestions from the researcher including distribution on seats of community bus services or during activities such as craft or exercise groups. The Campbelltown City Council had an information day about their services for older residents coinciding with the delivery of the surveys, and were willing to place a survey in each of the information bags given to people on that day.

Due to an initially low response rate of only 39 responses to the original 600 distributed, other avenues were then explored. These included a ‘hot desk’ at two council community centres in the under-represented councils of the City of Marion and City of Charles Sturt, whereby a researcher sat and distributed surveys (from the council’s original supply) to older people during various events. This method involved a researcher who was on hand to assist people who may have struggled with the wording or length of the survey.

As the response rate was still low, local chapters of the University of the Third Age were contacted via email to see if they were willing to participate in the research. The University of the Third Age is ‘an international volunteer organisation providing educational, creative and leisure opportunities in a friendly environment for people over 50 who are no longer in full-time employment’ (U3A South Australia 2017). Groups roughly corresponding to the council areas above were contacted, including the Campbelltown, Adelaide City and Flinders University chapters.

Of these, only the Flinders University chapter indicated a desire to participate, with the other chapters indicating survey fatigue amongst their members. Ten surveys were delivered to the Flinders University chapter president, who distributed them to interested individuals in the organisation; of these, three were returned. Volunteers for both the survey and the field study were also called for in local church groups, both via a message in the church newsletters and an in-person visit from the author. This resulted in 10 further surveys being distributed, with seven returned.

Finally, access was granted to a mailing list curated by The University of Adelaide's School of Public Health (formerly the Discipline of Public Health within the School of Health Science). This was a list of older people who had previously been involved in research at the University and who had indicated a willingness to be part of future research. A survey, along with a letter explaining what the study was about and why they had received it, was sent to 86 people on this list, with 31 being returned. These participants were also given the ability to opt out of any more future research if they so desired, with these responses being forwarded to the curators of the mailing list.

These combined methods of recruitment yielded a total of 80 returned surveys, with 32 participants volunteering for the field study. These 32 households were sent consent forms, of which 20 were returned. Of these 20 consenting households, 19 participated in the field study, as one household subsequently could not be contacted any further to arrange installation. One of these households then had to withdraw very soon after the study was started due to ill health within the household. This left a total of 18 households, of which four had two participants, giving a total of 22 participants.

3.4.4 **Analytical techniques**

Survey responses were entered into an online version of the survey hosted by SurveyMonkey (SurveyMonkey 2017). Whilst the use of an online survey for the participants themselves to use was initially deemed unsatisfactory as outlined above, creating an online version of the survey once the participants had returned their surveys allowed the researcher to quickly and easily input the answers from the paper version. The SurveyMonkey tools incorporate the ability to download the data in files compatible with both Excel and SPSS software. This enabled the same data to be used across the various statistical software packages, thereby minimising errors that might occur should the data set have to be reproduced for each program utilised. The specific statistical methods used in the analysis of these data are outlined in Chapter 4, which discusses the results of this part of the study.

3.5 Field study

Participants of the large-scale survey who volunteered for the field study were contacted with more information and a consent form specific to this phase, again distributed with a reply-paid envelope. Once the consent forms were returned, participants were contacted via email and phone to arrange a time to set up a meeting in order to explain the research project in more detail, install indoor environmental monitoring devices, and give the participants the comfort vote surveys, along with an explanation of how to fill them out.

3.5.5 **Indoor environmental monitoring**

This study utilised the Onset Hobo U12-013 data logger (Onset Computer Corporation 2016) with an Onset computer TMC6-HD temperature probe (Onset Computer Corporation 2015). The Onset Hobo U12-013 logger records air temperature and relative humidity with in-built sensors and has the capacity to record input from two external channels. It can store up to 43,000 measurements before its memory is full and is accurate to ±0.35 °C from 0 °C to 50 °C for temperature recording, and to ±2.5% from 10% RH to 90% RH for relative humidity (Onset Computer Corporation 2016). The Onset computer TMC6-HD temperature probe is accurate to ±0.25 °C from 0 °C to 50 °C when paired with the U12 series data logger (Onset Computer Corporation 2015). The sensor end of this probe was covered in a matte black sphere, made by the author's research group, to measure radiant temperature.

This type of data logger has been used extensively in thermal comfort research (Babich et al. 2016, Daniel et al. 2015, Kolarik & Olesen 2015, Straka & Aleksic 2009). It relies only on battery power, thus placing no strain on the participants' energy resources. In this study the decision was made to make the logger freestanding, as during the pilot phase of the survey a participant expressed concern, as noted above, about any device being attached to a wall and causing damage to wall finishes. The loggers and sensors were tested and calibrated to ensure accurate and consistent measurement across all houses.

3.5.6 **Logger setup design**

In order for the data loggers to be installed in houses, a stand was designed upon which the logger and its associated attachments could be mounted. A simple stand was designed that included holes for cable ties to pass through to hold the logger and the temperature probe in place (Figure 3-5). This stand was cut from acrylic and engraved with study information using a laser cutter. The engraving included the logo of The University of Adelaide, a generic statement about Thermal Comfort Research, and contact information for the School of Architecture and Built Environment to enable use in future research.

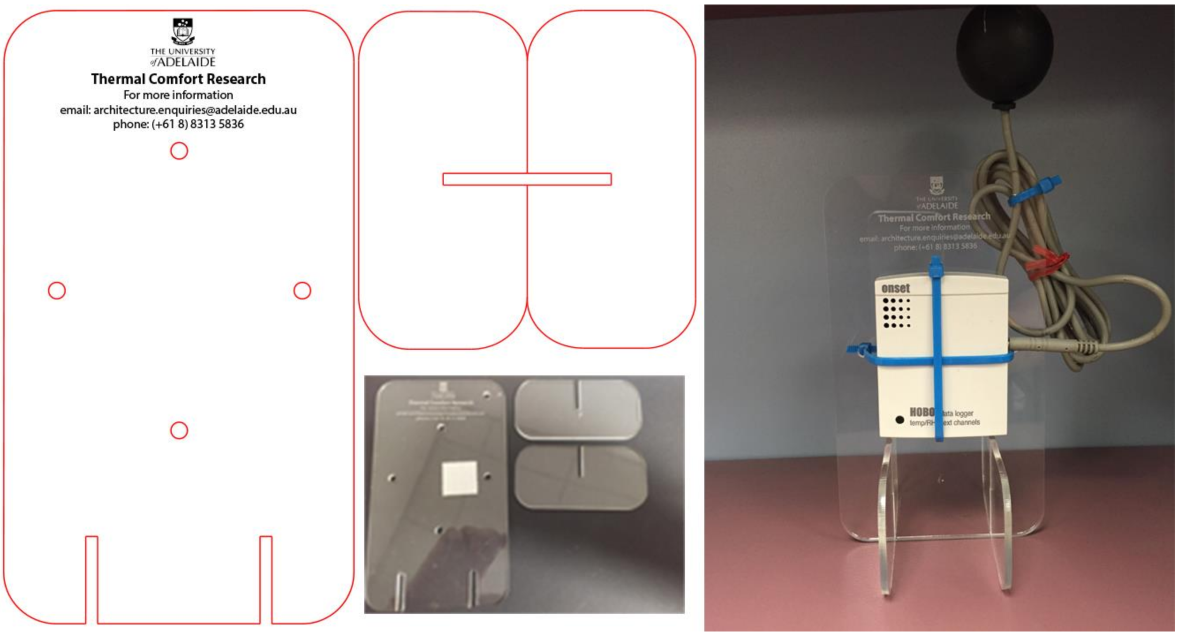


Figure 3-5: Logger stands

The red lines to the left are the cutting template, with the cut-out pieces shown below. On the right is the assembled logger stand with logger attached.

3.5.7 **Installation**

This study was designed to measure the conditions in the main bedroom and the main living area of each house. Thus, a minimum of two data loggers were installed in each house. Participants in two of the houses indicated that two areas were equally utilised as living areas, and therefore an extra logger was placed in these houses in order to fully record the conditions experienced by the occupants.

Data loggers were positioned on a flat surface, such as a coffee table or dresser, as closely as possible to the place where participants felt they were mostly likely to be when completing the comfort vote survey. The height of these loggers varied in the houses, typically between 500 centimetres and 1 metre from the ground. They were placed so that they would not be exposed to direct sunlight or radiant heat from lamps or other electronic devices. Where possible they were not placed near external walls, especially those facing north or west, as doing so has been known to affect temperature readings.

3.5.8 **Comfort vote survey**

3.5.8.1 *Survey design*

The comfort vote survey form was designed to take as little time as possible, as participants were encouraged to complete it as often and as regularly as they were able. A copy of the survey as issued to participants can be found in Appendix C. The frequency at which the surveys were filled out varied between participants; this was discussed when the loggers were installed. Some participants indicated a willingness to fill out the survey every day; others were more hesitant about the workload and agreed to fill out the survey once or twice a week. Most questions were multiple choice to allow the survey to be filled out in less than two minutes.

The survey design was based on the thermal comfort vote survey used by Daniel et al. (2015), with modifications tailored to the aims of this research. The questions were designed to gather all of the information required to compare the occupants' thermal comfort with existing standards, and to assess whether any symptoms had occurred which might be attributable to thermal conditions. Participants were asked to indicate the date and time they had completed the survey as well as the room they were in, so that this information could be matched with the data from the loggers. If there was more than one participant per household, they were asked to identify themselves by circling ‘A’ or ‘B’ at the top of the form.

3.5.8.2 *ASHRAE 7-point thermal sensation scale*

The ASHRAE 7-point thermal sensation scale is part of the PMV/PPD model of Thermal Comfort originally developed by Fanger (1970) to provide thermal comfort in office buildings. It remains a useful tool across various models of thermal comfort and gives a fairly specific measure of an occupant’s sensation at a given time. In this study, the middle or zero value was labelled as ‘just right’ rather than ‘neutral’ to make it easier for the participants to understand what was being asked. An image of how this question appeared can be found in Figure 3-6 below.

How do you feel?

☐cold ☐cool ☐slightly cool ☐just right ☐slightly warm ☐ warm ☐hot

Figure 3-6: ASHRAE 7-point thermal sensation scale as presented in the comfort vote survey

3.5.8.3 *Thermal acceptability*

Occupants were asked to indicate whether current conditions were thermally acceptable simply by indicating ‘yes’ or ‘no’ as shown in Figure 3-7. This question was also included in order to remove the difficulty of determining what factors to consider ‘acceptable’. Commonly, the middle three votes of the ASHRAE 7-point thermal sensation scale (Brager et al. 1993, Humphreys & Hancock 2007), or the ‘no change’ vote in a 3-point acceptability scale (discussed below), are considered ‘acceptable’, but by asking whether or not conditions are acceptable, these potential ambiguities can be removed. Asking this additional question also provided an interesting point of contrast between the two other potential measures of acceptability in this survey.

Are the current conditions thermally acceptable?

☐Yes ☐No

Figure 3-7: Question regarding thermal acceptability

3.5.8.4 *McIntyre 3-point preference scale*

This scale is a quick tool to determine whether occupants have a preference for being cooler or warmer (McIntyre 1973). It is usually assumed that the three central categories on the ASHRAE 7-point scale seen in Figure 3-6—that is, ‘slightly cool’, ‘just right’, ‘slightly warm’—indicate thermal comfort (Brager et al. 1993, Humphreys & Nicol 2004). It is, however, possible that, due to personal preferences or other reasons, the occupants’ preferences for cooler or warmer conditions do not align with the ASHRAE scale, and so the McIntyre 3-point preference scale was included (Figure 3-8). This scale also gives a further reference point for acceptability, as mentioned in the previous section.

How would you like to feel?

☐Cooler ☐No change ☐Warmer

Figure 3-8: McIntyre 3-point acceptability scale as presented in the comfort vote survey

3.5.8.5 *Clothing*

The level of clothing, known as the ‘clo value’, is important for determining PMV and is also a factor when using the Adaptive Thermal Comfort model. This question was asked pictorially, with images designed to represent the typical sorts of clothing that older people wear, seen in Figure 3-9 below. This was the same imagery used in the initial broader survey (Figure 3-2), shown again below in Figure 3-9 with the associated clothing insulation (clo) values, calculated from the values in Table 3-1 (following Figure 3-9).

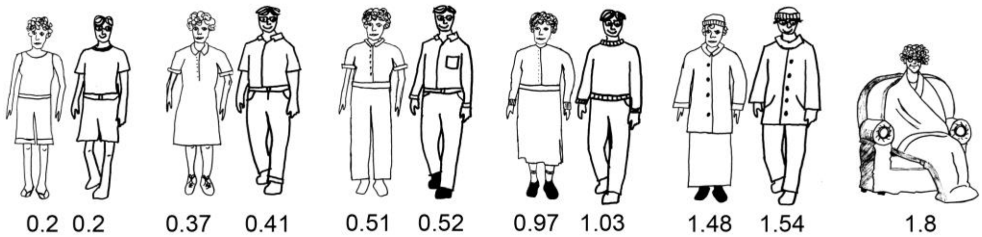


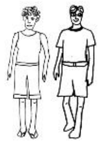
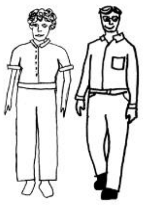
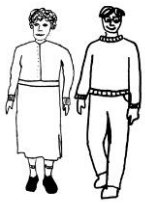
Figure 3-9: Pictorial examples of clothing levels with their associated clo values as per ASHRAE Standard 55-2013 (ASHRAE 2013) as presented in the comfort vote survey

3.5.8.6 *Windows and fans*

Questions about windows, doors and fan usage were included to approximate air movement within the dwelling. According to the graphical model of thermal comfort (ASHRAE 2013), the area in which conditions are considered comfortable can shift with higher air speeds, which are influenced by increased ventilation and by the operation of fans.

However, air movement was not specifically measured in this study. The measurement of air movement is made difficult by the delicacy and expense of the anemometer equipment required to measure it (Nicol, Humphreys & Roaf 2012). Thus a method of estimating air movement (Saman et al. 2013, Williamson, Coldicutt & Penny 1991), was utilised in this study when needed for PMV analysis. When all windows and doors are closed air speed is estimated at between 0 and 0.1m/s. With windows open it is estimated to be between 0.1 and 0.5m/s, and with air conditioning and/or ceiling fans in operation is it estimated to be >0.5m/s. These estimations are adequate to include for PMV calculation.

Table 3-1: Clothing insulation values as shown in Table 5.2.2.2B 'Garment Insulation' in the ASHRAE Standard 55 (2013)

Picture Example	**Ladies'**		**Men's**	
	Bra	0.01	Underwear	0.04
	Underwear	0.03	T-shirt	0.08
	T-shirt	0.08	Walking shorts	0.08
	Walking shorts	0.08		
	Total	**0.2**		**0.2**
	Bra	0.01	Underwear	0.04
	Underwear	0.03	Short sleeve knit sport shirt	0.17
	Short sleeve shirtdress	0.29	Straight trousers (thin)	0.15
	Ankle length socks	0.02	Calf length Socks	0.03
	Shoes	0.02	Shoes	0.02
	total	**0.37**		**0.41**
	Bra	0.01	Underwear	0.04
	Underwear	0.03	Long sleeve dress shirt	0.25
	Singlet	0.09	Straight trousers (thin)	0.15
	Short sleeve dress shirt	0.19	Knee socks	0.06
	Straight trousers (thin)	0.15	shoes	0.02
	Panty-hose/stockings	0.02		
	Shoes	0.02		
	Total	**0.51**		**0.52**
	Bra	0.01	Underwear	0.04
	Underwear	0.03	Sweatpants	0.28
	Singlet	0.04	Singlet	0.06
	Long sleeve shirtdress (thick)	0.47	Long sleeve dress shirt	0.25
	Long sleeve sweater (thin)	0.36	Long sleeved sweater (thick)	0.36
	Stockings	0.02	Socks	0.02
	Socks	0.02	Shoes	0.02
	Shoes	0.02		
	Total	**0.97**		**1.03**
	Bra	0.01	Underwear	0.04
	Underwear	0.03	Straight trousers (thick)	0.24
	Tights	0.02	Long sleeve dress shirt	0.25
	Long sleeve shirtdress (thick)	0.47	Long sleeve sweater (thin)	0.25
	Long sleeve sweater (thin)	0.25	Coat	0.6
	Coat	0.6	Knee socks	0.06
	Boots	0.1	Boots	0.1
	Total	**1.48**		**1.54**
	Underwear	0.57		
	Long sleeved dress shirt	0.03		
	Long sleeved sweater (thick)	0.7		
	Straight trousers (thick)	0.28		
	Slippers	0.03		
	Singlet	0.04		
	Blanket	0.7		
	Chair	0.15		
	Total	**1.8**		

3.5.8.7 *Heating and cooling*

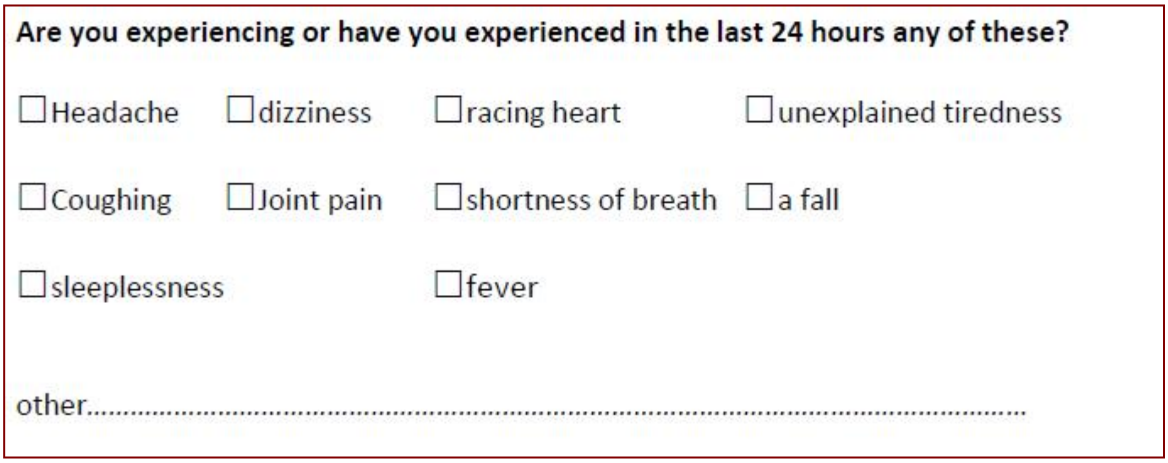
Participants were asked to indicate whether their heating or cooling devices were operating. This allows usage patterns to be assessed whilst also providing information needed for using the various thermal comfort models for analysis. The use of heating and cooling affects the calculation of air movement as mentioned in the previous section. Additionally, the Adaptive Thermal Comfort model (ASHRAE 2013) analyses naturally ventilated buildings. If votes are cast at times when heating and cooling is not operating, the Adaptive Thermal Comfort model can be utilised to examine the comfort of the participants in relation to this standard for naturally ventilated buildings.

3.5.8.8 *Curtains/blinds/shades*

Participants were asked whether they had their curtains or blinds closed, open or partially open in the room where they completed their survey. This question related to the heat potentially entering a building and its effect on temperature and perceived comfort.

3.5.8.9 *Symptoms experienced in the last 24 hours*

As shown in Figure 3-10 below, a list of heat- and cold-related symptoms was included on the comfort vote survey. This list was similar to the list given in the initial large survey and based on work from Nitschke et al. (2014). An ‘other’ option was included so that participants could note down any other symptoms they had experienced.



Are you experiencing or have you experienced in the last 24 hours any of these?

☐Headache ☐dizziness ☐racing heart ☐unexplained tiredness

☐Coughing ☐Joint pain ☐shortness of breath ☐a fall

☐sleeplessness ☐fever

other...

Figure 3-10: Question relating to recently experienced symptoms as it appeared on the comfort vote survey form

3.5.8.10 *Activity type*

A pictorial representation of a number of everyday activities was used to assess the participants' activity level in the time leading up to completing the survey (Figure 3-11). Activity level was then compared to Table 5.2.1.2 Metabolic Rates for Typical Tasks table in the ASHRAE Standard 55-2013 (p. 5) and converted to a met unit according to the values provided. Met units are required as part of the PMV calculations in Fanger's model of thermal comfort.

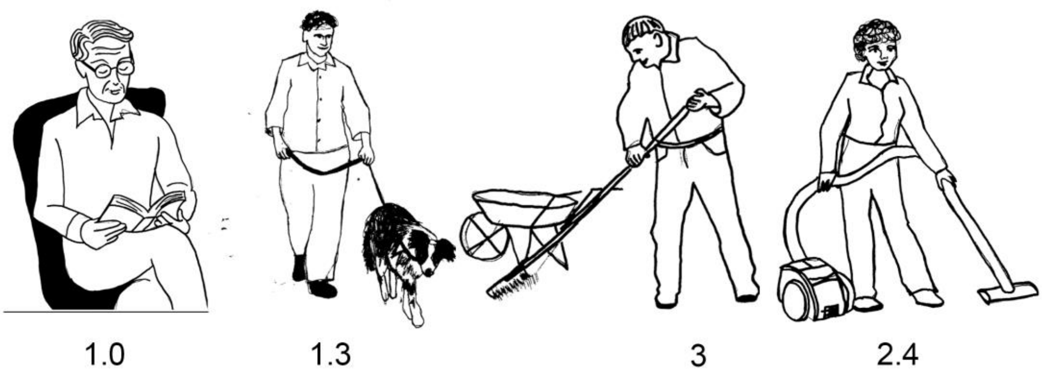


Figure 3-11: Pictorial representations of typical everyday activities to gauge the activity level of participants with their corresponding met units from Table 5.2.1.2 of the ASHRAE Standard 55 (2013)

3.5.9 **Analysis of field study data**

The participants were visited every 3–6 months to collect the completed surveys and to remove those data from the loggers. The loggers thus were able to continue recording for the entire study period without exceeding storage capacity. Data from the loggers were downloaded via a USB cable into the HOBOware software package (Onset Computer Corporation 2002-2015). These data were then exported as comma-separated values into Microsoft Excel for use in further analysis.

Data from the comfort vote survey forms were entered into a Microsoft Excel spreadsheet (Microsoft Corporation 2013); answers to each question were given a numerical code, and these numbers were placed in columns, initially by household. Once all comfort vote survey responses were entered into the spreadsheet, the temperature, humidity and radiant temperature data were matched via the time and date on the surveys.

Further analysis was conducted using Microsoft Excel to compare the data to three commonly used models of thermal comfort: the PMV/PMD model as developed by Fanger, the Adaptive Thermal Comfort model as developed by De Dear and Brager (2002), and the European Standard EN-15251 (CEN 2007). The former two are outlined in ASHRAE Standard 55-2013 (ASHRAE 2013), whilst the latter was recreated from parameters published in that standard.

These comparisons involved the recreation of given parameters using formulae and graphs published in the appropriate standards, and—in the case of the PMV/PMD model—an add-in for Microsoft Excel, which generates the graphs and equations needed to use the psychrometric graphical method detailed in ASHRAE Standard 55-2013, developed by kW Engineering Inc (2011). These graphs and standards allow the analyst to determine whether the perceived thermal comfort falls within existing standards, and if it does not, how the preferred comfort conditions differ from the predictions made by the standards.

Further to the comparison with the various thermal comfort standards, the data were further analysed to examine the neutral or comfort temperatures of this cohort and then compared to other studies. By determining the neutral temperature of each participant, comparisons can be made to other groups, as published in the literature. This also allows comparisons to be drawn amongst the participants—for example, whether any differences between neutral temperatures exist between the sexes or between different age groups. More detail about the methods for each of these analyses is covered in Chapter 5, which records and analyses the results of the field study.

3.6 Building performance and improvement study

A number of the buildings from the field study were further studied to determine if building improvements would impact significantly on the thermal conditions in the home. There were a number of criteria which determined whether a house was chosen for this part of the study. The primary criteria was whether there were building plans available for input into the building simulation software. Furthermore, buildings were chosen based on their construction type so that a range of buildings were represented. From the participants in the field study, five houses were chosen to include detached and attached dwellings, as well as brick veneer, double cavity brick and concrete brick construction types.

As outlined earlier, multiple practical considerations prevented physical building improvements being made and tested. As such, building simulation using the IES Virtual Environment software package (Integrated Environmental Solutions Limited 2017) was carried out in order to investigate the potential of building improvements to improve building performance in terms of thermal comfort and energy efficiency. Using IES Virtual Environment, building simulation of both the base design of the selected houses as well as potential changes to the buildings was conducted. This software package allows a range of variables to be examined, including indoor temperature and humidity, energy usage and more specific information about energy being used for cooling and heating. The software calculates the thermal properties of various materials and construction types based on a database of established experimental values. Where these thermal properties were not included in the database, these were sourced from data tables in the ASHRAE book of principles of heating, ventilating and air-conditioning (Howell, Saurer Jr & Coad 1998).

Simulating possible design changes allows the effects of these changes on indoor temperature and heating and cooling loads to be examined without costly physical changes to a building. In this way, it is possible to determine whether the building can be altered to produce conditions closer to the occupant's preferences both more often and with reduced use of heating and air-conditioning.

3.6.10 **Building selection**

Buildings were chosen for simulation based on several factors. First, for practical reasons, some form of drawing of the building needed to be available from the participant. Several participants did not have original drawings, so they were excluded from this part of the study.

Second, buildings were chosen as a representative of their type, so that a range of different types of construction methods and building types could be analysed.

Ultimately, five houses were chosen as representing the widest possible variety of houses. These houses were

- one detached and one attached Independent Living unit in the same complex (circa 1970s), double brick on concrete slab construction
- one older detached house of double brick construction on concrete slab, from the late 1970s or early 1980s
- one architect-designed house, concrete block from the 1960s
- one detached brick veneer house built in the mid-1990s.

3.6.11 **Drawing for simulation**

Each house was redrawn using the AutoCAD software package (AutoDesk Inc 2016) for ease of simulation. This was necessary as some of the plans had measurements written in imperial units, and so redrawing and relabelling in metric units was required for ease of input into the simulation program. Most plans were available as photographs only, and thus redrawing simplified the analysis.

3.6.12 **Simulations**

Each building was input into the IES-VE software using the existing (or base) design first. This process involves specifying the construction types of the floor, external and internal walls, doors, windows and ceilings. Construction types were determined from the building plans, the specifications on the Housing and Health survey, and observations made during the home visits. The constructions types were altered within the program, which draws information regarding the thermal properties of these construction elements from an in-built database. The building was then drawn at full scale, including external shading from verandahs, adjacent buildings and trees. Shading from curtains and blinds was input via the window construction information.

3.6.12.1 *Calibration of simulated buildings*

In order to ensure that the modelled buildings accurately represented the real buildings, each computer model was first calibrated against measured data from the building itself. The Typical Meteorological Year (TMY) outdoor climactic data were substituted with hourly climate data obtained from Exemplary Energy Partners for the calibration period. These data include solar radiation and wind speed data specific to the area the house was situated in. These temperature data are used by the IES software to generate indoor conditions via simulation. The predicted indoor hourly temperature in the computer model was then compared with measured indoor hourly temperatures from the same period. Through examination of the comfort vote surveys and measured temperature data, a time period of 10 to 14 days where little or no HVAC usage was evident was used to calibrate the building.

In some instances, it was possible to choose a time period where the occupant was absent for 10 or more days, and thus the building was free-running, without the added complication of human activity. When this was not possible, the effect of human activity was approximated using parameters within the IES software that allow for the heat load of humans and window opening and closing times to be accounted for in the simulation. Building occupation and ventilation was altered by creating profiles based on occupant interviews about their activity patterns, and examination of the comfort vote surveys and the measured indoor temperature data. Profiles included adjustments for approximate outdoor temperatures that would necessitate the opening and closing of windows. There were also separate ventilation profiles for summer and winter.

The coefficient of variance of the root mean square error (CV(RMSE)) was calculated in each instance as a measure of the difference between the predicted values and actual values—in this case, the predicted indoor air temperature vs the measured air temperature. According to (Royapoor & Roskilly 2015, p. 113), the CV(RMSE) is a 'measure of accumulated error normalised to the mean of the measured values', which 'closely reflects the accumulated magnitude of error' (Royapoor & Roskilly 2015, p. 113) and is given by the following formula:

$$CV(RMSE) = \sqrt{\frac{\Sigma_{i=1}^{N}\left[\frac{M_i - S_i}{N_i}\right]^2}{\frac{1}{N}\Sigma_{i=1}^{N_i} M_i}}$$

Where M_i = Measured data at instance *i*

S_i = simulated data at instance *i*

N_i = the number of values used in the calculation

CV(RMSE) is a statistic used by building simulators and recommended by ASHRAE as a way of ensuring accuracy of simulations (ASHRAE 2013). Typically, it is used to compare the simulated energy usage and the measured energy usage. However, in this study CV(RMSE) was calculated using predicted vs measured indoor temperature, a method previously used by Daniel, Soebarto and Williamson (2015) to similar effect in determining the accuracy of building simulation software. In this study, a CV(RMSE) of less than 10% was considered accurate for the purposes of simulating improvements for the house, as recommended by the International Performance Measurement and Verification Protocol (US Department of Energy 2002).

3.6.12.2 *Base performance modelling*

Once it was confirmed that the simulated model was an accurate representation of the building and its performance, the climate data for a typical meteorological year were reinstated, and the typical year-round performance of the building examined. This base performance modelling was performed with the building free running and then with heating and cooling usage patterns included in the simulation. Once the typical building performance was analysed, the simulation could then be changed to determine the effect of building improvements such as insulation and double glazing.

3.6.12.3 *Analysis of building improvements*

Following the base performance analysis, changes were made to the simulated building to determine the effect of increased ventilation and double glazing on its thermal performance and electricity usage.

As the aim of the building improvement study was to find ways to alter the building in order to create the conditions shown to be favourable both to the occupants specifically and to older people generally, the information about these favourable conditions was based on the results of the field study. The field study indicated the seasonal neutral temperatures for each participant and gave a range of conditions which occupants would find acceptable. Changes were specific to each building and each occupant, and thus the exact method regarding the changes that were made to each building can be found in Chapter 6, which presents the results from this section of the research.

3.6.13 **Life cycle cost analysis of photovoltaic system installation**

As well as changes to the building fabric, a simulation was also run for each house to add new or additional photovoltaic systems for household energy production. This was done to attempt to minimise electricity costs to the householders, and as such the overall cost benefit of installing such a system was carried out.

Life cycle cost analysis was carried out using the Present Value function in Microsoft Excel (Microsoft Corporation 2013). This function generated the present-day value of future payments or savings based on an interest or discount rate. The present value of the electricity costs plus the cost of the system was then divided by the present value of the money saved by installing said system to determine the cost-benefit over time. This life cycle cost analysis was based only on electricity costs and savings, rather than any health economics data. The pay-back period was determined by working out the annual savings to the household and dividing it by the initial installation cost of the system.

3.7 Summary

This chapter contains a summary of the various methods used in this research project. A survey in hard-copy form was used to capture information about housing and health from a sample of older Australians. The same survey was used to recruit for a field study of thermal comfort. The field study of thermal comfort measured both the thermal conditions of the participants' houses, via data logging, and their responses to these conditions, via a comfort vote survey. These conditions were then used to determine the overall thermal comfort preferences of these occupants in order to see whether the cohort generally displayed preferences different to those assumed by various thermal comfort standards. These preferences informed a study of possible design changes to the participants' houses, using building simulation software.

This chapter also examines in detail why these methods were utilised and gives an overview of the techniques used to collect and analyse data. In some instances, these techniques are further outlined in the corresponding results chapter rather than in this chapter, for ease of interpretation of the data presented.

CHAPTER 4

Results of the Housing and Health Survey

4.1 Overview

This chapter contains the results of the Housing and Health Survey used to collect information in a sample of the older population (65+ years) of South Australia, carried out at the beginning of the project. A complete copy of this survey can be found in Appendix B. This survey was conducted primarily to understand how a sample of older people experience the thermal conditions in their houses, and whether overall they are comfortable year-round. It also gives an overall snapshot of the self-assessed health of this population through a series of questions relating to medical conditions, medications and symptoms. The first part of this chapter (Section 4.2) examines the overall responses to each question, and the second part (Section 4.3) contains the analysis of these data.

Whilst this part of the study gives no indications of measurable thermal conditions such as temperature and relative humidity inside the houses of this sample of people, it does provide some insight into the attitudes and perceptions that older people may have towards their houses and their comfort. Although the sample size for the Housing and Health Survey was relatively small, it is hoped that the insights from these data may provide the basis for further study in this area.

4.2 Overall results

A total of 706 Housing and Health Surveys were distributed, with a total of 80 questionnaires returned in various states of completion. This represents a response rate of 11.33%. As detailed in Chapter 3 of this thesis, three council areas had 200 surveys delivered to them for distribution. There was no control over how or where the councils distributed the surveys, and the response rate for these was very low: only 39 of 600 were returned. A further 106 were then either sent by mail directly to participants on a mailing list of older South Australians or distributed to volunteers from local church groups and other services targeted at older people. Of surveys which were mailed directly to individuals, the response rate was much higher, with 38% of these returned. This is consistent with other studies which have had mail response rates between 38 and 39% (Kawasaki & Raven 1995, Parker 1992, Truell, Bartlett & Alexander 2002). Of the 80 survey respondents, 32 indicated a willingness to proceed in a field study of thermal comfort in which their houses were monitored, and short surveys were completed as discussed in Chapter 3.

A final sample size of 80 from this population is not large enough to be representative of the South Australian ageing population. The Raosoft online sample size calculator was therefore used to determine the margin of error and the required sample size for this population (Raosoft Inc 2004). The sample of 80 people from an estimated population of 211,403 (ABS 2016a) gives a margin of error of 9.19% with a 90% confidence interval. For a statistically significant sample, with a margin of error of less than 5%, the return of 271 surveys would have been needed (Raosoft Inc 2004). Ultimately, the research timelines and constraints on budget meant that this number could not be achieved in a timely manner for the rest of the research to proceed.

Where possible and applicable, respondents' answers to the survey questions have been compared to national and/or state averages. Due to the timing of statistical collection methods, especially the national census, much of the available reference data are more than five years old. At the time of publication, data from the most recent census (2016) were not yet available and therefore older data have been used.

4.2.1 **Demographics**

In the survey distributed to participants, the demography questions were presented last. However, for ease of understanding the rest of the survey, the demographic breakdown of the participants has been placed first in this chapter. This section of the survey dealt with general demographics such as household structure, age, gender, country of birth and length of residence in Australia, as well as income and tenure type. The findings show that the vast majority of households in this study comprised either one person (44.7%) or two people (46.1%). A two-person household typically indicated a married couple, although there were some instances of adult children living with parents. The proportion of one-person households was much higher than the nationally reported average of 25% (ABS 2013f). The proportion of two-person households is slightly lower than the national average of 56% (ABS 2013f).

4.2.1.1 *Age*

Figure 4-1 below shows the spread of ages in the cohort, with at least 10% of respondents coming from each of the five-year age groups between 65 and 90 years. The group aged between 65–70 years is under-represented in this sample: state-wide, 31% of people over 65 fall in this first bracket (ABS 2016c) compared to the 21.8% in this sample. Conversely, the group of people aged between 71–75 is over-represented, with this group making up only 23% of older people in SA (ABS 2016c) but 32.1% in this sample. The other age groups are closer approximations of the breakdown of ages within the South Australian population (ABS 2016c).

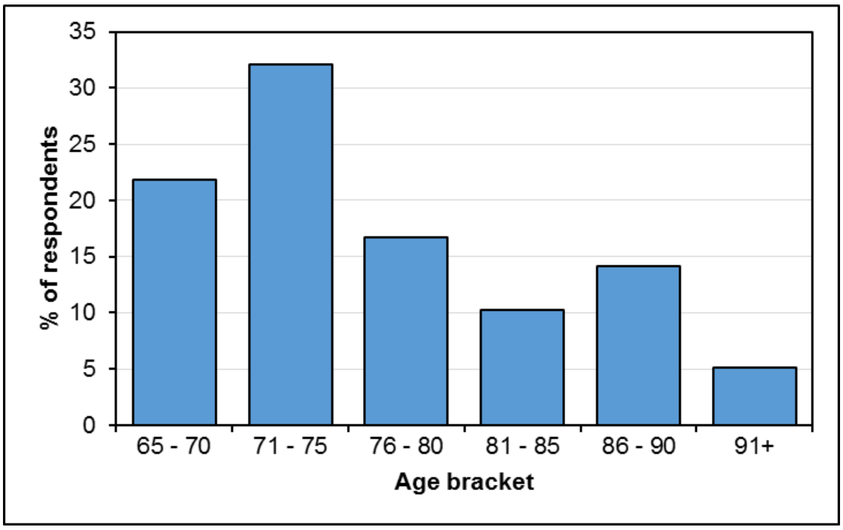


Figure 4-1: Age ranges of survey participants

4.2.1.2 *Gender*

The number of female (58.8%) respondents was higher than male respondents (35%). The remaining 6% of participants failed to indicate their gender. Females on average have a longer life expectancy than males, which leads to slightly larger numbers of females than males in older age groups; in South Australia, the gender breakdown for people over 65 is 54% female and 46% male. Thus females are slightly over-represented in this sample.

4.2.1.3 *Country of origin*

The majority of the respondents (68%) were born in Australia. As the minimum amount of time any migrant had lived here was 24 years, with an average of 51 years, the issue of recent migration and adjustment to the local climate was not a factor in the analysis of these results.

After Australia, the most common countries of origin were the UK (18%) and Germany (4%). The remaining 10% were from a range of other countries: Holland, Latvia, New Zealand, the Czech Republic, Italy, India and Cyprus. There was one participant from each of these countries, except for New Zealand, in which two people were born. According to the 2011 census, 26.7% of people in South Australia were born overseas (ABS 2016c), slightly less than the 32% in this cohort.

4.2.1.4 *Income*

The median gross income bracket of participants was $20,001–$40,000 (Figure 4-2). The median Australian weekly gross income of people over 65 is $725 per week, or $37,700 p/a (ABS 2015b). The median for the surveyed group is thus consistent with this national median.

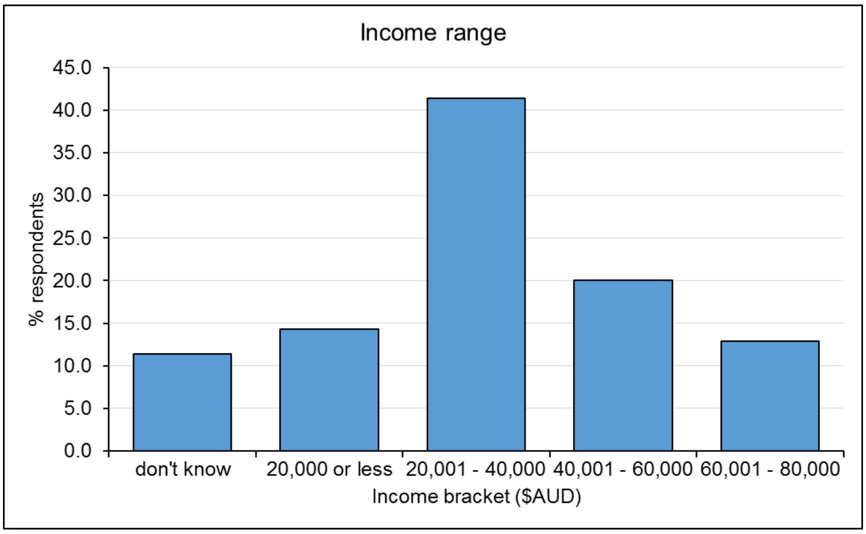


Figure 4-2: Income range

In the surveyed population, 65.4% of respondents recorded a government pension as a form of income (Figure 4-3). Nationally, the Age Pension is the main source of income for 63.7% of people aged over 65 (ABS 2015b). In the survey respondents were asked to list all income types rather than just the main source of income, and 21 participants reported more than one income type. Self-funded retirees (42.3% of this sample) may have their income supplemented by the Age Pension, should they meet means-tested requirements. Thus 15 of the participants in this survey listed receiving a government pension as well as a being a self-funded retiree. Very few participants (<10%) reported other income types such as full- or part-time work or Department of Veterans Affairs pensions. The 'other' category of income (19.2% of respondents) included UK pensions, occasional part-time work and partial pensions.

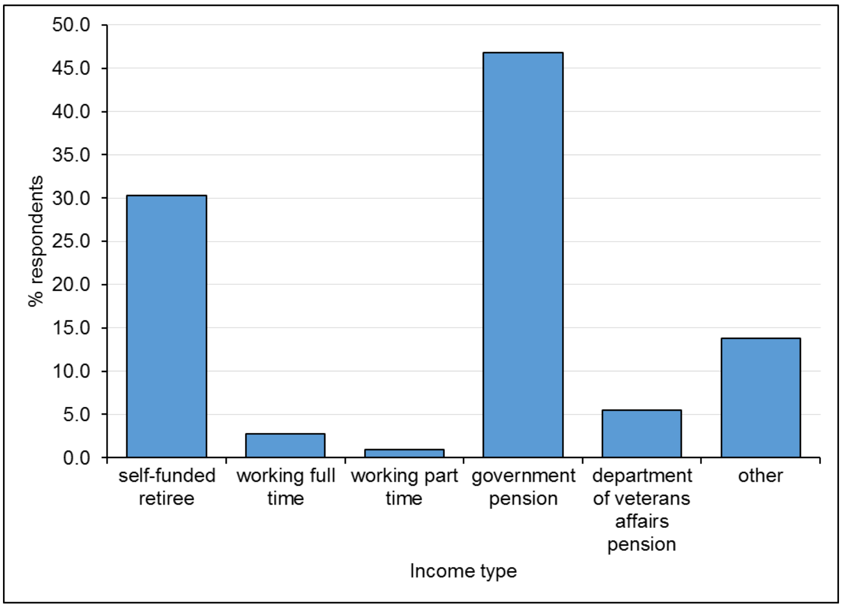


Figure 4-3: Income type

4.2.1.5 *Tenure*

The majority of survey respondents (72.5%) lived in a house they owned outright, with no mortgage. The next largest response group was the 'licence to occupy' group, which includes units and apartments owned by a third party (typically a not-for-profit aged care provider) for which the resident pays an entry fee for a lifetime lease. This group represented 20% of the survey respondents. Renters and owners with a mortgage made up the remaining 8%, with one participant not answering the question (1.25%). As of 2015, nationally 71.7% of older people own their own home outright with no mortgage (ABS 2015a), which is represented accurately in this cohort. However, the remaining 28% in this cohort is very different to national averages. The ABS reports that 6.2% of older people report 'that they [live] rent free or [have] other housing arrangements that [are] outside these categories, such as life tenure and shared equity schemes' (ABS 2015a), with 2013 reports that 5% of older people live in retirement village-style accommodation (ABS 2013f). Such numbers in South Australia are slightly higher, at 8.6% (Property Council of Australia 2014), and yet in this survey, 20% of respondents reported this tenure type. This over-representation of 'life tenure' or licence-to-occupy housings comes at the expense of renters and mortgage holders, which nationally represent 12.4% and 9.5% respectively (ABS 2015a), yet which represent only 6.25% of the total surveyed population.

4.2.2 **Questions about housing and energy bills**

This section dealt with the physical aspects of the housing of the participants. It included the type of dwelling, what it was made from, and its age and attributes, such as ceiling height and insulation. Participants were also asked to give the approximate amount they paid for gas and electricity bills in a year.

4.2.2.1 *Physical building characteristics*

Most (66.3%) of respondents lived in a detached house (Figure 4-4). Whilst this represents a significant proportion of the sample, it is lower than the national average for people aged over 65, which is 78% (ABS 2013f). This is likely due to a larger proportion living in the 'unit' types of housing—primarily single-storey types (21.3%). The proportion of older people living in these accommodation types in Adelaide is less than 10% (ABS 2012b), and thus is over-represented in this sample. Since the number living in licence-to-occupy tenure-type housing is also higher than the national average, and this category of housing tends to be unit- or apartment-style, it is likely that the over-representation of the housing type and the tenure type are linked.

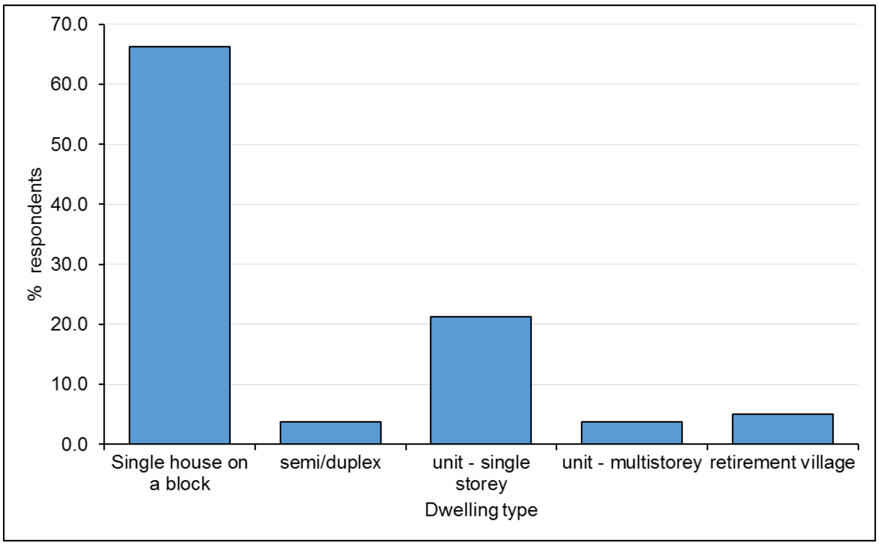


Figure 4-4: Dwelling type

Most participants (76.3%) lived in houses that were somewhere between 10 and 70 years old, with 35% living in houses that were 31–50 years old (Figure 4-5). When compared to South Australian statistics obtained from the Lands Titles Office, the results are quite similar, with the largest discrepancies being houses 31–50 years old and 91+ years old.

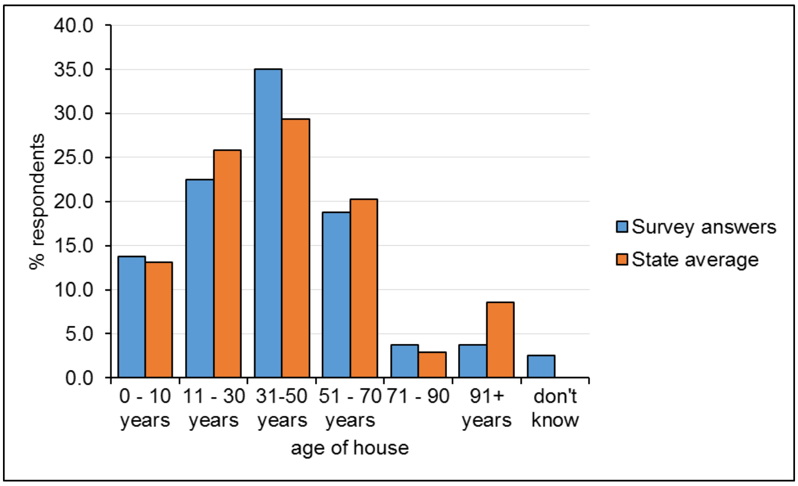


Figure 4-5: Age of dwelling

Of the respondents, 87.5% reported having homes of either double brick or brick veneer (Figure 4-6). The Lands Titles Office database (DPTI 2017), which does not distinguish between double brick and brick veneer, puts the total of all brick houses at 66.2%. The other constructions, which were represented in the survey at 2.5% each (fibro/timber/corrugated iron and concrete block), matched fairly closely to the Lands Titles Office data set, which had these buildings at 2.2% and 2.4% of these types respectively.

Whilst 11.6% of South Australian homes are built from stone and/or masonry according to the Lands Title Office database, none of the surveyed respondents lived in a house built from this type of material.

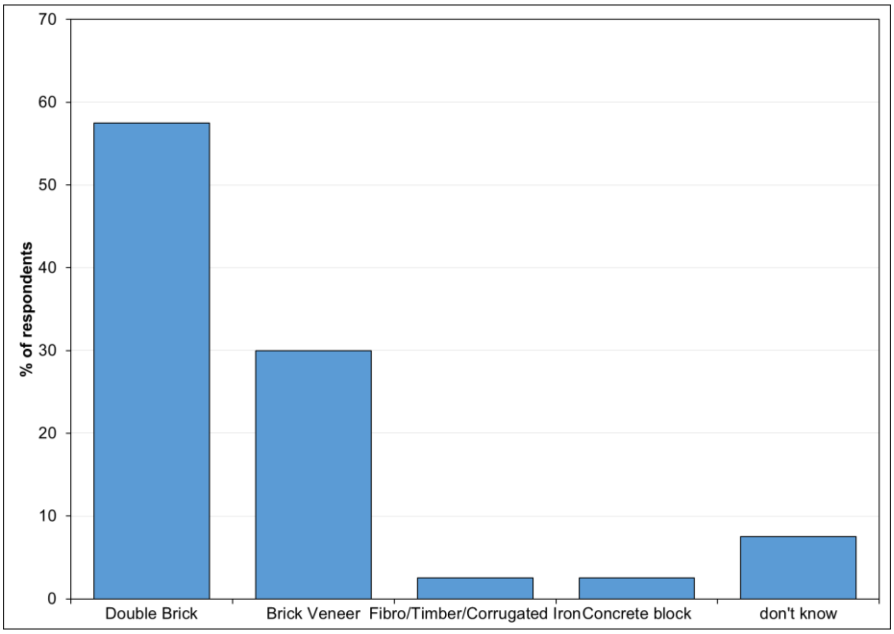


Figure 4-6: Dwelling construction type

Most of the respondents who were surveyed reported that their house had insulation at least in the ceiling (57.5%), with just over 30% reporting having both their walls and ceilings insulated, with a total of 88.8% of houses therefore being at least partially insulated (Figure 4-7). State-wide, the number of houses with insulation is reported to be 77% (ABS 2014b), although at recent study by Soebarto et al. (2019) showed more than half of the surveyed population had no insulation. That study included houses in remote and rural South Australia, whilst this study was limited to the metropolitan region only. It is possible housing construction differs by location, with insulation more common in the metrolpolitan region.

Participants were asked to estimate whether their ceiling was 'low' (2.2–2.4 m), 'medium' (2.5–3.5 m), 'high' (4–4.5 m) or 'very high' (>5 m). Ceiling height can be an important factor in the comfort of a home as well as the efficiency of heating and cooling systems. The vast majority of participants reported having a ceiling of 'medium' height, between 2.5 and 3.5 m (Figure 4-8).

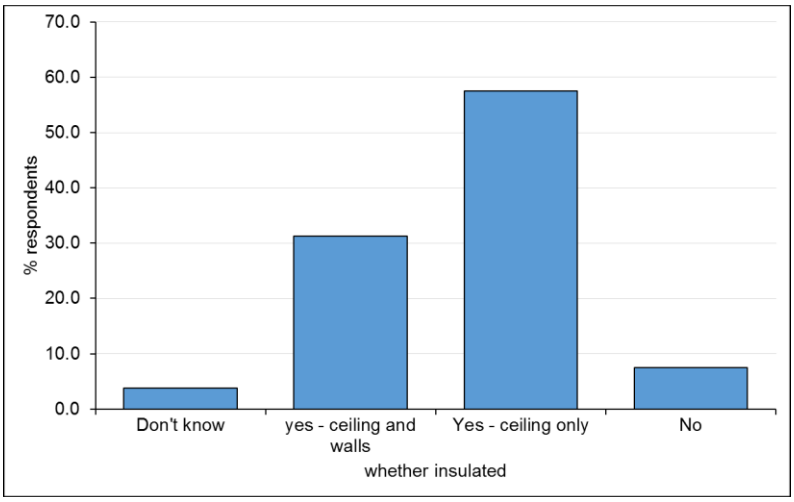


Figure 4-7: Dwelling insulation

This is typical of any house built after the introduction of the national building guidelines, called the National Construction Code (NCC), which came into effect in the early 1970s (NCC Online 2019) and specify a minimum ceiling height of 2.4 m for any habitable area. Whilst this height technically fell into the 'low' category in this survey, most participants estimated their ceilings to be 'medium'. Those houses with higher ceilings are more likely to be older. Higher ceilings can make a house feel cooler during summer months, as the hot air rises; however, a house with higher ceilings is more difficult to keep warm in winter.

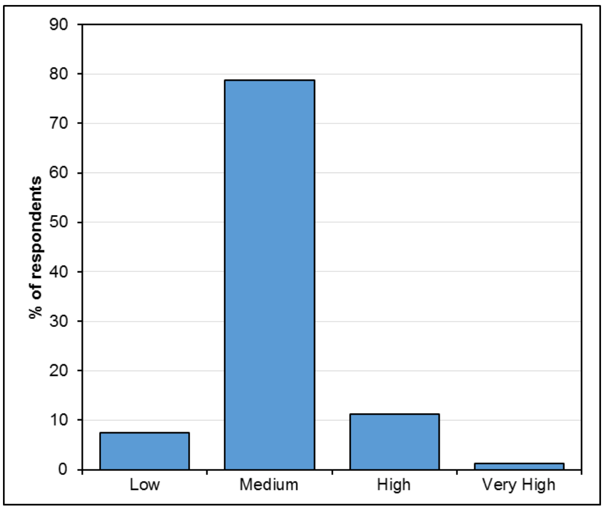


Figure 4-8: Ceiling height in main living area

4.2.2.2 *How long have you lived in your home?*

Participants had lived in their current residence for a median of 22.5 years (SD 17.1). There was a great deal of variability in the responses to this question, with length of occupancy ranging from six months to just over 54 years.

The participants in this study were slightly more likely to have moved house recently than the national average. Nationally, around 10% of people aged over 75 are likely to have moved in the last five years (ABS 2012a). In this study, 19% of those aged over 75 had moved in the last five years. Only 14% of those aged between 65 and 74 had moved within the last five years, lower than the national average of 17.2% (ABS 2012b).

4.2.2.3 *Gas and electricity costs*

Of the 80 people surveyed, 43 (53%) provided an approximate annual amount spent on reticulated natural gas. Eleven indicated that they did not have gas connected, and a further 26 did not answer this question. State-wide, 71.7% of people use reticulated natural gas (ABS 2014b). Participants were not asked to specify what they used the gas for, but the large range of expenditures in this sample suggest a varied range of uses in the home. In South Australia, gas is used for water heating in 63.1% of homes, and for space heating in 24.6% of homes (ABS 2014b).

For this cohort, the median expenditure on gas was $600 per annum (mean $647), although there was a large range of responses, with answers between $150 and $1500 being recorded (Figure 4-9). These data are based entirely on the respondents' responses, rather than any analysis of energy usage or access to bills. It is thus possible that respondents under- or overestimated their average spending.

The median yearly expenditure was divided by 52 to give a weekly gas expenditure, which for this cohort was $11.53. The South Australian average is $8 (ABS 2013d), which means either that this cohort is spending more on gas than households across the state, or that they are overestimating their spending.

Of the participants surveyed, 64 (80%) gave an estimated yearly electricity bill. Three participants gave an answer of $0, accompanied by an explanation that they had photovoltaic cells installed and therefore, by means of feeding power back to the grid, they did not pay electricity bills. In total, 11 participants indicated that they had solar panels installed. This was not a question asked specifically, but was rather indicated in written notes by participants.

According to the ABS, the median Australian household expenditure on electricity is $29 per week (ABS 2013d). The median weekly expenditure for the surveyed group, calculated by dividing reported yearly expenditure by 52, was $19.62. Overall, the households in this survey therefore paid less than the national average on their electricity bills. This may be because the vast majority of the participants were either single-person or two-person households. Fewer people in a house will use less electricity than a household with more people.

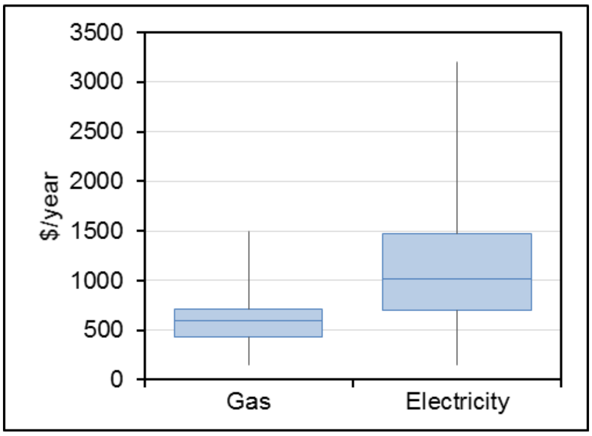


Figure 4-9: Annual gas and electricity expenditure

4.2.3 **Summer comfort and cooling practices**

This section of the survey addressed the degree of comfort experienced by participants during hot weather. Cooling methods were examined, as well as the use of internal and external shading devices, the use of fans, and the frequency of their usage. A question about clothing level, being a further behavioural factor of thermal comfort, was also included in the survey.

4.2.3.1 *General thermal comfort in summer*

Most participants reported being comfortable in the summer months, with more than 90% recording that their house was comfortable 'mostly' or 'always'. A very small percentage (7.5%) said that their house was only comfortable sometimes; and no respondents said that their house was never comfortable in summer (Figure 4-10 & Figure 4-11). There was no specification in this question about whether heating or cooling was being used, as the frequency and pattern of heating and cooling use was covered in a later question.

Interestingly, only 37.5% of respondents reported that their house was 'just right' in summer in terms of the thermal conditions. A further 31.3% of respondents considered their house to be 'a bit warm' and 18.8% 'warm' (Figure 4-11).

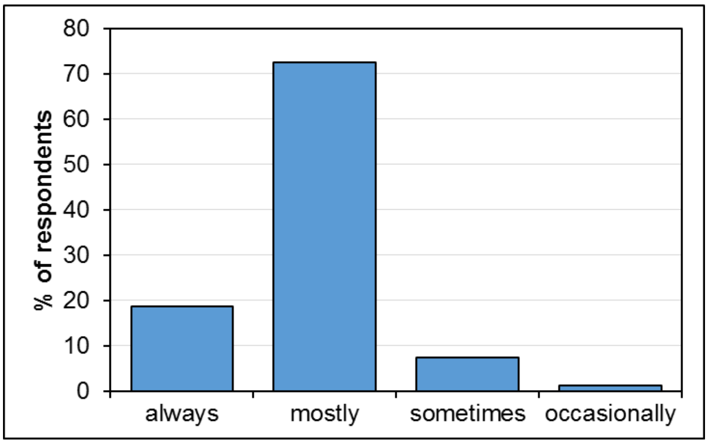


Figure 4-10: Frequency of dwelling comfort in summer

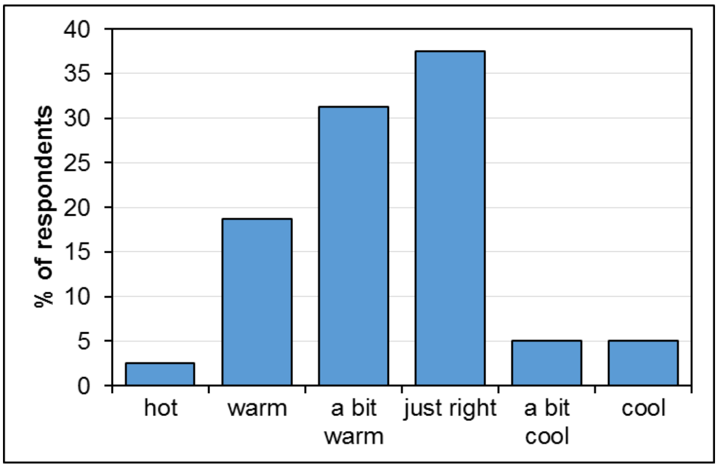


Figure 4-11: Dwelling thermal conditions in summer

4.2.3.2 *Window treatments*

Most participants had some kind of internal window covering, whether on some or all of their windows. A very small proportion had other window treatments, such as double glazing or tinting (Figure 4-12). Most (85%) participants utilised these internal window treatments during hot weather closing windows or blinds (presumably to keep some of the heat out).

Similarly, most (81.3%) participants had external window blinds or awnings on at least some windows (Figure 4-13). A few participants mentioned other external structures that acted as external shading, such as verandas or shady trees, rather than specific window blinds or awnings. A further 17.5% had no external fittings. Of those who did have external window fittings, 63.8% used them in the summer. It is possible that the discrepancy between the 81.3% of participants who reported having blinds and the 63.8% who said they used them was in part due to permanent structures or blinds, rather than adjustable/removable blinds.

The impact of such treatments on indoor thermal conditions is substantial; depending on the type of blind and how it is installed, internal window treatments can reduce the thermal transmittance of a window by up to 50% (Anderson 1982, Hassenboehler & Donoghue 1981). In order to keep the survey length to a minimum, participants were not asked about the use of curtains and blinds during winter in this survey; neither was the design of the internal window treatments examined any further to determine their real effectiveness. External window treatments are even more effective than internal ones at reducing solar heat gains in summer, with studies showing that they can reduce overheating by up to 71% (Porritt et al. 2012), and thus it is important that they are both present and easy for the occupant to operate.

A question about whether there was anything that prevented participants from using their outdoor window fittings was included; however, there was only one response that indicated that increasing frailty with age might be the reason for not using these: 'When I am not feeling well I couldn't be bothered and go to another room'. Other reasons for not using or not being able to use their blinds were: 'I do not like feeling shut in'; 'We like to keep our street view [west] most of the day'; and: 'There is trellis work covered by bougainvillea'. All other participants simply answered 'no' to this question or left it blank.

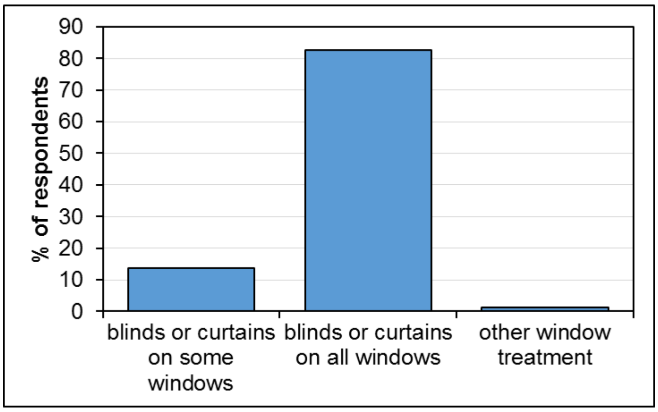


Figure 4-12: Presence of internal window treatments in summer

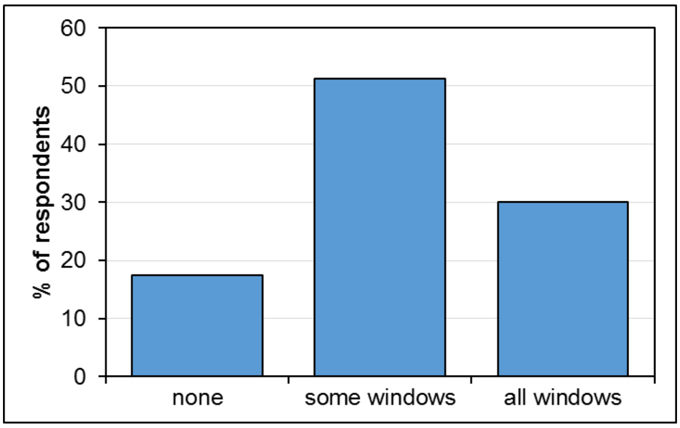


Figure 4-13: Presence of external window treatments on dwelling windows

The design of verandas and any other structures, along with the presence of deciduous shady trees, was not examined in this study. However, it is acknowledged that all of these factors can also have an influence on both summer and winter comfort and thermal conditions.

4.2.3.3 *Cooling appliances and their usage*

Participants were asked a range of questions about the cooling appliances available to them and how they used them. This included questions about what kind of cooling was installed, what thermostat settings were used, when people were likely to use their cooler, whether they ever avoided using it, and—if so—why.

Of the 80 survey participants, only four (5%) recorded having no cooling system installed in their home. Across South Australia, 85% of homes have air-conditioning installed (ABS 2009). This survey sample thus has a slightly higher proportion of air conditioner installation (95%) than the state average.

A split system/reverse cycle system was the most commonly installed and used type of air-conditioning reported by participants in this survey, with 48.8% reporting having one installed (Figure 4-14) and 44.6% reporting it being their main source of cooling (Figure 4-15). This is in line with ABS reports that show the use of individual reverse-cycle-type air conditioners growing in popularity, as the installation of evaporative systems has declined (ABS 2009). Ducted reverse cycle systems have also grown in popularity (ABS 2009), as reflected in the survey results seen below.

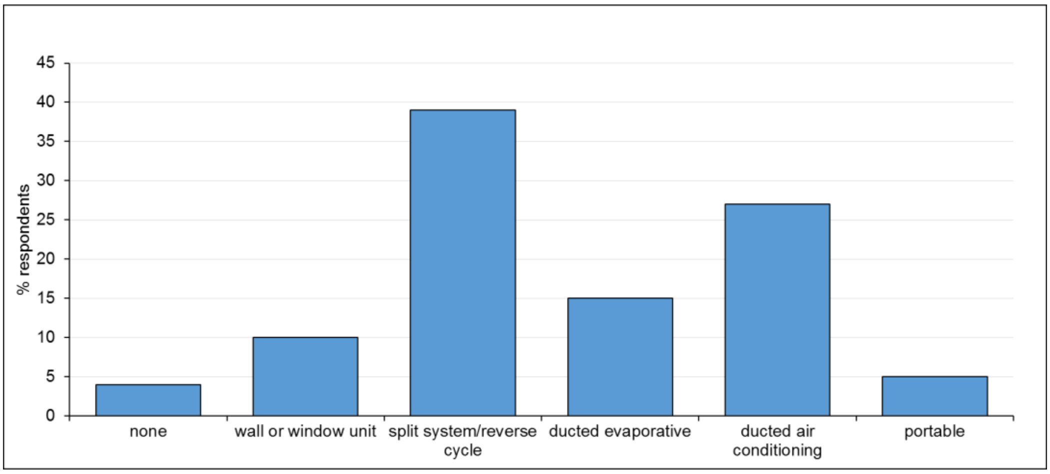


Figure 4-14: Cooler types

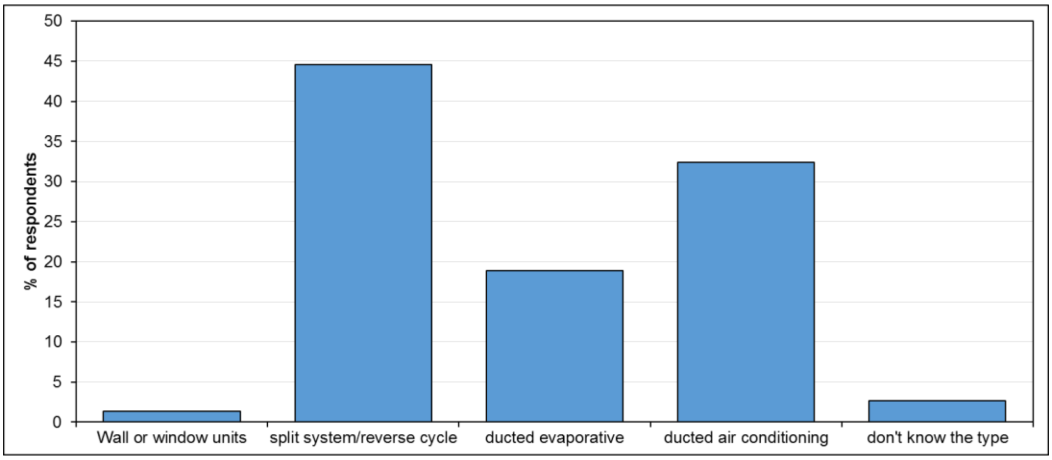


Figure 4-15: Main source of household cooling

The median and the modal thermostat setting reported was 23 °C, with a range of between 18 °C and 28 °C, as seen in Figure 4-16. This was based on only 55 participants, as the remainder did not answer this question. Participants were asked if they knew how to change the thermostat settings on their cooler, and very few (6.45%) answered in the negative. However, some ducted systems allow different temperatures to be set in different zones, whilst some systems, such as evaporative coolers, are usually adjusted by a fan speed and general settings rather than by a thermostat which sets a specific temperature, and this may account for the lower number of thermostat settings reported.

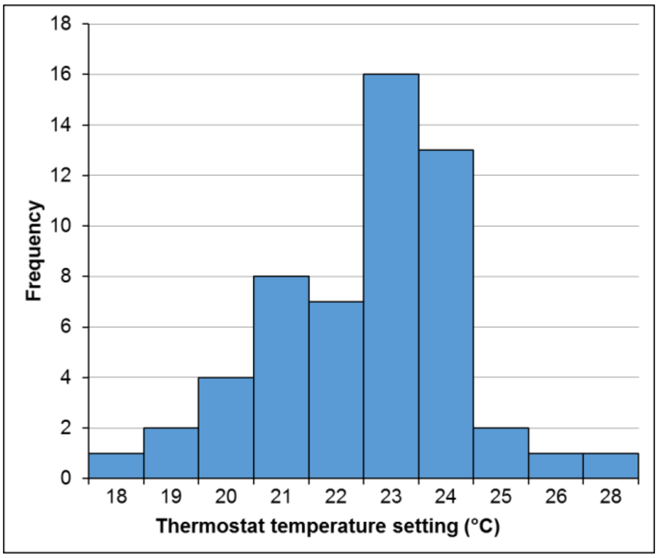


Figure 4-16: Thermostat setting frequencies

Participants were asked to indicate when and why they used their coolers. This question allowed multiple responses to a multiple choice question, and thus the total number (113) of responses was higher than the number of participants. Thirty respondents gave more than one answer to this question, and seven gave more than two. All responses to this question can be found in Figure 4-17 below. The times and reasons for using coolers varied widely between participants. However, there was a general trend towards using cooling as a response to the environment being too hot, rather than for preventing discomfort from occurring: ‘when I feel too hot’ and ‘only when it gets hot inside’ were the most common answers amongst this cohort. The third most common response from participants was that they only used their cooler during the day, not overnight. Overnight cooler avoidance was also observed amongst almost all of the field study participants.

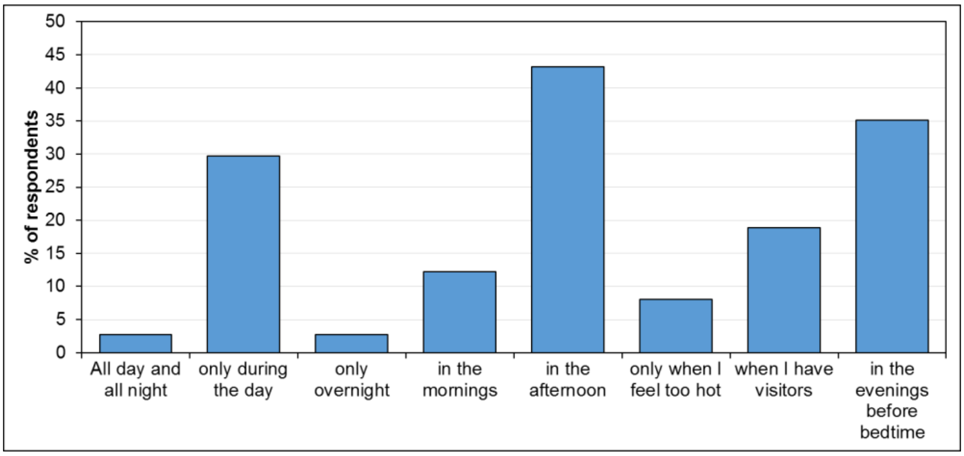


Figure 4-17: Times and reasons for cooler usage

Of the survey respondents, 28% (23/80) reported avoiding using their cooler even if they felt hot, at least occasionally (Figure 4-18). Of these 23, only 18 gave a reason for avoiding cooler use. Economic reasons were the most common reason for avoiding cooler use: 50% of these 18 respondents reported not wanting to spend money on electricity as their primary reason for not using cooling despite discomfort, and a further 11% stated that they could not afford it (Figure 4-19).

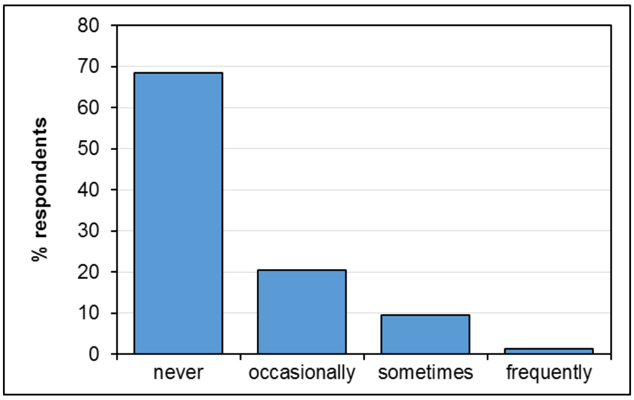


Figure 4-18: Cooler usage avoidance despite discomfort

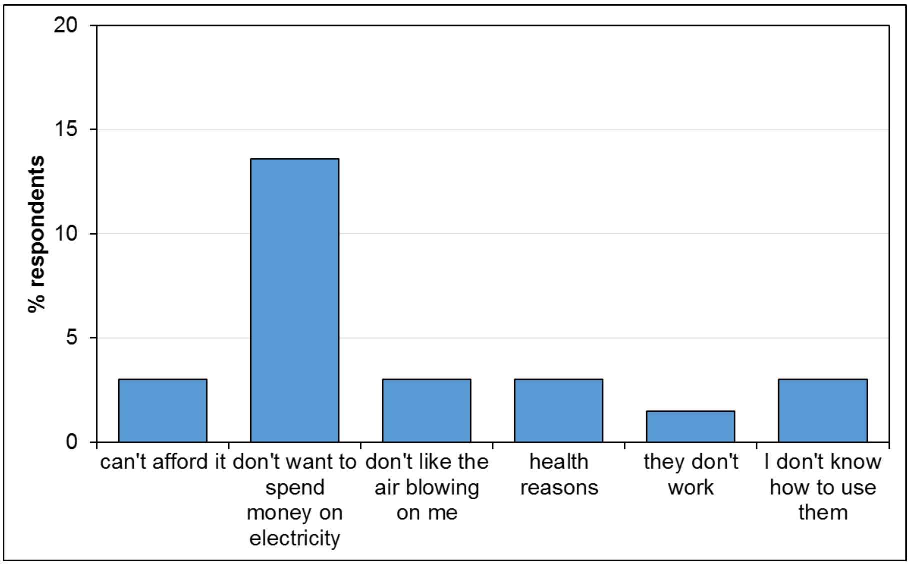


Figure 4-19: Reasons for cooler usage avoidance

4.2.3.4 *Other cooling mechanisms: Windows, fans and clothing*

As well as air-conditioning and other coolers, participants were asked about the use of windows for natural ventilation, the use of fans, and what clothing they typically wear in summer.

Almost all respondents reported that at least some of their windows opened, with 85% of people saying all their windows could be opened (Figure 4-20). There were no follow-up questions about whether or not participants actually opened these windows, or if so, when.

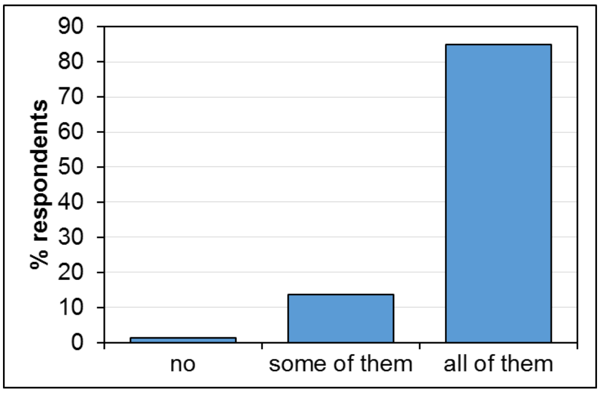


Figure 4-20: Whether windows are able to be opened

Participants were also asked whether there was anything that stopped them from opening their windows. Only nine participants mentioned factors that stopped them from opening their windows; the rest answered 'no' or left the question blank. These factors ranged from mechanical problems with the windows (being stiff or painted over), safety and security concerns, or issues with the window's placement (for example, the lock being out of reach without a ladder). One participant stated: 'I usually don't think about it as if we want cooler air to come in we often open the glass doors from the lounge, also from [the] main bedroom onto the balcony if it is cooler outside than inside'—thereby indicating that they utilise other behaviours for ventilation before they use the windows.

Participants were asked about ceiling fans as well. Of the surveyed participants, 82.1% had some kind of fan available in their house. This question allowed for multiple responses to a multiple choice question. Amongst the respondents, 66.7% had fans of some sort in their main bedroom and 52.6% in their living rooms (Figure 4-21). Other than the options listed, participants listed having fans in veranda areas and in the study. This question covered both ceiling fans and pedestal fans: participants were not asked to specify which kind of fans they had and/or used in which areas of the house.

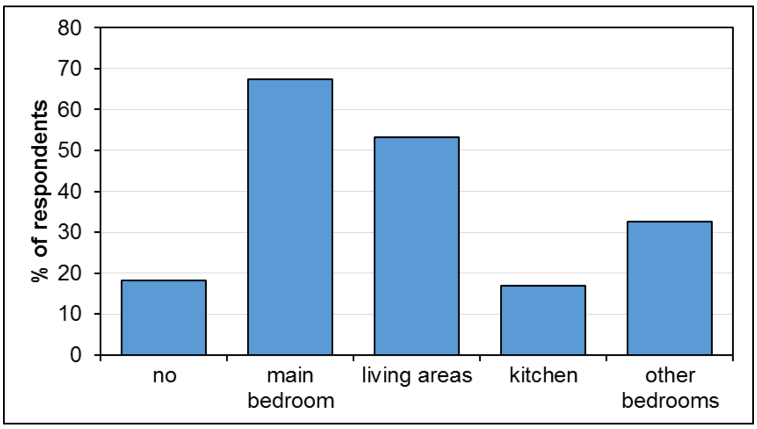


Figure 4-21: Presence of ceiling fans

Fan use was slightly more frequent in the bedroom than in the living area. The percentage of respondents answering that they never use a fan in the bedroom (7.9%) (Figure 4-22) was smaller than the percentage who stated that they never used one in the living room (14%: Figure 4-23). Responses indicating fan use 'occasionally' in the bedroom and living room (33.3% and 38.6%, respectively) and 'frequently' (30.2% and 35.1%, respectively) suggest that respondents either rely on fans a lot of the time, or, alternatively, they rarely use them at all.

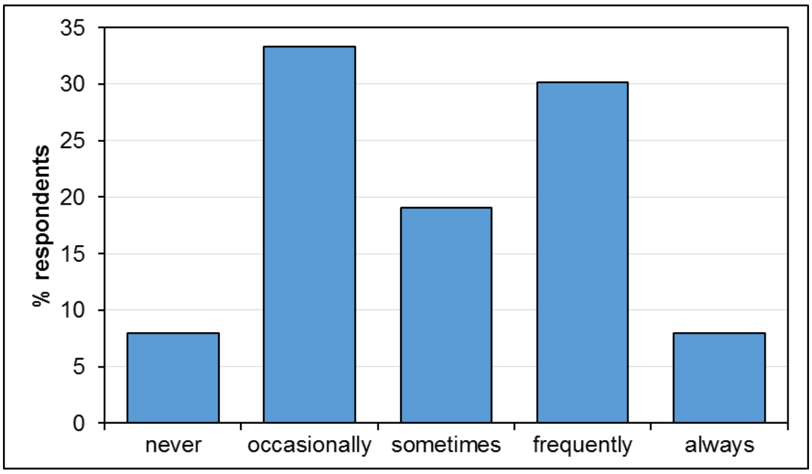


Figure 4-22: Use of a fan in the main bedroom

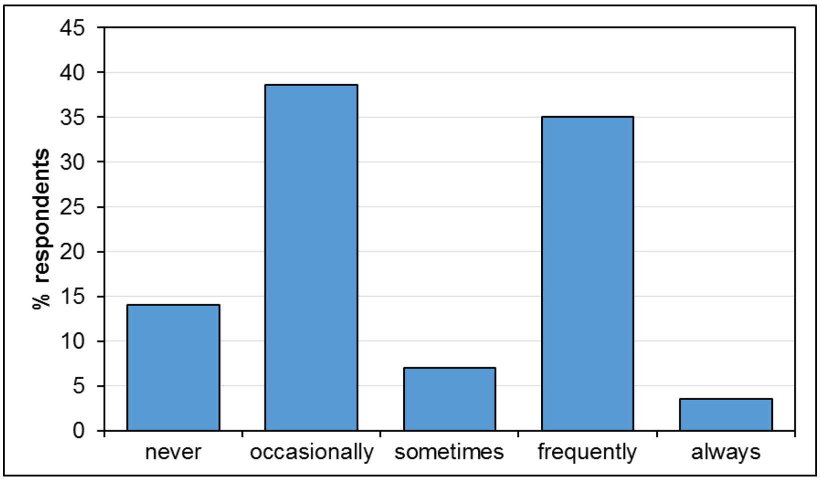


Figure 4-23: Use of a fan in the living areas

Participants were asked to indicate their typical clothing type by the use of the picture shown below in Figure 4-24a. The responses to this question suggest that for the most part, the older people participating in this survey tend to wear appropriate clothing during the summer to keep cool. Clothing levels represented by Option 1 (clo value of 0.2 for male and female) and Option 2 (clo value of 0.37 for female and 0.41 for male) respectively were by far the most popular responses. These responses together represented over 80% of responses. A smaller number indicated Option 3, which equates to a clo value of 0.51 for females and 0.52 for males. The explanations of these clo values can be found in Chapter 3.

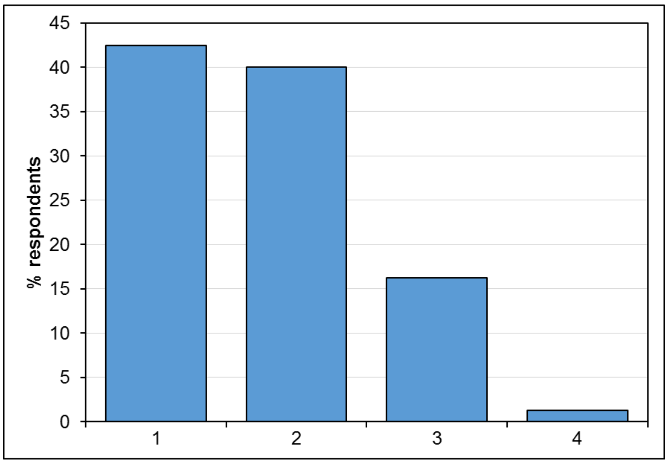


Figure 4-24: Clothing types in summer

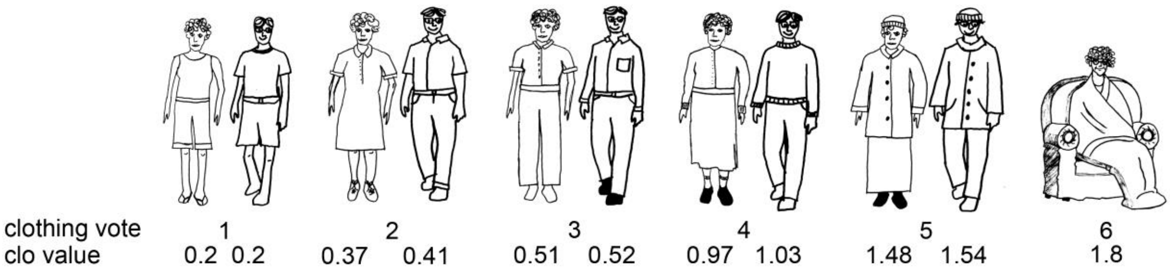


Figure 4-24a: Pictorial representations of different clothing levels

4.2.4 **Winter comfort and heating practices**

In this section, participants were asked questions about their comfort in winter, the kinds of heating appliances they use, and what clothing they typically wear during colder weather.

4.2.4.1 *General comfort in winter*

Similarly to the summer results, most participants found their homes to be comfortable at least most of the time, with almost 90% responding with 'always' or 'mostly' (Figure 4-25). One participant answered that their house was never comfortable in winter, and two said their house was only comfortable occasionally.

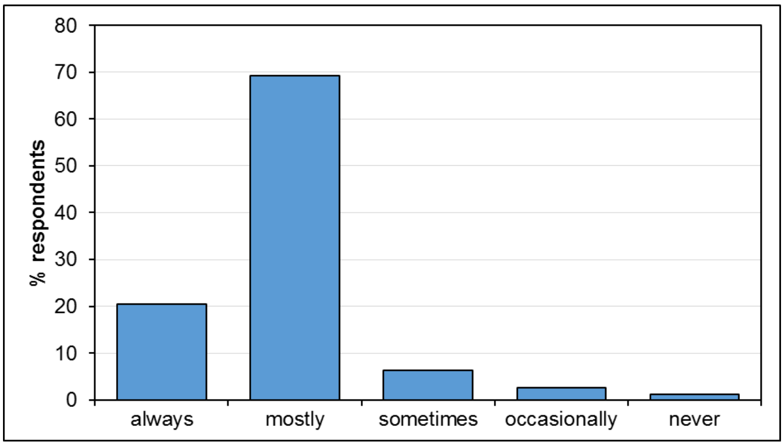


Figure 4-25: Frequency of dwelling comfort in winter

These results of thermal sensation proved interesting, if a little unusual (Figure 4-26). Despite 89.7% of respondents saying that their house was at least mostly comfortable in the winter, only 64.5% of respondents' answers fell within the range typically considered 'acceptable' or 'comfortable' by thermal comfort researchers (Brager et al. 1993, Humphreys & Nicol 2004). A relatively and unexpectedly large proportion (16.5%) claimed that their house was 'warm' in winter, which typically represents uncomfortably high temperatures. However, the term 'warm' may also indicate comfort in cold weather. The complications of wording and semantics and the implications for thermal comfort research are discussed later in this chapter.

A further 19% of respondents recorded their house as 'cool' or 'cold', which again falls outside what is usually considered acceptable by thermal comfort researchers. It is possible that the 10% who said it was cold are largely the same 10% whose houses were not 'always' or 'mostly' comfortable—such correlations in the data will be discussed later in this chapter—but it is also possible that some older people are claiming comfort at cool and cold temperatures because of a preference for such temperatures over warmer ones.

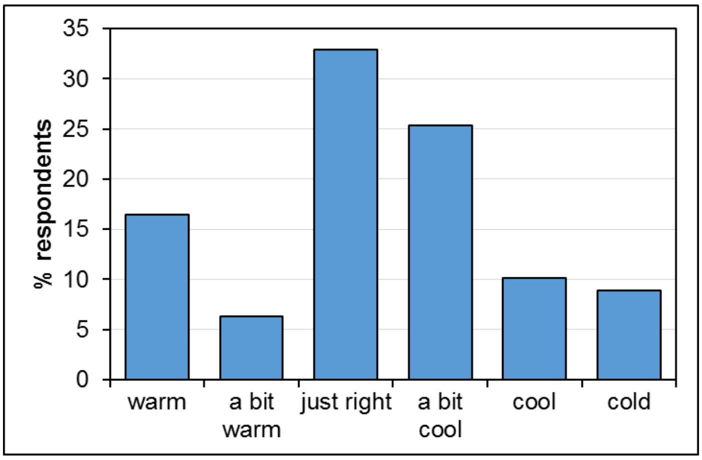


Figure 4-26: General dwelling conditions in winter

4.2.4.2 *Heating types and their use*

The popularity of the reverse cycle system was once again seen in the questions about heating, with 37% of households listing them as their primary source of heating (Figure 4-28). A large range of heating types were installed or available to people, with 44% of participants having more than one kind of heater in their house. This is nearly twice the percentage of participants than had more than one kind of cooler. This may reflect the usage of portable heating units, which are more common than portable air-conditioning units. Fan heaters, bar radiators and oil column heaters are all small enough to move around, and can thus provide localised heating in whichever room a person is currently using. For instance, 11.2% of people answered that they had fan heaters available (Figure 4-27), but none had this type as their primary source of heating (Figure 4-28).

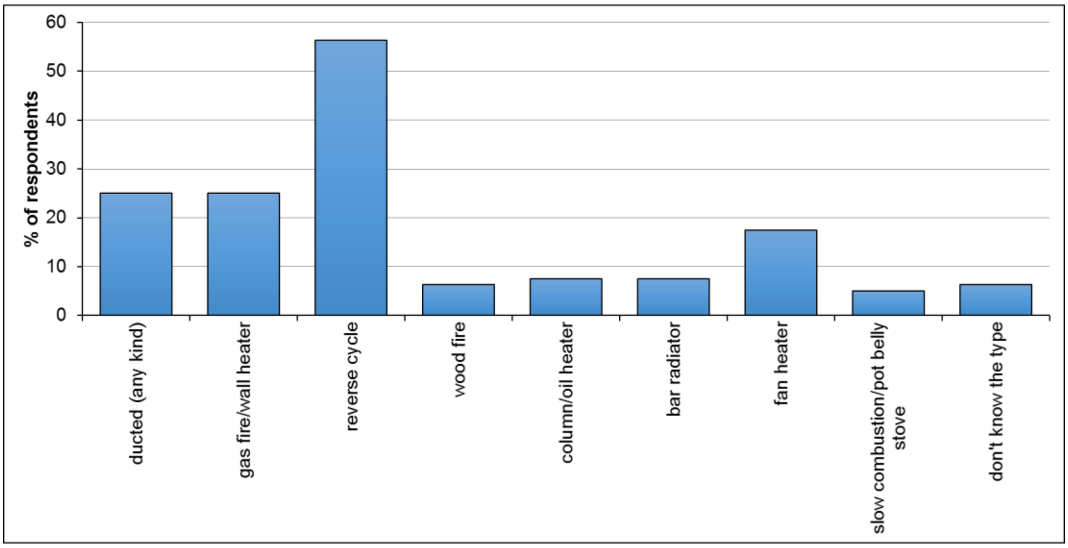


Figure 4-27: Heating types installed or available

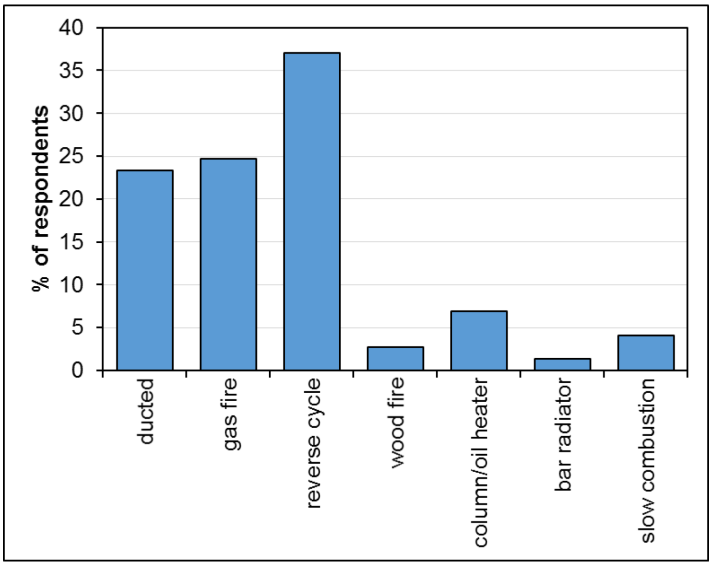


Figure 4-28: Main source of heating

As in the previous section, participants were asked the thermostat settings on their main source of heating. The mean thermostat setting for winter was 22.3 °C (SD 2.48). There were only 51 answers to this question, slightly lower than that for cooling thermostat values. This may be due to the use of gas wall heaters, which often do not have a thermostat measured in degrees. The modal thermostat setting for winter was 24 °C, one degree higher than the median thermostat setting for summer. This modal setting and the mean setting are much higher than the government suggestions of 18 °C and 20 °C (Milne et al. 2010), thus potentially leading to much higher energy bills than are in fact needed to keep a home comfortable and healthy in winter. Only 21% of the respondents had winter thermostat settings of 20 °C or lower (Figure 4-29).

A further examination of the comparison between summer and winter thermostat settings can be found in Section 4.3.4 of this chapter.

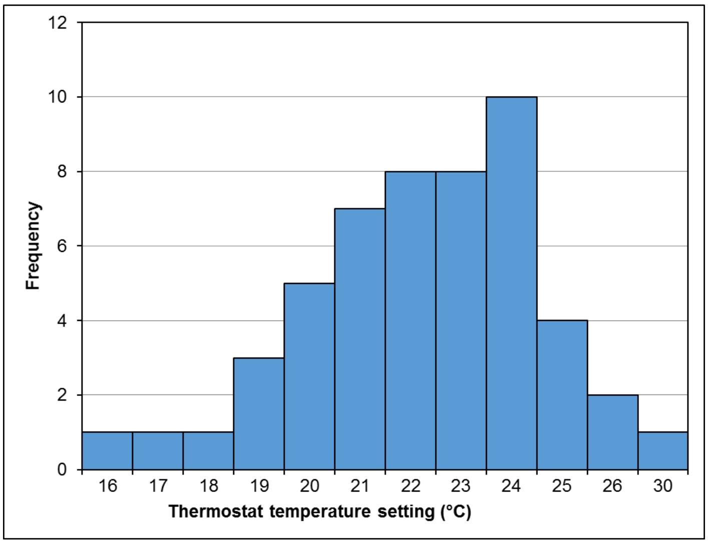


Figure 4-29: Thermostat settings in winter

A similar pattern to cooler use was evident in the results for heater use, in that respondents are most likely to use their heaters in response to feeling cold rather than as a measure to prevent discomfort (Figure 4-30). Again the 'only if I feel too cold' answer was the most common, with 46.8% of respondents answering this way.

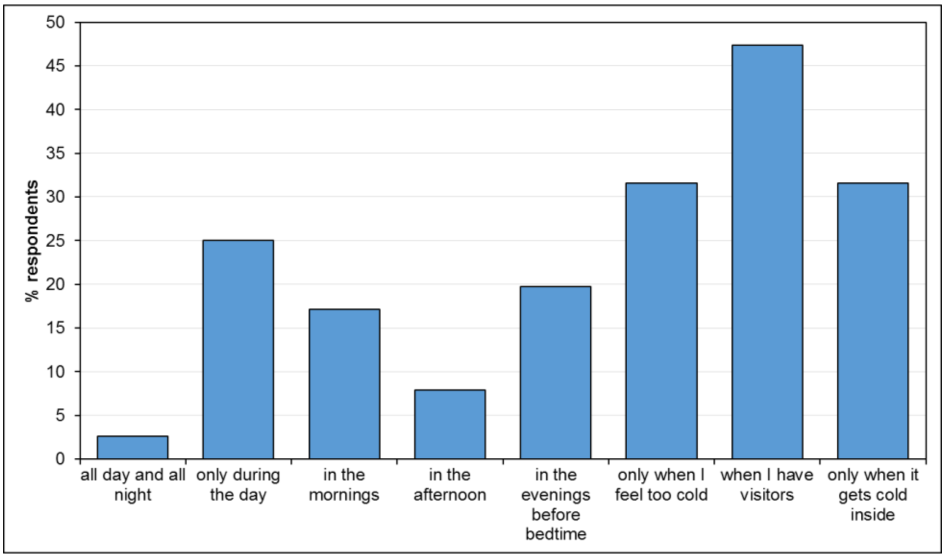


Figure 4-30: Heater usage

The proportion of people who reported at least occasionally avoiding heater use was very similar to the avoidance of using coolers, with 30% recording avoidance at least occasionally (Figure 4-31).

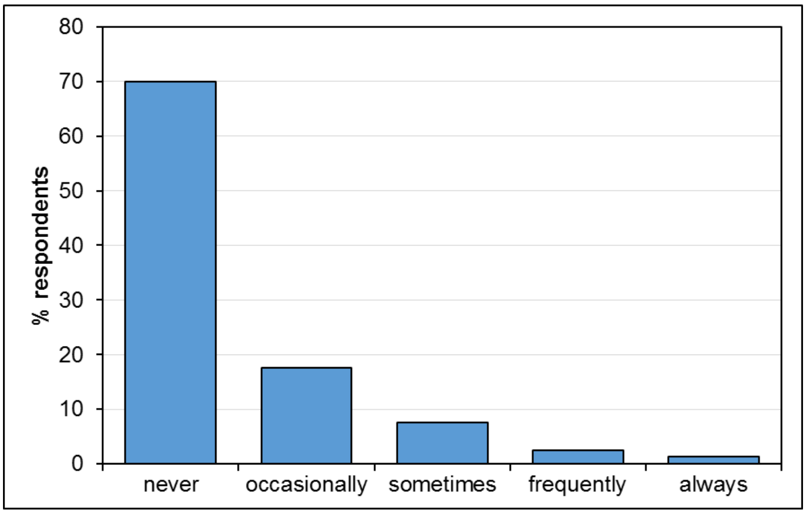


Figure 4-31: Heater use avoidance

Of those who did avoid using their heater, more than half reported that this was due to not wanting to spend money on electricity, whilst 17.3% indicated that they could not afford it. A further 17.3% also cited environmental concern as their motive for avoiding using heating (Figure 4-32). This question had a large number of 'other' responses, which included preferring to use clothing or 'rugging up' rather than turning the heater on, relying on physical activity to keep warm, or not remaining in the room where the heating is and therefore not wanting to waste the electricity it takes to keep an empty room warm. One respondent reported their heater being too noisy. Of these ‘other’ responses, three included wanting to economise or reduce fuel use, which technically put them in the ‘don’t want to use electricity’ category; however, this was not how they answered. One was concerned that due to the age of their heater it might stop working, and so they had got used to not relying on it.

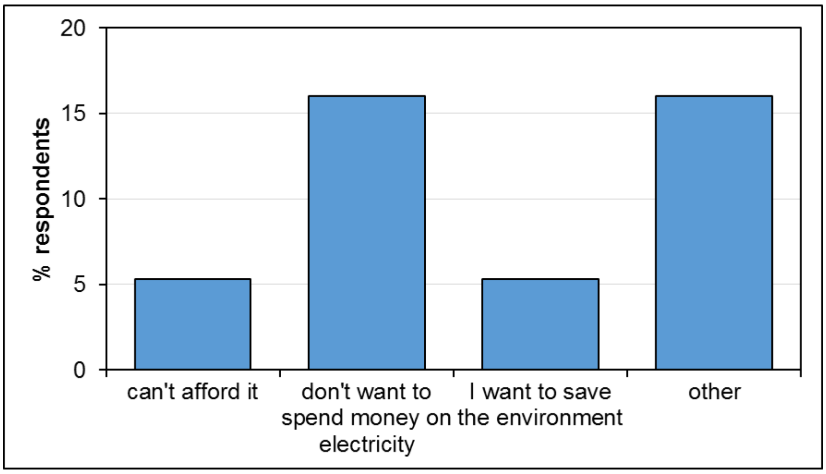


Figure 4-32: Reasons for heater use avoidance

4.2.4.3 *Winter clothing*

A clo level of 1, which is represented by the number 4 in this survey, as shown previously in Figure 4-24a, was by far the most common type of clothing worn in winter, with 68.8% reporting this clothing type. The results showed less variation when compared to the summer clothing values, which were spread between the first three categories more evenly.

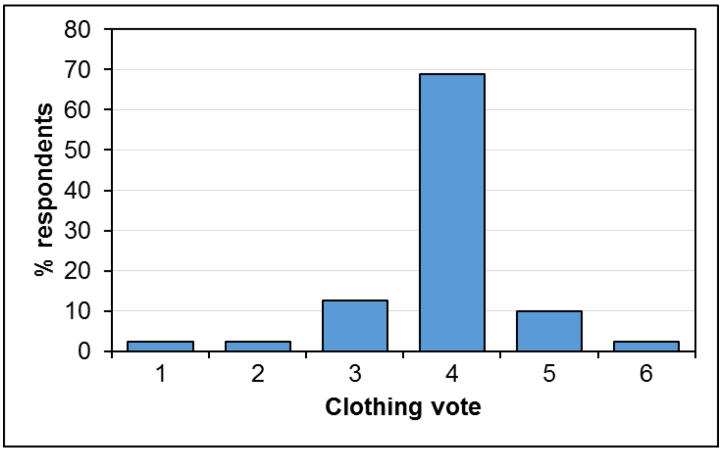


Figure 4-33: Clothing worn in winter

4.2.5 **General health in both summer and winter**

In this section, participants were asked to self-rate their health. They were also asked about any medications they take for common complains, and whether they experience any specific symptoms in hot or cold weather. Participants were asked whether they worry more about their health at different times of the year and whether anyone checks on their wellbeing during extreme weather events.

4.2.5.1 *Self-rated health*

Overall, participants did not rate their health particularly highly, with only 5.1% saying their health was 'excellent' and 74.4% indicating only 'good' or 'fair' health (Figure 4-34). This is quite different from answers to the same question recorded by the ABS Australian Health Survey (AHS), to which this survey has been compared in Figure 4-35, but similar to a recent study in South Australia by Soebarto et al. (2019). The numbers who rated their health as 'very good' or 'excellent' were much lower than national averages across all older age groups (ABS 2013c). The proportion who rated their health as 'fair' was conversely much higher, and those rating their health as 'good' was slightly higher than the national average as well. It is possible that due to the number of people who were recruited for the survey via City Council support services, a higher level of illness and disability is present amongst this cohort.

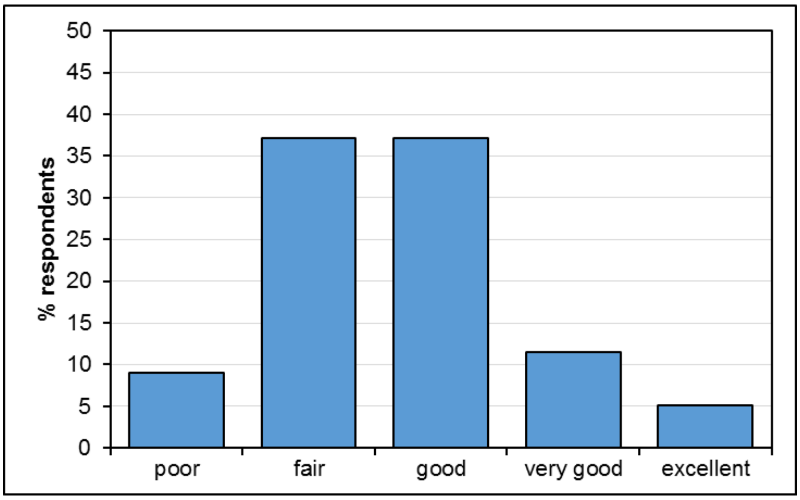


Figure 4-34: Self-reported health

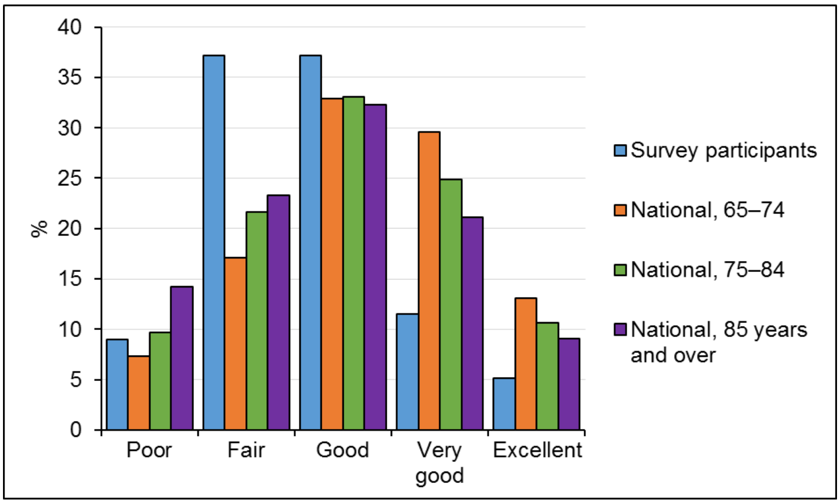


Figure 4-35: Self-rated health compared with national averages

4.2.5.2 *Medications*

Of the surveyed respondents, 26.6% said they did not take any medications for long-term health conditions (Figure 4-36). Whilst, according to the ABS, nearly 100% of people aged over 65 have some form of long-term health complaint, not all of these require medication and thus they will not be captured by this question; for instance, the Australian Health Survey (ABS 2013c) includes complaints such as short- and far-sightedness. This specific question was not aimed at determining all medications and all health conditions present in this cohort; rather, it aimed to determine the number of people taking medications that might influence the way the body responds to changes in temperature, as outlined in Chapter 3.

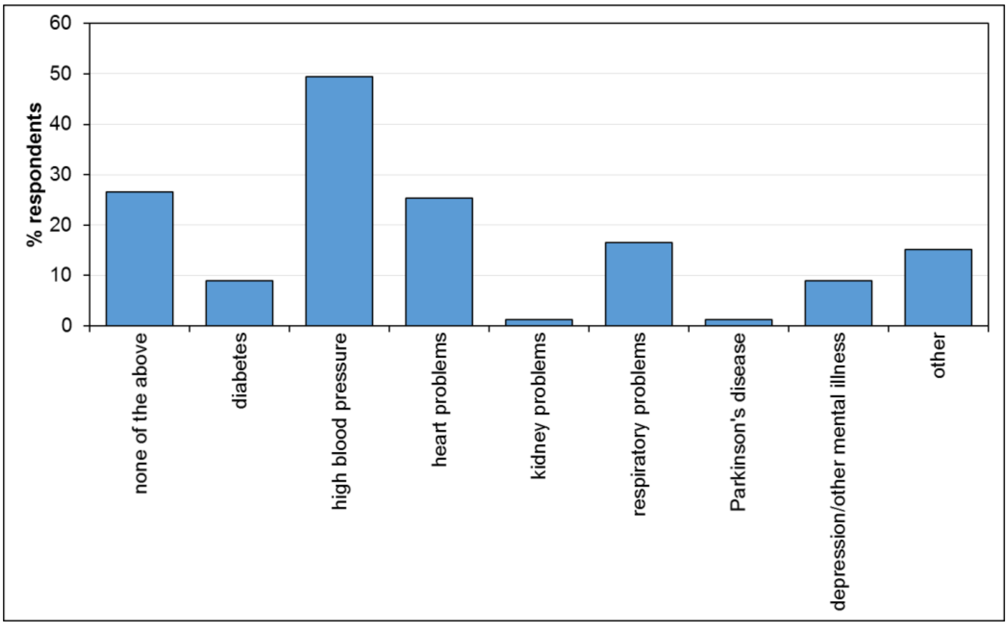


Figure 4-36: Health conditions requiring medications

The national averages of these various conditions are similar for most of the listed conditions. Hypertension is possibly under-represented, with 49.4% of this sample requiring medication for the disease, compared to 69.1% of Australians aged between 65 and 74 suffering from the condition and 80.5% of those aged 75–84 (ABS 2013b). It is possible to suffer hypertension without being medicated for it, and so it is possible that more respondents fell into this category. Levels of diabetes in this cohort were also slightly lower than the national average of 15% for those aged 65–74 (ABS 2013a), but, again, it is possible that the total number of people in the sample who suffer from diabetes was higher but that they manage it without medication.

Some of the conditions listed in the survey, such as 'heart problems' and 'respiratory problems', are too generalised to make comparisons with available ABS data. The Nitschke et al. (2013) survey, however, did include similar wording, and found a comparable number of participants with 'other heart problems', with 20.3% indicating that they took medication for such conditions, compared with 25.3% in this study. That same study had a smaller proportion of participants taking medications for respiratory disorders: 9.8% compared to 16.5% in this study (Nitschke et al. (2013).

4.2.5.3 *Symptoms during extreme weather conditions*

Respondents were more likely to report experiencing symptoms during cold weather (43/80) than during hot weather (35/80). Participants were also more likely to report suffering from more than one symptom during cold weather than in hot weather, with 22 of the 43 (51%) people who suffered symptoms in winter reporting more than one, compared with 14 of the 35 (40%) who reported symptoms in hot weather (Figure 4-37).

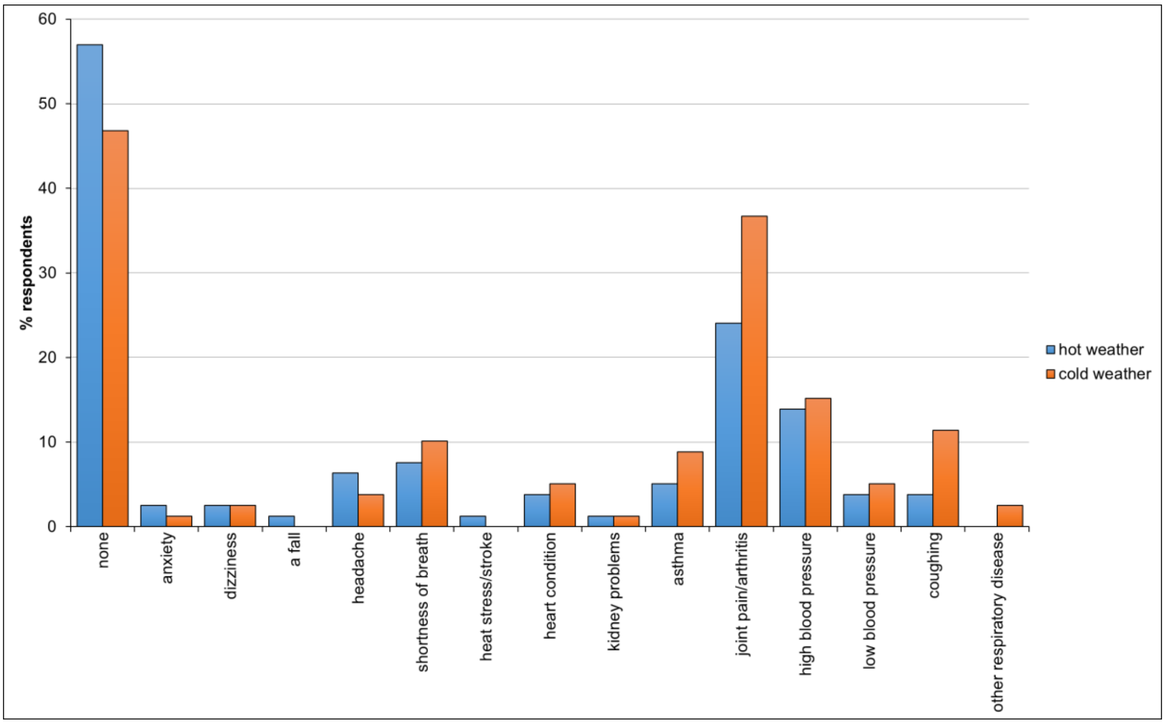


Figure 4-37: Symptoms experienced during extremes in hot and cold weather

The most commonly reported symptom in both data sets was joint pain/arthritis. Since arthritis affects approximately 50% of people over 65, this is not a surprising result (AIHW 2014). A higher number reported joint pain in winter (36.7%) than in summer (24.1%), which again reflects the typical presentation of joint pain. There was a higher incidence of coughing in the winter than in the summer: this may be due to coughing induced by cold air, but it may also be an indication that people suffer from colds and other respiratory infections more in winter and are reporting coughing as a symptom of that.

Headache and anxiety were the only symptoms that presented in higher numbers during hot weather than in cold weather; however, overall numbers for these responses were very small, with only one or two respondents reporting these conditions in either season.

Despite reporting fewer symptoms during hot weather, overall, participants reported worrying about their health during hot weather more often than they did during very cold weather (Figure 4-38). The differences between how much people worry about their health in summer and winter are quite marginal; however, they warrant further investigation.

As well as reporting worrying about their health more often in hot weather than in cold weather, participants were also somewhat less likely to have someone check on their wellbeing during very cold weather than they were in very hot weather (Figure 4-39).

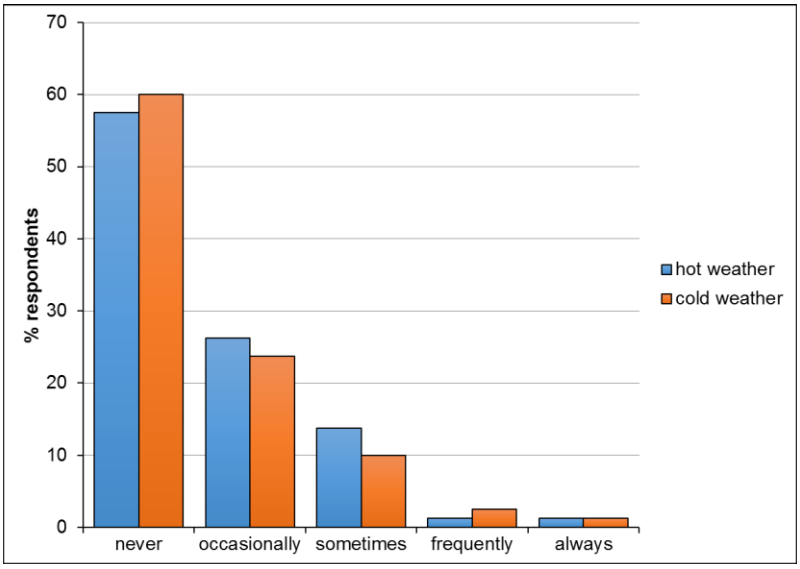


Figure 4-38: Concern for own health during very cold weather and heatwaves

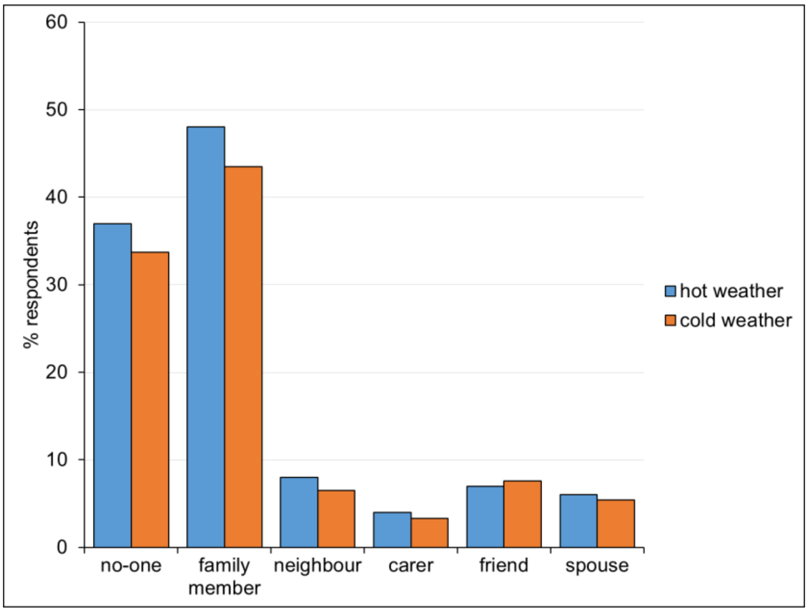


Figure 4-39: Wellbeing checks during very hot and very cold weather

4.3 Analysis of results

The purpose of the Housing and Health Survey was to answer Research Question 2—What is the current understanding of housing and health within a sample of older South Australian people?'. Thus, as well as the descriptive statistics as shown above, it was important to determine what relationships exist between the answers to questions relating to housing, thermal comfort and health.

Statistical analysis was undertaken using the SPSS (version 25) statistics package (IBM 2017). Cross tabulations of the relevant questions was undertaken to compare the answers both across and within different sections of the survey. Chi-squared tests were used to determine the associations between sets of tabulated variables.

4.3.1 Housing and thermal comfort

A significant relationship was found between the insulation levels of houses and the level of thermal comfort provided, but not the frequency of comfort. The Pearson chi-square test of the cross tabulation (Table 4-1) had a statistically significant result ($p<0.05$). Whilst the overall survey numbers are low it appears that houses with high and very high ceilings are slightly warmer than those with medium-height ceilings. This is the opposite of what is expected given that hot air rises and homes with high ceilings typically stay cooler for longer in hot weather. It is possible the heat in these houses is linked to other factors not captured in this survey which allow for heat penetration in hot weather, such as house condition. This result is also complicated by more than 75% of the votes being in the 'medium' category.

Table 4-1: Cross tabulation of ceiling height and thermal sensation vote in summer

		In general in summer, would you say your home is ...?						Total
		hot	warm	a bit warm	just right	a bit cool	cool	
How high is the ceiling in the main living area in your home?	Low	0	2	2	1	1	0	6
	Medium	1	11	18	26	3	4	63
	High	0	2	4	3	0	0	9
	Very High	0	0	1	0	0	0	1
	Total	2	15	25	30	4	4	80

When insulation and thermal comfort were cross tabulated, Chi-square analysis showed there was a significant relationship between insulation and the thermal sensation vote ($p<0.05$)but not the frequency of comfort ($p>0.05$).

Those whose homes had ceiling insulation were almost twice more likely to say their house was warm in summer than those with ceiling and wall insulation (Table 4-2). More than half of those with ceiling and wall insulation reported their house was 'just right' in summer but only around one-third of those with insulation in their ceiling only reported this sensation. Overall houses with ceiling and wall insulation were more likely to be reported by the occupants as having acceptable thermal conditions that those with only ceiling insulation. This is in line with the fact that wall insulation can prevent heat transfer into a house in hot weather, so long as there is adequate heat escape when necessary.

Table 4-2: Cross tabulation of levels of insulation and thermal sensation vote in summer

		In general in summer, would you say your home is...?						Total
		hot	warm	a bit warm	just right	a bit cool	cool	
Is your home insulated?	Don't know	1	1	0	0	0	1	3
	Yes - ceiling and walls	0	3	7	14	0	1	25
	Yes - ceiling only	1	10	15	15	3	2	46
	No	0	1	3	1	1	0	6
	Total	2	15	25	30	4	4	80

There was also a relationship between the presence of blinds on a house and the thermal sensation of the occupants. Those whose homes were not fitted with any external shades or awnings were more likely to report thermal sensations of a bit warm, warm and hot than those who did have these features fitted (Table 4-3). Those who had blinds or awnings fitted on some windows were also more likely to report feeling warm than those with blinds on only some.

It is possible that external blinds may prevent night time heat transfer from windows, and thus if they are installed on all windows this may account for the warmer sensations of those with all windows covered by blinds or awnings than those with only some windows covered.

Table 4-3: Cross tabulation of the presence of external blinds and thermal sensation in summer

		In general in summer, would you say your home is...?						Total
		hot	warm	a bit warm	just right	a bit cool	cool	
Does your home have awnings or external shade window blinds?	None	1	3	6	4	0	0	14
	Some windows	0	10	9	18	1	3	41
	All windows	1	2	10	8	2	1	24
	Total	2	15	25	30	3	4	79

There was a statistically significant relationship found between the presence of ceiling fans and thermal comfort. In this instance however it was between the frequency of comfort ($p<0.05$) rather than the thermal sensation vote ($p>0.05$). The presence of ceiling fans in the bedrooms related to houses being ‘mostly’ or ‘always’ comfortable (Table 4-4). Fewer participants had ceiling fans in their main living areas than in their bedrooms; this may be due to the preference of most participants to not use the air-conditioning in their bedrooms.

Table 4-4: Cross tabulation of the presence of ceiling fans and the frequency of comfort in the home during summer

		In general, would you say your home is comfortable in summer?				Total
		always	mostly	sometimes	occasionally	
Do you have ceiling or pedestal fans in your home?	No	4	9	1	0	14
	Main bedroom	10	40	1	1	52
	Living areas	0	6	3	0	9
	Kitchen	0	0	1	0	1
	Other bedrooms	0	1	0	0	1
	Total	14	56	6	1	77

Cross tabulation also revealed a significant relationships between the ceiling height and both the frequency of comfort (p=0.011) and the thermal sensation vote (p=0.005). These results are however complicated again by the fact most participants recorded a 'medium' ceiling height and also by the fact that of those who said their homes were 'always' or 'mostly' comfortable in winter often said their houses were 'warm' rather than 'just right' (Table 4-5) For instance 31.3% of people who said their house was always comfortable in winter said it was 'warm', the second most common response after 'just right'. Underlying this is a difficulty in understanding and semantics: for someone to say they feel both 'warm' and 'comfortable' in winter makes a certain amount of sense.

This issue of semantics, and of the way that human preferences and perceptions of what is comfortable change in different conditions, is not a new one in thermal comfort research. Several papers have examined the semantics of describing comfort and the difficulty it presents for researchers in the English language, even before translations are considered (Humphreys & Hancock 2007, Pitt 2006, Van Hoof, Mazej & Hensen 2010).

4.3.2 **Housing and health**

Whilst there was a relationship found between housing and comfort, there were no statistically significant (<0.05) associations found between respondents self-reported health and any of the variables relating to housing characteristics. Cross tabulations with Chi-square analysis was conducted for self-assessed health status and construction type, the presence of insulation, ceiling height, age of the building and whether it was a detached or attached dwelling, all which had no statistically significant relationship. Thus in this sample it can be concluded that building characteristics such as construction type, insulation, ceiling height or the age of the building do not impact on the occupants health in a significant way. These results are similar to those seen by a recent larger study by Soebarto et al. (2019) in which no relationships were found between housing quality variables and health.

4.3.3 **Thermal comfort and health**

Whilst there were no relationships found between housing factors and health, it is important to note that there was a significant relationship between winter thermal comfort and self-reported health, although not between summer thermal comfort and health. A relationship was found between self-reported health, how frequently the house was comfortable (Table 4-5) and the thermal sensation vote of the participants (Table 4-6).

Table 4-5: Cross tabulation of self reported health and frequency of thermal comfort in winter

		In general, would you say your home is comfortable in winter?					
		always	mostly	sometimes	occasionally	never	Total
In general, how would say your health is?	poor	2	5	0	0	0	7
	fair	8	17	2	0	0	27
	good	2	23	3	1	0	29
	very good	3	6	0	0	0	9
	excellent	1	1	0	1	1	4
	Total	16	52	5	2	1	76

This data suggest that those who consider their health to be 'fair' or 'poor' have comfortable homes in winter slightly more often than those with better self-reported health. This may indicate a desire to remain comfortable in cold weather in as a response to their poor health. The majority of respondents did however respond that their house was comfortable at least 'mostly' which again complicates the data analysis.

Table 4-6: Cross tabulation of self-reported health and thermal sensation vote

		In general in winter, would you say your home is...?						
		warm	a bit warm	just right	a bit cool	cool	cold	Total
In general, how would say your health is?	poor	1	0	2	3	1	0	7
	fair	4	1	13	6	2	2	28
	good	5	3	6	10	5	0	29
	very good	1	0	4	1	0	3	9
	excellent	2	0	0	0	0	2	4
	Total	13	4	25	20	8	7	77

Interesting to note is that of those who said their health was 'poor', five said their house was 'mostly' comfortable (Table 4-5), and yet in Table 4-6 it seems that their houses tend to be slightly on the cooler side in winter. Again the semantics of warmth and comfort complicate this result, however it is a result that warrants further investigation: if older people with already poor health are finding their cold homes thermally comfortable, this may have further health effects which leave them vulnerable to further cold related illness.

There were no significant relationships found between summer comfort and self-related health.

4.3.4 **Other factors**

4.3.4.1 *Thermostat and cooler usage*

As reported in Figure 4-16 and 4-29 earlier in this chapter, the mean thermostat settings for winter and summer were very similar. Of the 80 survey respondents, 45 gave an answer to both summer and winter thermostat settings. Of this 45, 16 (35.6%) reported the same thermostat setting throughout both seasons. A further 13 (28.9%) reported having higher settings in winter than in summer, contrary to energy efficiency guidelines. The Australian Government's *Your Home* guide (Milne et al. 2010) recommends thermostat settings of between 25 °C and 27 °C in summer to save energy and thus keep energy bills low. The South Australian Government's *Summer Cooling Guide* (2016) similarly recommends a setting of between 24 °C and 27 °C or 'as high as is comfortable for you' (SA Government 2016) to reduce running costs. Thus, 38 of those who answered had a thermostat setting lower than that recommended by the South Australian Government for saving energy.

It is estimated that each extra degree (°C) of cooling increases energy consumption by 5–10% (Milne et al. 2010), and thus for those concerned about electricity prices, education about thermostat settings may be beneficial. Whilst the general trend showed slightly higher thermostat settings in summer than in winter, no statistical significant difference was found between the means of the summer and winter thermostat settings.

Given that the most common reasons people gave for avoiding heater or cooling use was that they did not want to spend money on electricity, it is possible that despite government advice making clear recommendations about thermostat settings and energy efficiency, there is a lack of understanding of how best to manage these settings. This is not necessarily a behaviour of just the older people in this cohort: a study in the US found that only 30% of those with programmable thermostats actually programmed them (Meier 2012). The US study did not break down results by age group, but it was not aimed specifically at older people. It is thus possible that similar behaviours would be seen across more age groups than just the older age groups.

4.3.4.2 *Pattern of heating and cooling use*

These data raise a concern as to the pattern of cooling usage, with participants typically turning off cooling overnight in summer. Whilst 12% of responses indicated that occupants used a cooler before going to bed, in order to bring the temperature down for comfortable sleeping conditions, in Adelaide in summer the nights can still be warm, especially during heatwaves and on extreme heat days. High overnight temperatures are associated with health challenges during extreme heat events, a factor which was not examined in this questionnaire (Bi et al. 2011, Loughnan, Nicholls & Tapper 2010). It is, however, important that adequate measures are taken to keep houses at appropriate temperatures overnight.

The winter pattern of heating was similar, with 31.2% of respondents reporting using their heaters in the evenings (Figure 4-30). This may be a means to warm the house up before sleeping, although it may also just be because evenings are the coldest time of the day, and participants are attempting to keep comfortable. No participants reported using their heaters only overnight; however, 25% reported using it only during the day, again showing a pattern of use in which a person turns off heating devices overnight, much as with cooling. Whilst it is easy to adjust to cold temperatures at night with blankets and clothing, low overnight temperatures are a possible factor in morbidity and mortality amongst older people (Milo-Cotter et al. 2006).

4.3.4.3 *Clothing levels*

Despite having answers that fell into all categories, there was less variation in the clothing level in the winter sample than in the summer sample (Figure 4-41). In the questions regarding summer clothing levels, the responses were spread over three categories in an almost 40:40:20 ratio. For winter, most of the responses are clustered together at the one clo value level. Detailed patterns of clothing level are discussed further in later in this thesis; however, this survey result does indicate a wider range of clothing adaptation in summer than in winter (Figure 4-40).

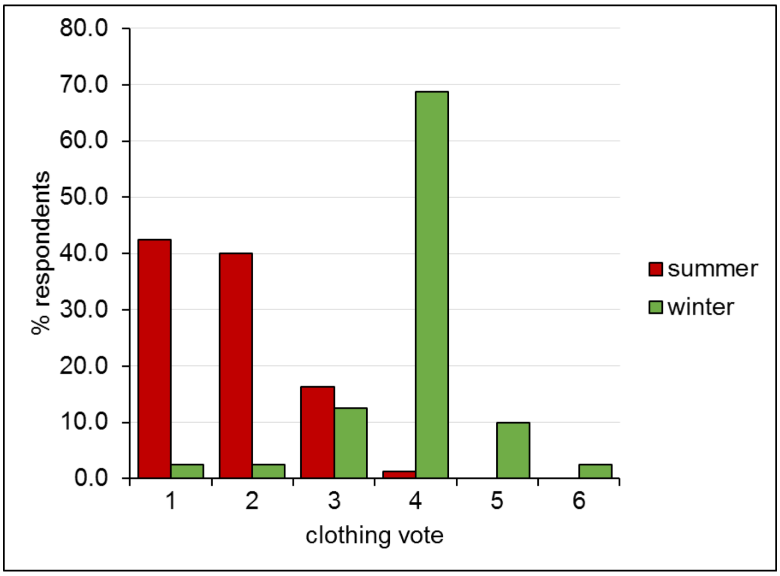


Figure 4-40: Clothing levels in summer (red) and winter (green), showing the different distributions of clothing types across different seasons

4.4 Summary

This chapter examines the responses from the Housing and Health Survey, which was conducted during the early stages of the research project. It both reports on the information gained from the survey and seeks to analyse this information.

Whilst survey numbers were too few to represent a statistically significant sample of the South Australian population, the data were consistent with, or at least close to, known data across a number of issues, in terms of the demographics as well as the age and construction of the respondents' houses. Their self-reported health was similar to the national Australian Health Survey but quite different from the findings of other research in this area. Answers to questions regarding thermal conditions and comfort showed an acceptance of conditions wider than typically anticipated by researchers. Respondents' answers also highlighted the ongoing issue amongst thermal comfort researchers of language and semantics.

Cross tabulation with Chi-square analysis showed that there was no significant relationship between the housing characteristics studied and self-reported health. There was however a relationship between some of these variables and comfort in both summer and winter: insulation and ceiling height had statistically significant relationships across both winter and summer comfort sensation and the frequency of comfort. There was also a relationship between self-reported health and winter thermal comfort; those with poor or fair health were slightly more likely to indicate their house was comfortable more of the time, but potentially with cooler thermal sensation votes. This is a concern as it could lead to further cold-related illness in already vulnerable people.

Thermostat usage across the seasons was very different from local published guidelines and may be a target for future policy and education. Future research into the attitudes towards health in summer compared to winter should also be considered, as, overall, participants seemed less concerned about their health in winter than they were in summer, despite the fact they displayed more symptoms during winter. Further to this, research shows that winter may be as deadly as summer heatwaves, if not more so.

As a selection of these survey respondents were part of the field study, this chapter seeks to examine the overall preferences and comfort of this cohort in order to determine how they relate to the field study, which will be discussed in the next chapter.

CHAPTER 5

Results of a field study of thermal comfort

5.1 Overview

The review of the literature in Chapter 2 indicates that research about the thermal conditions inside the residences of older people is an emerging area with few studies examining the relationship between indoor conditions, thermal comfort and the health of the occupants. It is also unclear whether the climate related illnesses reported in older people are strongly connected with indoor temperatures. One of the stated aims of this thesis was to conduct a study to explore this connection.

This chapter will discuss the results of the field study conducted in Adelaide, South Australia, between February 2015 and August 2016. The detailed methodology for the study has been discussed in Chapter 3. This chapter addresses research Question 3 as outlined in Chapter 1 and included below:

- What thermal conditions exist in the houses occupied by older people in Adelaide, and what impact do these conditions have on the health and wellbeing of the occupants?

This question will be addressed in Section 5.5 of this chapter with an examination of the thermal conditions during the study period, as well as the experiences of the occupants. This section will also report on whether these thermal experiences may be altered by gender or age.

Sections 5.6 and 5.7, also compare the acceptability reported by participants in the field study cohort with international standards of thermal comfort. This allows the experience of the participants in this study to be compared with predicted comfort levels in other previously studied cohorts. The relationship between the thermal conditions, thermal comfort and symptoms reported by participants are discussed in Section 5.8.

Section 5.9 will present the analysis of the results to determine the 'ideal' range that should be aimed at in order to determine optimal thermal comfort of the occupants. Then it will be determined what overlap, if any, exists between the conditions which provide optimal thermal comfort and those which produce the fewest symptoms, in order to determine a range at which to aim so that older people both feel comfortable and experience the fewest possible temperature-related illnesses. This analysis will provide the basis for the investigation in Chapter 6, which will present the results of a computer simulation of building improvements and discuss the potential of these improvements to create comfortable spaces for older people whilst reducing the presence of heat- and cold-related symptoms.

5.2 Participants

Participants were recruited from the pool of respondents who participated in the Housing and Health Survey portion of this study, the results of which are presented in Chapter 4. Those who expressed interest in participating in the field study component of this research project were asked to return a consent form regarding their participation and were then contacted to arrange a time to install the data logging equipment and discuss the details of their participation.

A total of 19 households participated in the study, with one household requesting to withdraw due to ill health only two weeks after beginning. Of the 18 remaining households, seven were single-occupant households, and the remaining 11 had more than one occupant. In 10 of these households, the occupants were a married couple, while in the remaining household one occupant lived with an adult son. In these multi-person households, only four had more than one person participate in the study. Thus, over the 18 households a total of 22 people participated in the study. There were 11 male participants and 11 female participants.

Table 5-1 shows the breakdown of participants by age range and sex. Participants aged between 71 and 75 years old made up the largest group in this cohort. Other groups were mostly evenly distributed, except that there was a lack of any females in the group aged 81–85 years old.

Table 5-1: Age range and sex of study participants

Age range	Female	Male	Total
65–70	2	2	4
71–75	5	3	8
76–80	2	2	4
81–85	0	2	2
86–90	2	2	4

5.3 Houses

Whilst initially it was hoped to recruit households primarily from the areas with high heatwave vulnerability as addressed in Chapter 3, a wider area was utilised when recruitment numbers from the initial areas surveyed were lower than expected. The map in Figure 5-1 shows the locations of the 18 houses (yellow) and the three BOM weather stations from which data has been included in this study (blue). The coastal areas of Adelaide have a slight variation from the more inland areas, necessitating the use of data from both Adelaide Airport (A) and Kent Town (B). One house was located in the Adelaide Hills area, and thus despite being close to Adelaide Airport in terms of distance, the climate in the hills area is very different, especially in winter, and so data from a third weather station in the hills at Mt Lofty (C) was needed.

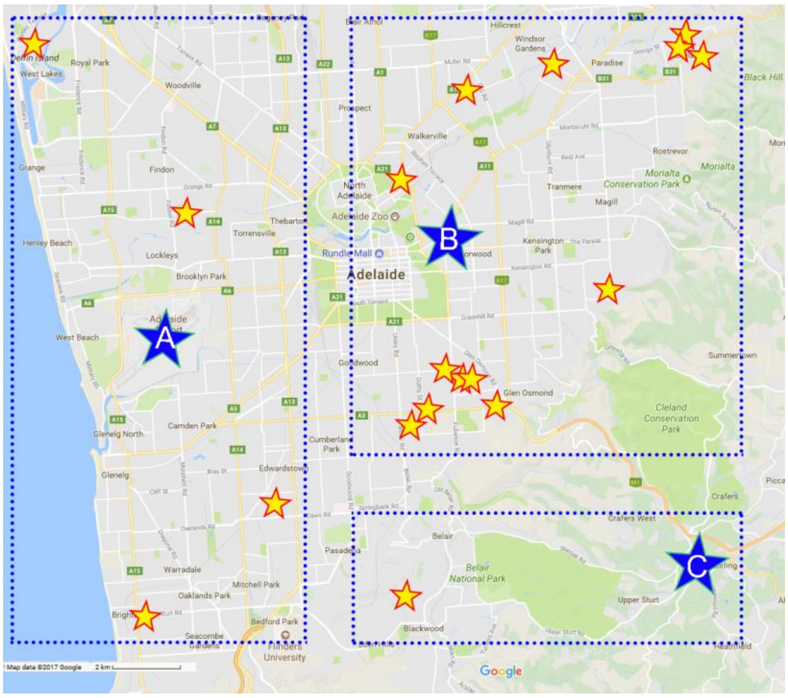


Figure 5-1: Map of the locations of the participating households (yellow stars) and weather stations (blue stars).

Weather station A = Adelaide Airport, B = Kent Town, C = Mount Lofty. Dotted lines indicate which weather station was matched with which houses.

The houses in the study covered a cross-section of building type, age and materials (Table 5-2, page 156). Of the 18 houses, most (13) were detached dwellings, with two semi-detached dwellings and three which were units in either a single or multistorey complex. The houses varied in age from five years to 82 years old. Whilst many were older than 31 years, this represented roughly the same proportions as seen in the Housing and Health survey (Chapter 4). The majority of the houses were built from double cavity brick or brick veneer construction types, with the exception of one timber A-frame house and two houses built from concrete or concrete block. These different types, ages and materials gave enough contrast for comparison in the building improvement phase of the study, the results of which will be presented in Chapter 6.

All except one house had cooling installed, and all had at least some form of heating available to the occupants. One participant was renting, three were in a licence-to-occupy arrangement and the remainder were owned outright by the participant. The details of each of the houses involved in the study are outlined in Table 5-2.

5.4 Thermal Comfort Survey

A total of 2667 valid comfort vote forms were returned. Some forms that were returned without dates or times filled in were excluded due to the inability to match these votes with measured data. Votes were also excluded if they did not indicate in which room the form was completed, as this also prevented data being matched to the correct readings. Other vote forms also had information missing, but were included: 20 did not include a thermal sensation vote, three did not indicate whether the conditions were thermally acceptable, two did not indicate whether they had a preference for change, 29 failed to indicate what level of clothing was being worn, 10 did not indicate whether fans were in use, six did not include whether their heating or cooling was operating, and 11 failed to indicate their current activity level.

Table 5-2: Properties of the houses participating in the study

House #	Nearest weather station		Age of house (years)	Length of occupancy (years)	Construction	HVAC type	Tenure
1	A	Detached	51–70	30	Brick veneer	R/C Ducted	Owned outright
2	B	Detached	51–70	8	Brick veneer	R/C Ducted	Owned outright
3	B	Detached	31–50	34	Double brick	R/C ducted	Owned outright
4	B	Attached unit	31–50	0.5	Double brick	R/C wall	License to cccupy
5	C	Detached	51–70	42	Timber frame + cladding	None	Owned outright
6	B	Detached	31–50	46	Double brick	R/C Ducted	Owned outright
7	B	Semi-detached	31–50	35	Double brick	R/C Wall	Owned outright
8	B	Multi-storey apartment	<10	5	Concrete block	R/C Ducted	License to cccupy
9	B	Detached	31–50	8	Double brick	R/C Ducted	Owned outright
10	B	Detached	31–50	4	Double brick	R/C Ducted	License to cccupy
11	B	Detached	31–50	6	Brick veneer	R/C Ducted	Owned outright
12	B	Detached	11–30	24	Brick veneer	R/C Ducted	Owned outright
13	B	Detached	31–50	46	Double brick	R/C Ducted	Owned outright
14	B	Detached	71–90	36	Double brick	R/C wall	Owned outright
15	A	Detached	51–70	1	Double brick	R/C Ducted	Rented
16	B	Detached	51–70	54	Concrete block	R/C Wall + SC	Owned outright
17	B	Detached	31–50	14	Double brick	R/C Ducted	Owned outright
18	A	Detached	31–50	20	Double brick	R/C Ducted	Owned outright

Votes missing information were used for general analysis and only excluded if the missing information was specifically required for analysis—for instance, the calculation of PMV/PPD requires all of this information.

5.5 Results of the field study

5.5.1 The study period

Installation of monitors in houses was staggered due to difficulties in recruitment. Monitoring and completion of comfort vote surveys in the first seven houses began in February 2015. In May the same year, a further six houses were added to the study, followed by a further five in September the same year. Houses were monitored for at least one winter and one summer. Over the study period, houses were monitored for between nine and 12 months, covering at least one summer and one winter. All monitoring was completed by September 2016.

The locations of the houses in this study fell into areas monitored by three different Bureau of Meteorology weather stations: Adelaide Airport, Kent Town and Mount Lofty. The highest temperature recorded during the study period was 42.8 °C at the Kent Town weather station on 19 December 2015 at 3 pm. The lowest temperature recorded during the study period was 1.9 °C at Kent Town on 20 July 2015 at 2 am. The same low temperature of 1.9 °C was recorded at Adelaide Airport twice, at 7 am on 19 July 2015 and 1 am on 20 July 2015. July 2015 recorded the lowest mean minimum temperature since 1998 (BOM 2015a), with the lowest mean maximum temperature since 1997 (BOM 2015a).

Because of the diversity of locations of the houses in this study, weather data from three different Bureau of Meteorology locations were compared to show the range of weather conditions that occurred over the study period. Figure 5-2 shows the average maximum and minimum temperature, as well as the highest and lowest maximum and minimum temperature recorded each month at each location.

During the warmer months (October–March), on average the maximum temperatures at the airport were lower than those recorded at the Kent Town station, but this difference is less or non-existent during the cooler months (April–September), seen graphically in Figure 5-3. The Mount Lofty station (elevation 685 m (BOM 2017a)) consistently recorded lower temperatures than Kent Town (elevation 48 m (BOM 2017b)) and Adelaide Airport (elevation 2 m (BOM 2017c)).

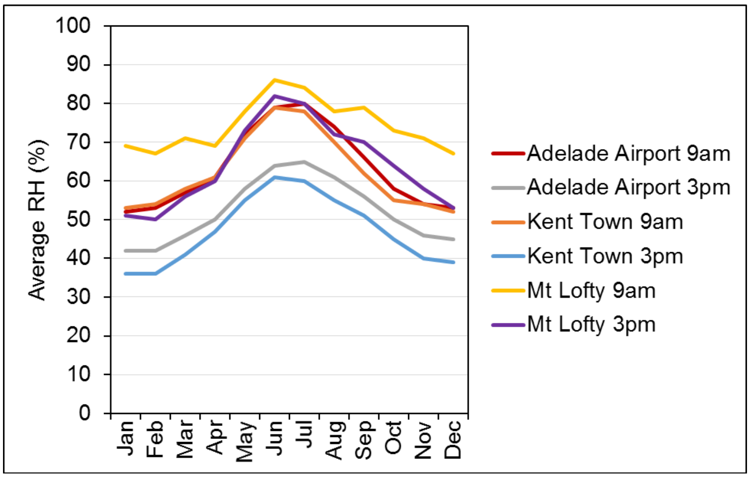


Figure 5-2 Relative humidity at the three measurement sites closest to the participant houses

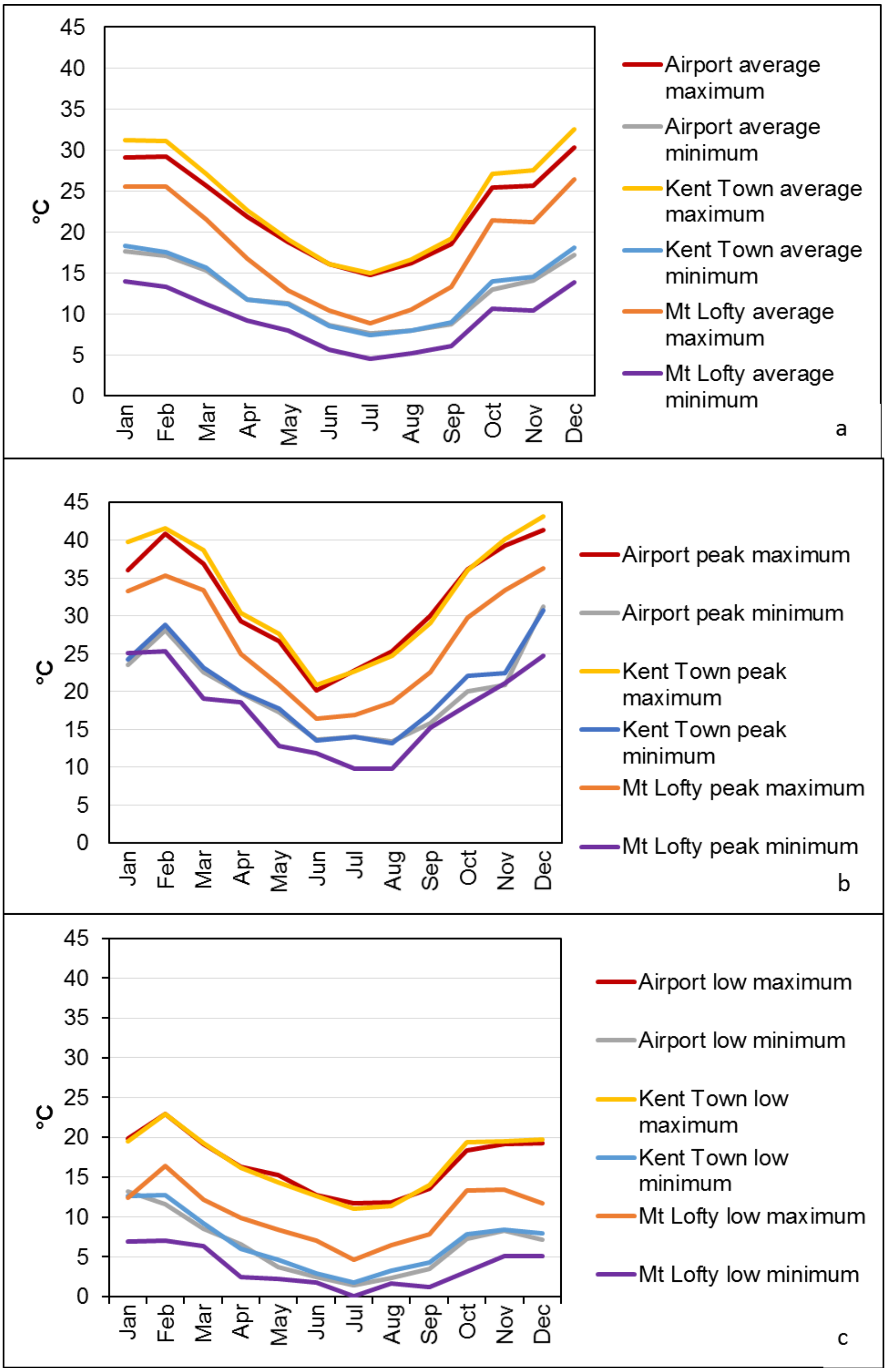


Figure 5-3: Monthly climate averages during the study period at the Adelaide Airport, Kent Town and Mount Lofty weather monitoring stations. 5-2a shows average maximum and minimum temperatures. 5-2b shows peak maximum and minimum temperatures. 5-2c shows low maximum and minimum temperatures

5.5.2 **Indoor climate during the study**

Typically, bedroom temperatures were lower than living room temperatures, especially in regard to the minimum temperatures in all houses. These differences are small in most houses, but the average bedroom temperatures were up to 1.2 °C lower in some houses.

Average living room temperatures ranged between 19.2 °C and 23.7 °C. Average bedroom temperatures ranged between 18.4 °C and 23.1 °C, with all results shown in Figure 5-4 and Table 5-3.

House 5—a lightweight timber A-frame house—recorded both the lowest and the highest temperatures out of all the houses in the study, ranging between a minimum of 9.5 °C and a maximum of 39.4 °C. This house had no cooling and very little heating available, and had very little thermal mass or insulation. In the boxplot of temperatures in Figure 5-4, the maximum temperatures from House 5 have been shown as outliers in order to give a truer indication of typical house conditions across the cohort.

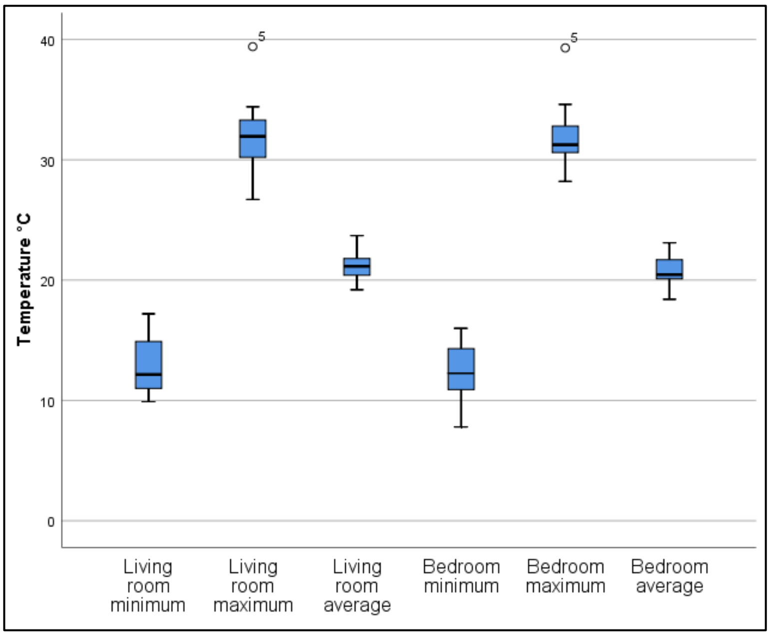


Figure 5-4: Boxplot showing the range of temperatures in the living room and bedroom of the houses in the study

Table 5-3: Maximum, minimum and average air temperatures in the living room and bedroom of each participating household

House #	Living minimum °C	Living maximum °C	Living average °C (SD)	Bedroom minimum °C	Bedroom maximum °C	Bedroom average °C (SD)
1	14.9	29.6	22.1 (2.5)	14.3	28.8	21.4 (2.6)
2	17.2	26.7	22.2 (1.9)	16.0	28.2	21.9 (2.6)
3	11.0	31.8	20.5 (4.0)	10.1	32.5	20.4 (4.2)
4	12.6	33.8	21.4 (3.6)	12.4	32.7	20.2 (3.9)
5	9.9	39.4	19.2 (4.9)	9.5	39.3	18.4 (4.6)
6	10.3	32.1	19.3 (4.4)	10.9	33.4	19.1 (4.8)
7	12.5	33.9	21.8 (3.7)	12.6	31.6	21.6 (4.1)
8	15.5	29.5	21.0 (2.8)	14.6	29.1	20.2 (3.0)
9	15.1	32.5	21.4 (3.4)	14.5	34.6	21.7 (3.8)
10	13.9	30.8	22.9 (3.0)	14.3	30.6	22.7 (3.0)
11	11.8	31.7	21.5 (2.9)	11.7	30.7	21.8 (2.9)
12	12.8	30.2	21.1 (3.4)	11.5	33.4	20.5 (4.3)
13	11.1	32.1	20.4 (4.1)	12.3	30.8	20.6 (3.9)
14	10.6	28.8	19.7 (3.5)	10.1	30.4	19.3 (4.5)
15	10.8	33.1	19.8 (4.7)	12.0	32.0	19.8 (4.4)
16	16.2	33.3	23.7 (3.3)	15.5	32.8	23.1 (3.7)
17	11.6	34.4	21.2 (3.4)	7.8	30.9	20.1 (4.5)
18	11.8	31.5	20.8 (3.4)	12.2	30.8	20.3 (3.7)

The relationship between outdoor hourly temperature and indoor hourly temperature varied seasonally, with winter temperatures being less varied than summer temperatures. By binning the outdoor temperatures into 1 °C bins and averaging the indoor measured temperature in these bins, a largely linear trend can be seen in both seasons. However, the slope of the weighted linear regression of outdoor and indoor temperature in the summer months is steeper (Figure 5-5, x-coefficient of 0.283) than that in the winter months, showing a closer relationship with the outdoor temperature than seen in winter, where the line is flatter (Figure 5-6, x-coefficient of 0.160).

The mean difference between the hourly outdoor temperature, taken from the closest weather station, and indoor temperature also varied with the seasons. There was a small but statistically significant difference ($p<0.01$) between the mean absolute difference between outdoor and indoor temperature, further confirming that indoor temperatures in summer are closer to the outdoor temperature (4.13 °C difference) than in the winter (5.39 °C difference).

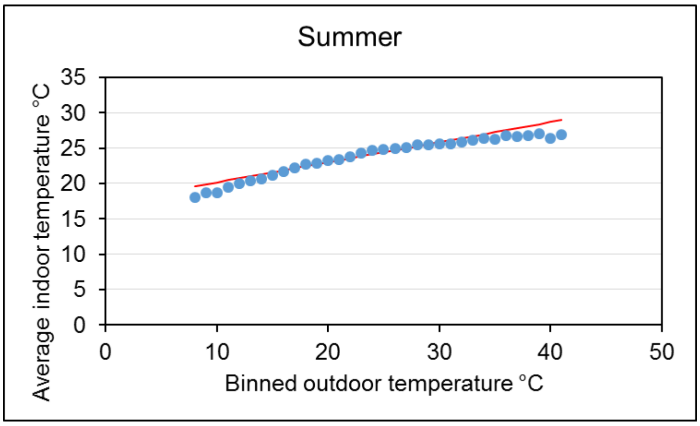


Figure 5-5: Comparison of binned hourly outdoor temperature and average hourly indoor temperature during summer (Dec–Feb), with the red line indicating the weighted linear regression

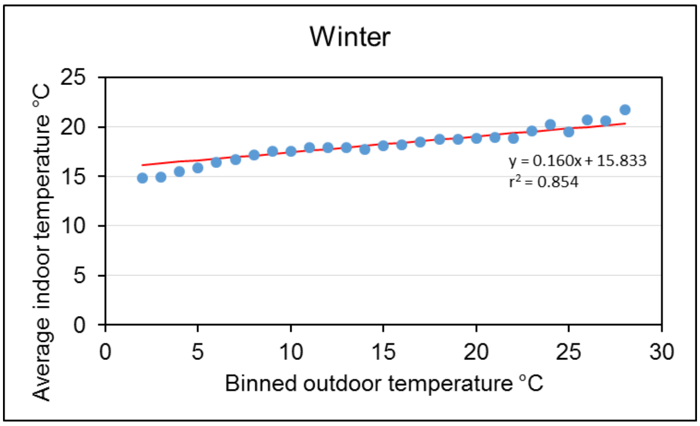


Figure 5-6: Comparison of binned hourly outdoor temperature and average hourly indoor temperature during winter (Jun–Aug), with the red line indicating the weighted linear regression

In both seasons, it is clear that whilst the linear regression equations provide a reasonable match to the binned data, there is some curvature of the line in both winter and summer. In summer, the line flattens slightly at the higher binned outdoor temperatures (Figure 5-5), most likely due to increased use of cooling during these higher temperatures. In the winter (Figure 5-6), the curve is seen at lower outdoor temperatures.

This is likely due to the fact that these lower temperatures occur overnight, and most of the participants in this study expressed a preference for not having heating turned on whilst sleeping.

5.5.3 **Thermal experience of the participants**

The figures below show the thermal sensation votes (TSVs) cast during the entire study period compared with the indoor temperature in the room at the time the vote was cast. A total of 2648 thermal comfort votes were cast across all households. The number of votes cast for each TSV can be seen in Figure 5-7.

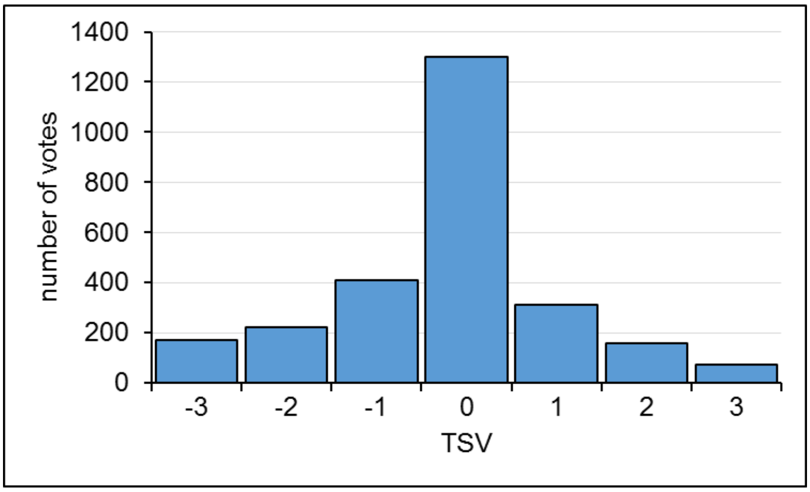


Figure 5-7 Total number of votes cast for each TSV

All votes were plotted against temperature (Figure 5-8). To gain a stronger linear relationship between the votes and the temperature, the votes were binned into 1 °C intervals, with each bin representing values within 0.5 °C from the whole value—for instance, the bin for 15 °C contains all votes cast at temperatures from 14.5 °C to 15.4 °C. The TSVs in each bin were then averaged and weighted, giving the average vote for each degree (°C), and plotted against the temperatures (Figure 5-9).

In each case, linear regression analysis of the temperature and TSV was carried out in order to be able to predict the temperature at which specific thermal comfort votes would be cast.

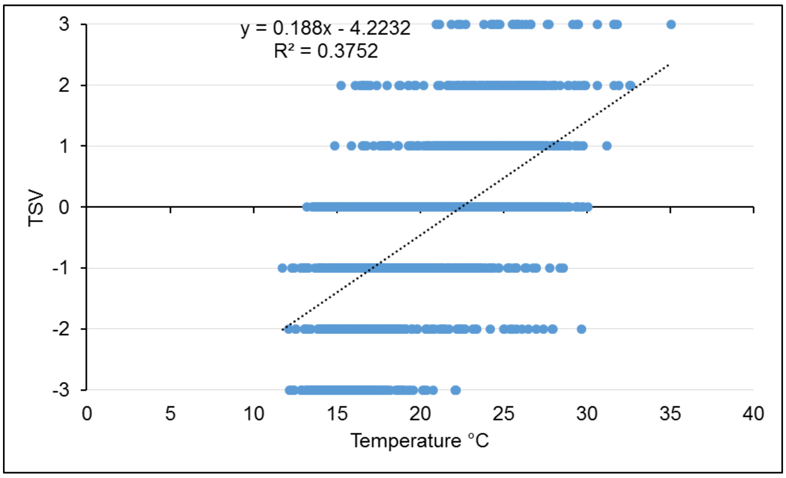


Figure 5-8: All TSVs plotted against temperature

Whilst the overall trend in Figure 5-8 is linear, it does not provide a clear picture of the trend of voting. Statistical analysis showed the linear relationship to be significant, but the data lack enough clarity to draw conclusions. Therefore, going forward all data concerning TSV and temperature have been binned as shown in Figure 5-9.

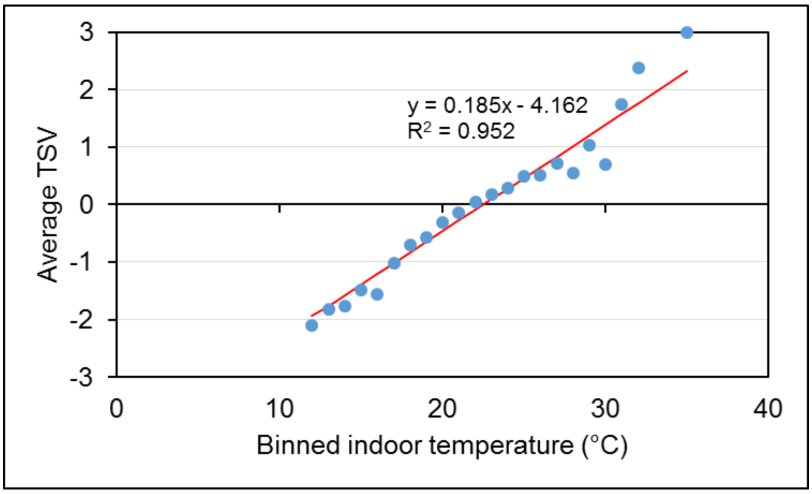


Figure 5-9: Average TSVs for the study period binned by indoor temperature intervals of 1 °C The red line indicates the weighted linear regression equation of the relationship between TSV and indoor temperature.

By averaging the votes in bins of 1 °C, a much stronger relationship between temperature and TSV can be seen, with a stronger R-squared value indicating a better fit of this linear model to the data (Figure 5-9).

This relationship is stronger at temperatures up to 25 °C, at which point the line does not fit the data as well. This is most likely due to fewer votes being cast at these temperatures, as it was uncommon for houses to reach temperatures higher than 26 °C. Therefore, weighted linear regression was carried out on the binned temperature vs TSV, in order to more accurately represent the line of the data. Solving a weighted linear equation for zero gives a neutral temperature of 22.5 °C. This is 0.2 °C lower than the neutral temperature reported by Saman et al. (2013) for Adelaide residents, although that study reported only on summer, rather than a year-round value, as are the data represented here.

5.5.3.1 *Seasonal variations in comfort temperatures*

Typically, people respond differently to indoor temperature across different seasons due to a range of reasons, including comfort expectations and clothing level (Humphreys & Nicol 1998). For this reason, the same method as above was performed on votes cast specifically in the winter months (June–August) and the summer months (December–February).

Averaging the votes across 1 °C bins for the summer months gives a strong and statistically significant ($p<0.05$) linear relationship (Figure 5-10). In this instance, neutral temperature is 22.0 °C, which is 0.7 °C lower than reported in a study during the summer months in Adelaide amongst a general population (Saman et al. 2013). This model shows the same breakdown at temperatures above 25 °C, probably for the same reasons seen in the whole-of-year model.

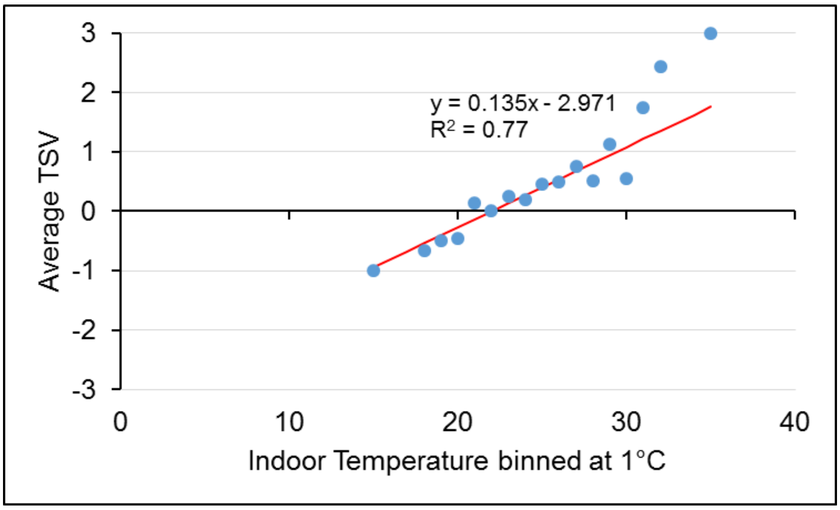


Figure 5-10: Average TSV for each °C in summer months (Dec–Feb)

The red line indicates the weighted linear regression equation of the relationship between TSV and indoor temperature.

In winter, averaging the votes across 1 °C bins gives a better linear model of the data and a statistically signicicant (p>0.05) linear regression (Figure 5-11). This equation gives a neutral temperature for the winter months of 19.4 °C.

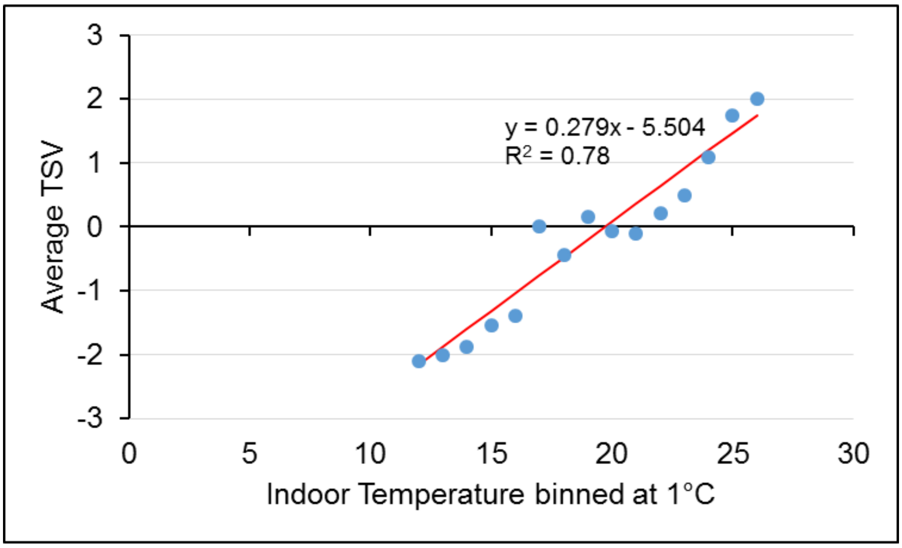


Figure 5-11: Average TSV for each °C in winter months (Jun–Aug)

The red line indicates the weighted linear equation of the relationship between TSV and indoor temperature.

The comparison of the average TSVs in summer vs winter shows a significant difference in neutral temperatures between the two seasons of 2.6 °C. This could be due to a number of factors, such as clothing level and other behaviours.

5.5.3.2 *Gender differences in neutral temperatures*

There is some debate in the literature about the difference in thermal sensation between men and women. Some studies find that women in general are more likely to report thermal dissatisfaction (Schellen et al. 2012), whilst others have found no difference (Karjalainen 2012). To determine whether there was a gender difference in neutral temperature in this experimental cohort, the same linear regression that was previously applied to all votes was performed according to the gender of the participant (Figure 5-12). The neutral temperature for female participants was 22.5 °C, while for males it was 22.9 °C, with no statistically significant difference found between the mean temperatures of male and female neutral votes ($p = 0.35$). Typically, it is reported that neutral temperatures for females are warmer than for males (Karjalainen 2007, Lan et al. 2008); however, this study found no significant difference.

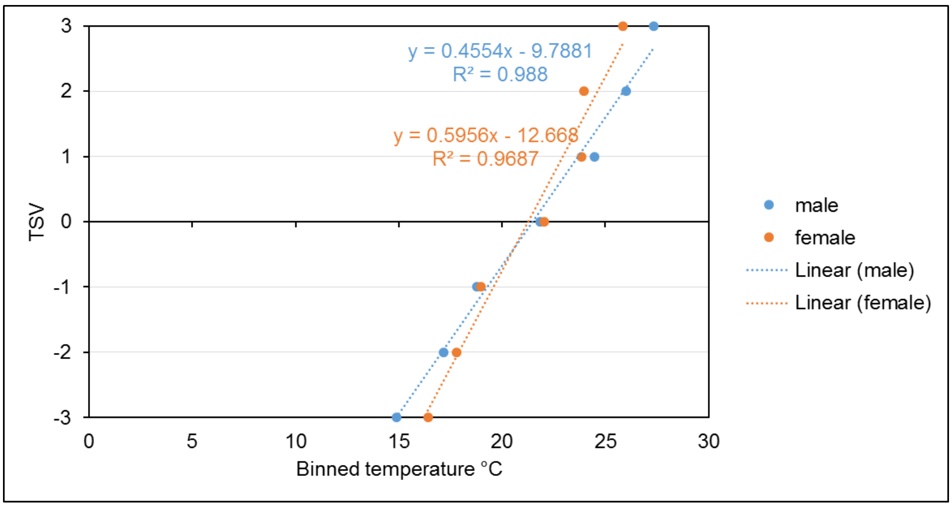


Figure 5-12: Average TSV for each binned °C grouped by participant gender

5.5.3.3 *Age-related differences in neutral temperatures*

A further factor that may have influenced thermal comfort amongst these participants is age. With increasing age, the risk of chronic disease and disability also increases (Fries 1980), which can lead to further decreases in activity level and metabolic rate, which in turn change the way the body experiences temperature. In order to see what effect, if any, age may have on the perception of thermal comfort, the equations from the linear regression analysis for each age group were placed on a single graph for ease of comparison, shown below in Figure 5-13. For the sake of clarity, this graph shows only the linear equations for each age group, a result of linear regression of the TSV/temperature data for each age group.

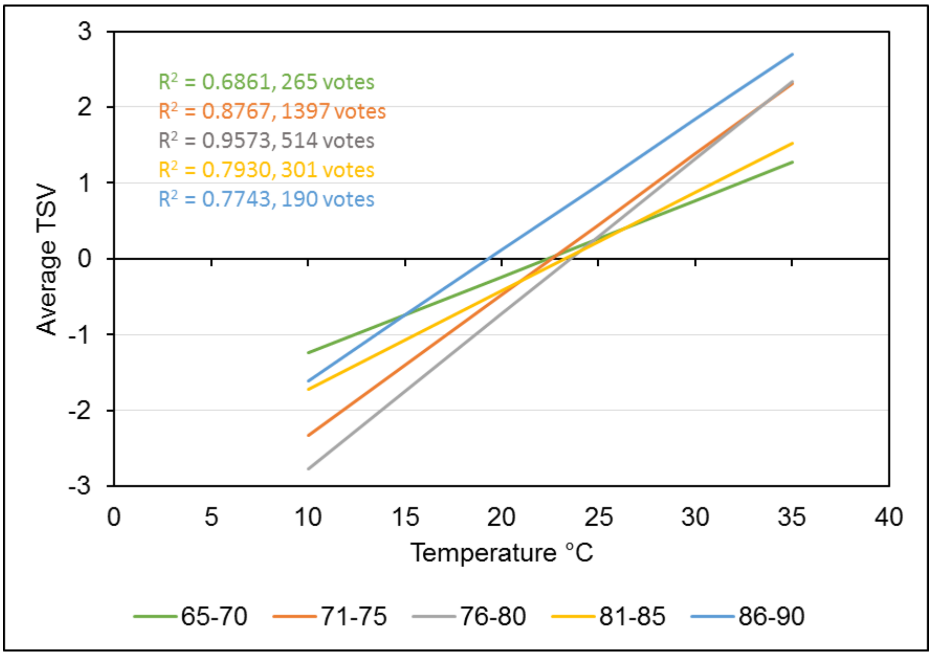


Figure 5-13: Linear regression for each age group of average TSV for each binned °C

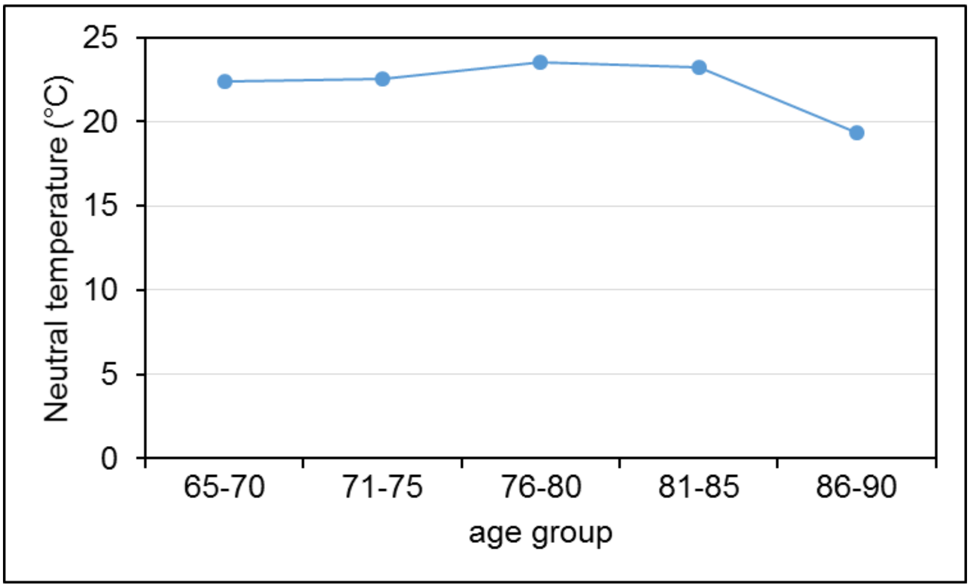


Figure 5-14 Neutral temperatures of each age group, showing the drop at the highest age bracket

The slope of each line gives an indication of the range of temperatures over which participants report neutral thermal sensations. A steeper, more vertical slope indicates a narrower neutral range, whilst a slighter slope, closer to horizontal, indicates a wider range of thermally neutral conditions. In this group, the youngest age group indicated by the green line has the lowest gradient of 0.10, indicating that this age group is more likely to report an acceptable thermal sensation over a wider range of temperatures, as the values of the TSV of –1 and +1 are the furthest apart.

Whilst the lines for the following age groups do not increase in slope in a consecutive manner, the neutral temperatures for those aged 65–85 cluster at approximately the same point, between 22.5 °C and 23.5 °C (Figure5-14). The slope of the line for the oldest participants, aged between 86 and 90, is slightly less than that of those aged between 70 and 80, indicating a slightly wider range of temperatures that correlate to acceptable TSVs. However, most significant here is the shift of the entire line towards the left. This means that the range of acceptable sensation temperatures (–1 to +1) for this age group is lower than that of the other age groups, with the neutral temperature lower at 19.3 °C. A one-way ANOVA with a Tukey post-hoc test found that the mean neutral temperature of the oldest age group was significantly lower than for all other groups ($p<0.05$, data not shown).

Some differences between other groups existed, but not in the consistent manner exhibited by the oldest group.

5.5.3.4 *Seasonal changes in clothing levels*

There were different trends seen in the amount of clothing worn in different seasons. In summer, there was a negative correlation between the clothing vote and the indoor air temperature: as indoor air temperature decreased, the average clothing vote increased. In this section clothing vote has been used rather than clo value due to the slight variations between the male and female clo values in the images on the comfort vote survey. A visual reminder of which clothing vote equates to what clo value can be seen in Figure 5-15.

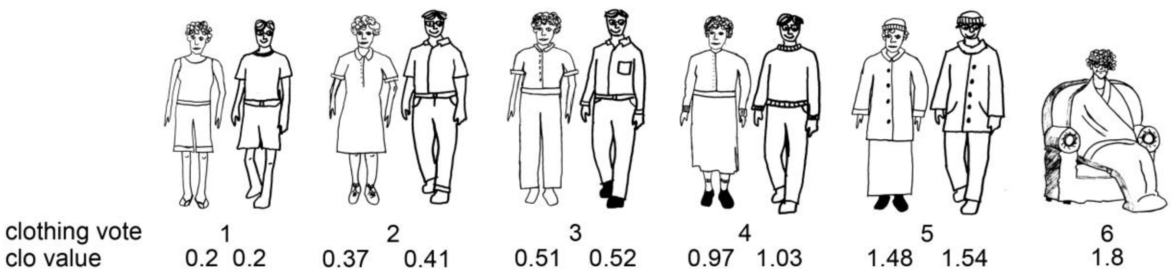


Figure 5-15: Clothing examples from the comfort vote form with the vote number and equivalent clo values

This relationship was confirmed by weighted linear regression to be statistically significant ($P<0.01$). Interestingly in winter, there was no significant change in the clothing vote across different temperatures, with linear regression showing no statistical correlation between the two variables. This was similar to the finding from the general survey. The difference between the seasonal relationships between clothing and indoor air temperature can be seen in Figure 5-16.

Note the low R-squared value for the linear equation for the winter votes, which is due to the lack of variation in clothing votes for this period. During the winter months, 68% of the votes were for the fourth clothing image seen in Figure 5-15, leaving not much data in the other categories. These data suggest that in winter, the participants were less likely to change their clothing in relation to the temperature. It suggests that people's attitude in winter was that they would wear a 'winter outfit' and a type of clothing that was seasonally appropriate regardless of temperature, whereas in summer their clothing varied depending on indoor air temperature.

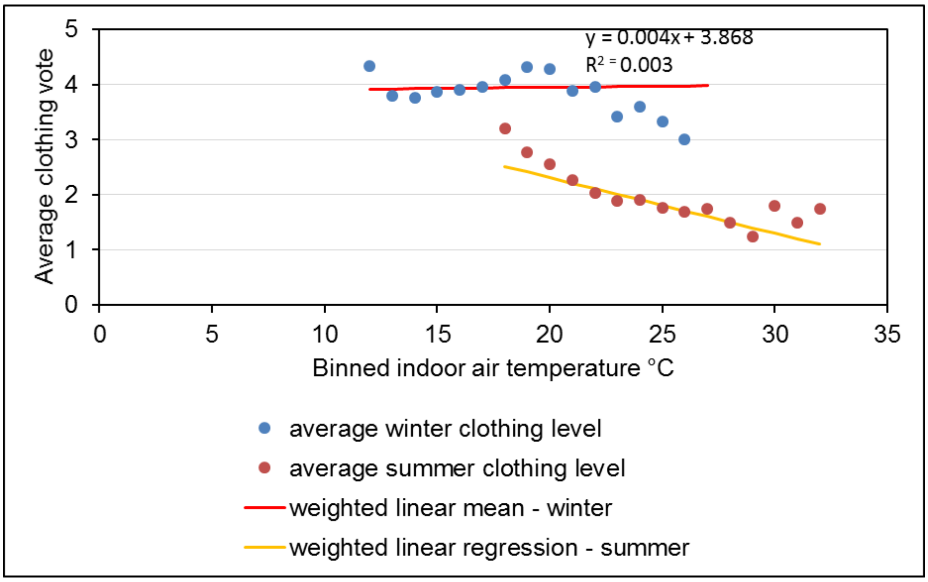


Figure 5-16: The relationship between clothing vote and average indoor air temperature in summer and winter

A similar difference is seen in the summer and winter relationships between clothing and TSV (Figure 5-17).

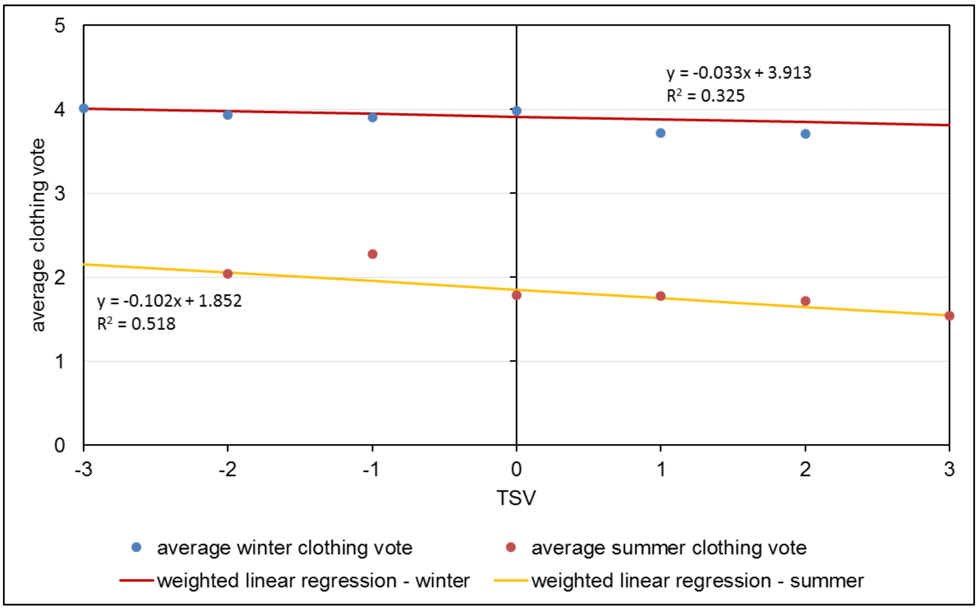


Figure 5-17: The relationship between TSV and average clothing votes in summer and winter

Once again, the relationship between the variables in winter is almost flat, with a lower R-squared value than seen between the variables in summer. An ANOVA test revealed that there was no significant difference ($p>0.05$) in the mean clothing vote number in winter, but that there was a small but significant difference ($p<0.05$) in the means in summer. This confirms that in summer older people are more likely to change their clothing in relation to how they feel than they are in winter, when they tend to wear the same amount of clothing regardless of their thermal comfort. Other studies into the adaptive behaviours of older people have shown the opposite: there is greater clothing adaptation by older people in winter than in summer, when increasing ventilation is more common (Hwang & Chen 2010). The same phoenomenon is seen in younger people (Cao et al. 2011), although this study showed differences in people in different geographic locations, and in people who were more acclimatised to the study region than others. Differences in adaptive behaviour by means of clothing across seasons, climates and cultures may therefore pose a possible area for further research into differences in thermal comfort and health across different groups of older people.

5.6 Thermal acceptability and satisfaction

In the previous section, neutral temperatures were established by using the central TSV of zero only. Whilst this gives an indication of the temperature at which participants will vote for neutral sensation, it does not give any information about what other conditions the occupants find acceptable or comfortable.

There is some discussion in the literature about whether people prefer to feel 'neutral' or to feel some other thermal sensation (Humphreys & Hancock 2007, Van Hoof 2008). There is also discussion about what should be considered 'acceptable' conditions—whether they are those that resemble neutrality of sensation, or those at which people are satisfied with the conditions and have no preference for change in their environment, or whether acceptability needs to be measured in some other way (Fountain & Huizenga 1996). Measures of thermal acceptability are not part of the PMV/PPD model of thermal comfort, which assumes neutrality as acceptability (Fanger 1970).

In this study, participants were asked to indicate their current thermal sensation, their preference for any change in conditions, and also whether the thermal conditions were acceptable to them. This allows comparisons to be drawn between the different potential measures of thermal comfort as well as with established standards of thermal comfort. For ease of expression, a positive outcome for any of these questions (a neutral TSV, no preference for change or thermally acceptable conditions) is referred to as 'satisfaction' or 'satisfactory' in this chapter.

Table 5-4 compares the various measures of satisfaction as measured in the comfort vote survey. It shows the average operative temperature, the average TSV and the percentage of votes that reported the conditions acceptable or not acceptable at each point on McIntyre's 3-point preference scale. A preference for warmer temperatures occurred at temperatures between 12 °C to 27 °C. A preference for cooler occurred at temperatures between 15°C to 35°C. A vote for no preference for change cooler occurred at temperatures between 12°C and 27 °C.

Table 5-4: Average operative temperatures and percentages of votes reporting that conditions were acceptable at each point of the preference scale

	Prefer to be cooler	**Prefer no change**	**Prefer to be warmer**
Average operative temperature	25.5 °C	21.4 °C	16.8 °C
SD	2.7	3.6	2.6
Average TSV	1.55	–0.15	–1.53
SD	0.79		0.93
% find conditions acceptable	67.5%	99.4%	81.2%

These data show that when participants feel cool and would prefer to be warmer, they find the conditions acceptable 81.2% of the time. Conversely, when they feel warm and want to be cooler, conditions are acceptable to them only 67.5% of the time. Whilst the average TSVs for the desire to be cooler and warmer were roughly equidistant from the central vote of zero, there was greater acceptability of cooler sensations than warmer sensations. In addition, overall TSV at times when no change was preferred erred to the cooler end of the 7-point scale (average –0.15), albeit only slightly.

In Figure 5-18 ,Figure 5-19 and Figure 5-20, the differences between the different measures of acceptability are compared and contrasted, showing that, overall, participants found cooler thermal conditions more acceptable than warmer ones. These graphs show the different percentages of satisfied and dissatisfied votes at each degree of binned temperature, depending on the measure of satisfaction. This survey included three such measures: TSV, preference for change and thermal acceptability.

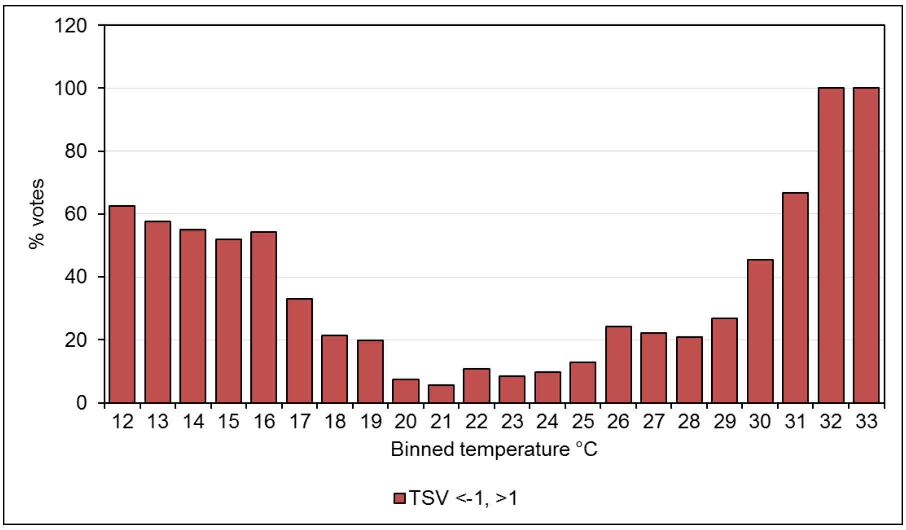


Figure 5-18: Percentage of votes at each binned °C TSVs <–1, >1

When considering TSV as a measurement of satisfaction, acceptability is determined by a vote of –1 to +1 on the 7-point scale. Votes outside of this represent unacceptable conditions. In this measure of occupant acceptability of the thermal environment, more than 80% of acceptable votes occurred between 20 °C and 25 °C (Figure 5-18). More votes recorded unacceptable TSVs at the extreme high end of the temperature scale than at the lower end, with 100% unacceptable votes at 32 °C and 33 °C, as opposed to only 62.5% and 57.7% at 12 °C and 13 °C, which were the lowest temperatures with sufficient votes to be included in this analysis. This indicates, again, a preference toward lower temperatures and lower levels of comfort at higher temperatures.

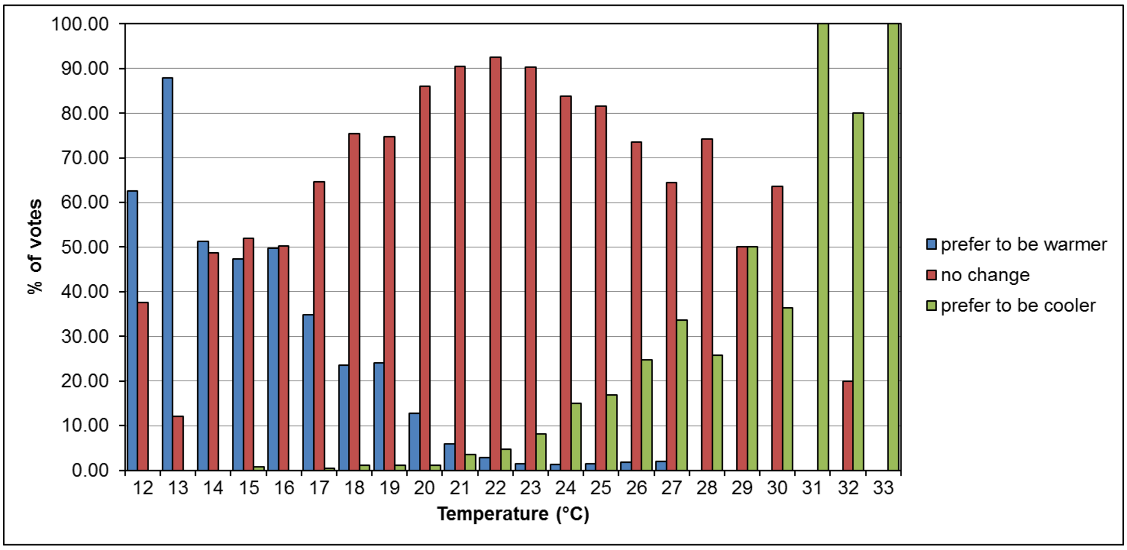


Figure 5-19: Percentage of votes at each binned °C for each point of the McIntyre 3-point preference scale

The second measure of satisfaction asked the participants about their preference for change to either warmer or cooler conditions (Figure 5-19). As temperatures increase, the percentage of votes indicating a preference to be warmer decreases as the preference for cooler conditions increases. The percentage of votes with no preference for change is at its highest (>80%) between 20 °C and 25 °C. Typically, more preference for change was seen at the warmer end of the scale than at the cooler end.

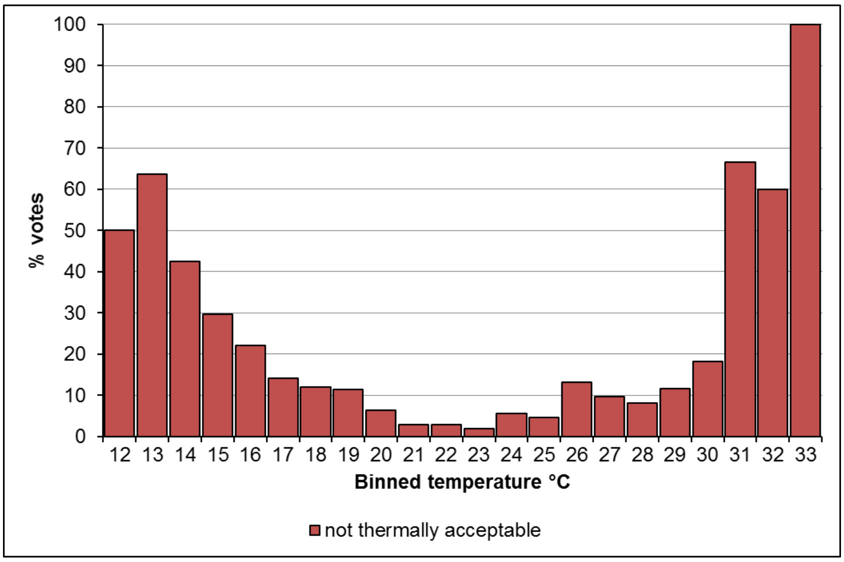


Figure 5-20: Percentage of votes at each binned °C when conditions were deemed 'thermally unacceptable'

When asked, ‘Are the current conditions thermally acceptable?’, participants answered positively over a larger range of temperatures than would seem intuitive, given the information about TSV and preference for change shown previously. Figure 5-20 shows that greater than 80% acceptability was seen in a much wider range than in the other two measures—from between 17 °C and 30 °C. The measure of dissatisfaction, in this case ‘not acceptable’, is once again higher at the warmest end of the scale (33 °C, 100% unacceptable) than at the coldest (12 °C, 50%), although there are some inconsistencies at the extreme ends, where fewer votes were recorded.

This acceptance and preference for cooler conditions over warmer conditions can also be seen when considering the preference for change at each level of thermal sensation. Figure 5-21 shows the percentage of participants, separated by TSV, recording either a preference to be cooler or warmer or a preference for no change. The largest difference in preferences for change can be seen at the extreme ends of the TSV scale. When recording a ‘cold’ vote of –3, respondents reported a preference for warmer conditions 71.6% of the time, with 28.4% expressing no preference for change. This is in contrast with the times when a ‘hot’ vote of 3 was recorded, when 94.1% of participants expressed a desire for cooler conditions (Figure 5-21).

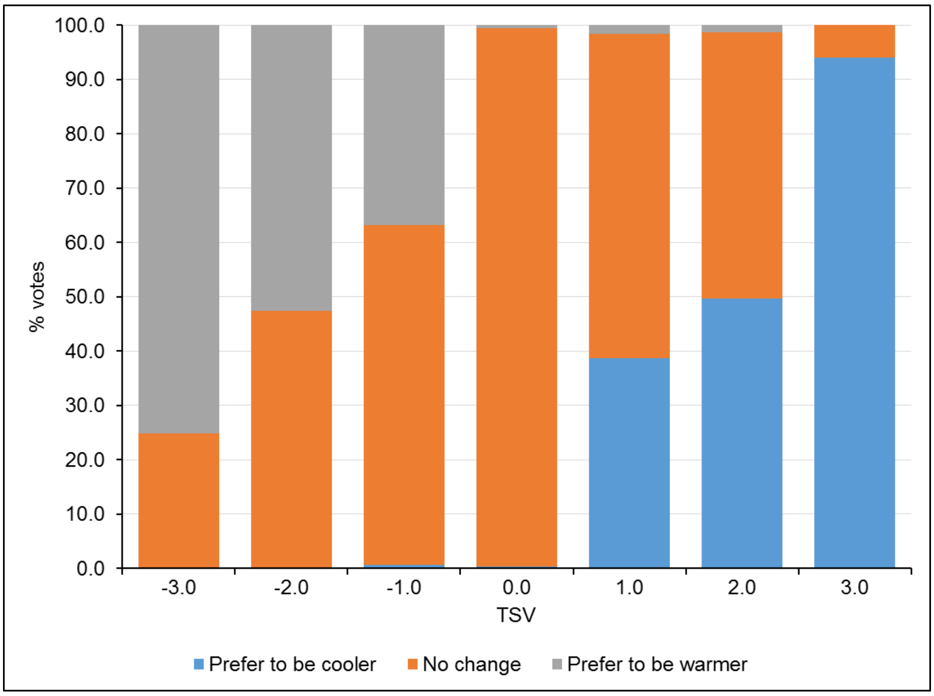


Figure 5-21: Preferences for change at each thermal sensation vote

Another way to look at overall preferences and acceptability is to compare the thermal sensation votes with the percentage of people who find that the conditions are not acceptable or who would prefer change. When examining the acceptability of thermal conditions from TSVs, Fanger (Fanger 1970) concluded that those who vote ±1 or 0 are comfortable, and those who vote ±2 and ±3 are uncomfortable. However, Fanger (1970) noted that not all those who are comfortable are satisfied. Using the PPD equation, at a PMV of 0, there will still be 5% of people who are dissatisfied.

In this study, participants were not specifically asked about 'satisfaction'; however, they were asked about 'acceptability' and 'preference for change'. Figure 5-22 shows the percentages of respondents who indicated either that conditions were unacceptable or that they had a preference for change for each TSV, compared with Fanger's PPD model.

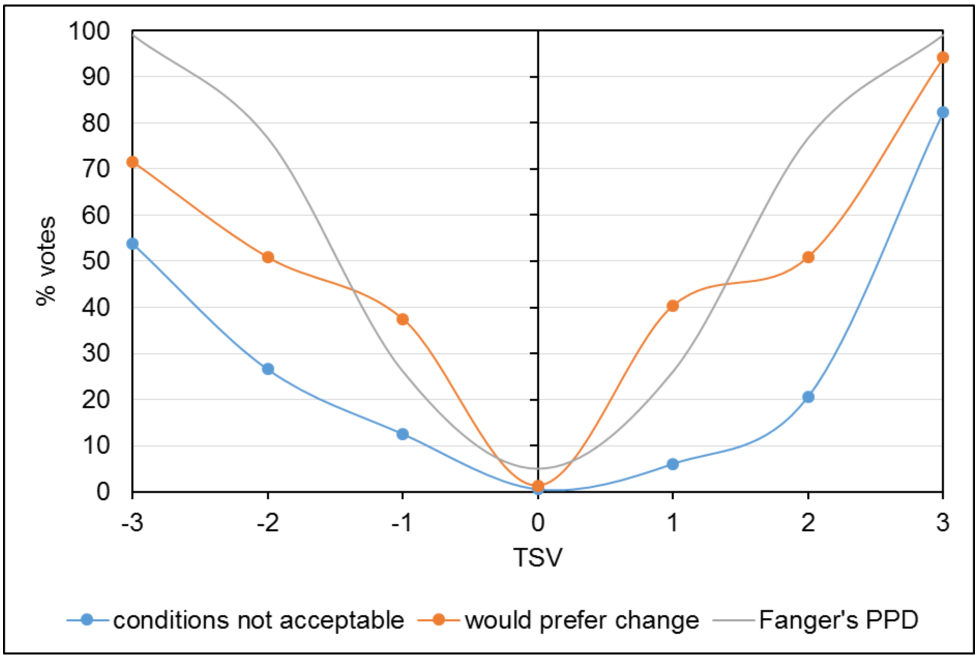


Figure 5-22: Unacceptable conditions (blue), some preference for change (orange) and Fanger's PPD (grey)

Whilst Fanger's model is perfectly symmetrical and assumes equal dissatisfaction with both cold and heat, the results from this study show less acceptability of the positive TSVs, which is the warmer side, than on the negative side, which is the cooler side. This indicates that, overall, participants found lower temperatures more acceptable than warmer temperatures. The 'not acceptable' line consistently has a smaller percentage of people 'dissatisfied' than Fanger's PPD line, indicating a wider range of acceptable conditions than predicted by Fanger's model. The 'preference for change' line, however, does cross the PPD line: more people than predicted by the Fanger (1970) model expressed a preference for change at the supposedly 'comfortable' TSVs of ±1.

It is worth noting at this point that the 'preference for change' measure included both those who would prefer to feel cooler and those who would prefer to feel warmer, at both sides of zero. For a TSV of –1, there were 0.7% who voted that they would still prefer to be cooler despite feeling slightly cool, and for a TSV of 1, there were 1.6% who voted that they would like to feel warmer. At a TSV of –1, there were 37.5% of votes expressing a desire for change, as opposed to the 26.1% predicted by Fanger. At a TSV of 1, there were 40.4% of votes expressing a desire for change, as opposed to the 26.1% predicted by Fanger. This indicates that more people are 'dissatisfied' according to the TSV measure than predicted by the PPD, but only in the TSVs closer to zero.

Overall, this evidence shows that in this cohort, there is a weaker relationship between TSV and acceptability of current conditions than typically predicted by Fanger's model. There is also a distinct skew toward cooler conditions being more acceptable than warmer conditions. Even when voting 'cold' with a TSV of –3, only 71.6% of respondents wanted to feel warmer, and only 53.8% said the conditions were unacceptable. However, for both acceptability and the preference for change, these trends were only seen at the extreme ends of the TSV scale. There were fewer votes at these extremes, which therefore may increase the impact of outliers.

What is clear from these data is that a wide range of conditions is considered 'acceptable', and that, even when there is a preference for a change in conditions, these conditions may still be deemed acceptable. The implications of this and possible explanations can be found in Section 5.9

5.7 Comparison with thermal comfort standards

Thermal comfort standards exist primarily for use in buildings where it is important to keep a large number of people as comfortable as possible. In the home, there are fewer people whose preferences need to be accommodated. Therefore, it is expected that some differences will exist between the experiences of residents in a home compared with the experiences of larger numbers of people in commercial buildings.

There are a number of models in existence which can be used to compare the experience of the participants in this study with predicted comfort conditions, and these models typically comprise parts of the standards by which HVAC systems are designed. These include the ASHRAE Standard 55-2013 (ASHRAE 2013), which includes both the PMV/PPD model and the Adaptive Thermal Comfort model, and the European standard, Comité Européen de Normalisation (CEN) Standard EN 15251–2007 (CEN 2007). Both of these standards include means by which results can show graphically any differences between predicted comfort and that of the actual comfort of participants in this study. In the sections below, results from this study have been compared to each of these models of thermal comfort to determine how well they predict the thermal comfort of older people.

Following the examination of PPD in the previous section, it seems logical to examine how the PMV of the study group compares to the actual votes. For this comparison, the PMV was calculated and the results binned by degrees (°C) and compared with the average TSV for the same bin. Figure 5-23 shows the results of these calculations. Whilst at the very lowest temperatures the average PMV and TSV is almost identical, the regression line for the average TSV is steeper, as the data points move vertically away from the regression line for the PMV. This indicates that participants overall felt warmer sensations than predicted by the PMV model.

Other than at very cold temperatures, this also shows that participants sense lower temperatures as more satisfactory and higher temperatures as less satisfactory, if using TSV as a measure of satisfaction with the thermal environment. This is consistent with the previous finding that the older people in this cohort found lower temperatures more acceptable than higher temperatures.

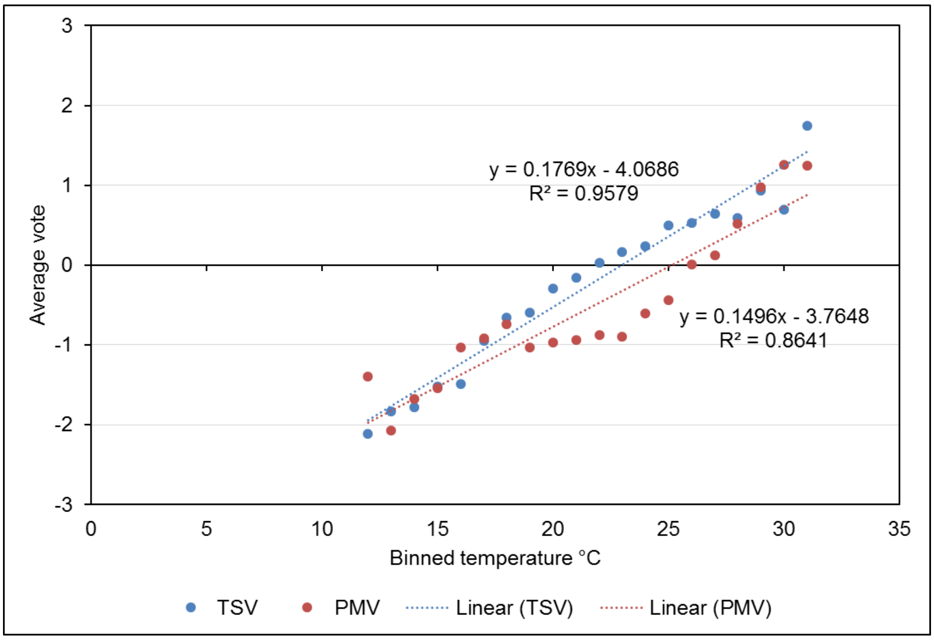


Figure 5-23: Average TSV and PMV at each binned degree of temperature

An alternative method of examining this cohort in relation to the PMV/PPD thermal comfort model is to use the graphical method from ASHRAE Standard 55-2013. By comparing the qualifying TSVs of this cohort to the comfort zone marked on the graph shown in Figure 5-24, the neutral TSVs of the study cohort can thus be compared to the conditions predicted to satisfy the general population. A qualifying vote is one which meets the model's definition of comfort as being ±1 or 0, as well as a metabolic rate of less than 1.5 Met and a clothing insulation value of between 0.5 and 1 clo. Thus, those votes of ±1 and 0 which had clothing scores higher than 4 and activity scores higher than 2 were excluded in this comparison.

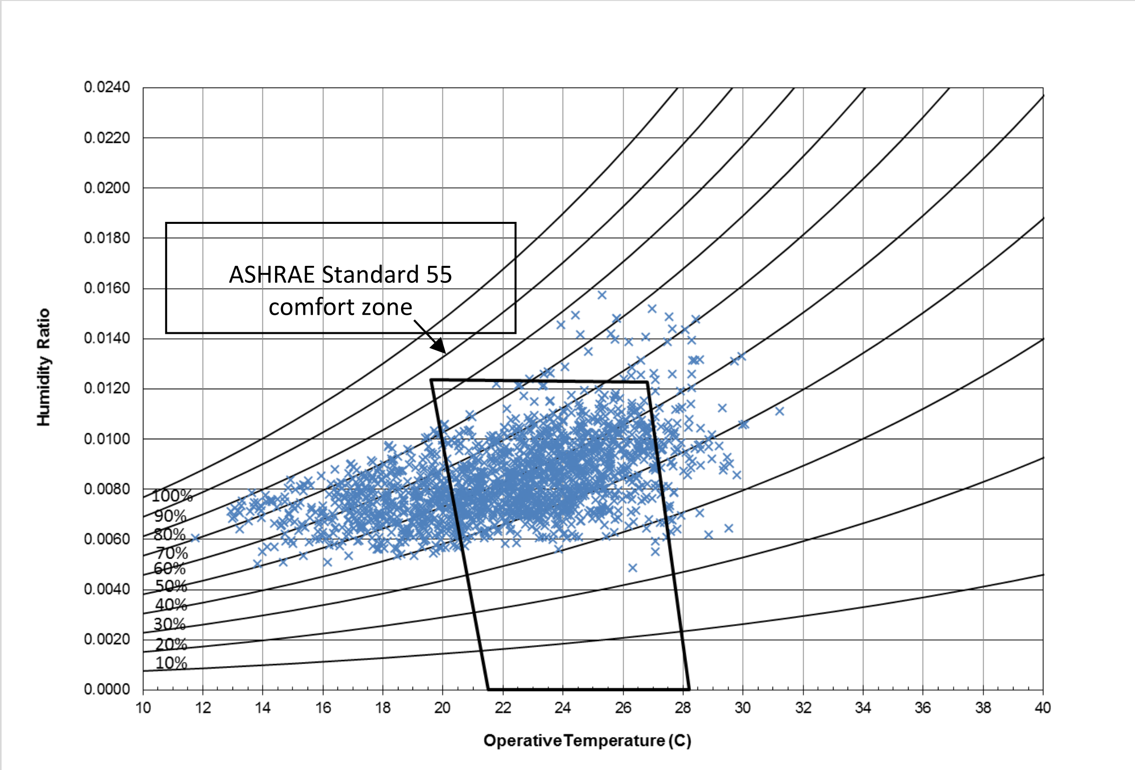


Figure 5-24: Psychrometric chart showing the placement of all qualifying neutral TSVs (n = 1974) for the study period compared to the ASHRAE Standard 55 comfort zone. In this instance, votes include times when heating and cooling is off as well as on

When all TSVs during the study period were plotted, 65% of these votes fall within the zone where conditions meet the ASHRAE Standard 55-2013. The remaining 35% of the votes fall outside of the ‘comfort zone’, with the majority falling to the left, indicating neutral votes cast at temperatures lower than those considered to be thermally satisfactory by the standard.

To determine the influence of seasonal variation on thermal sensation and comfort, the qualifying TSVs cast during the summer months and the winter months were plotted separately. For TSVs cast during the summer months (Figure 5-25), only 18% are outside of the comfort zone, indicating that during these times the thermal sensation and satisfaction of the participants largely matched the model’s predictions.

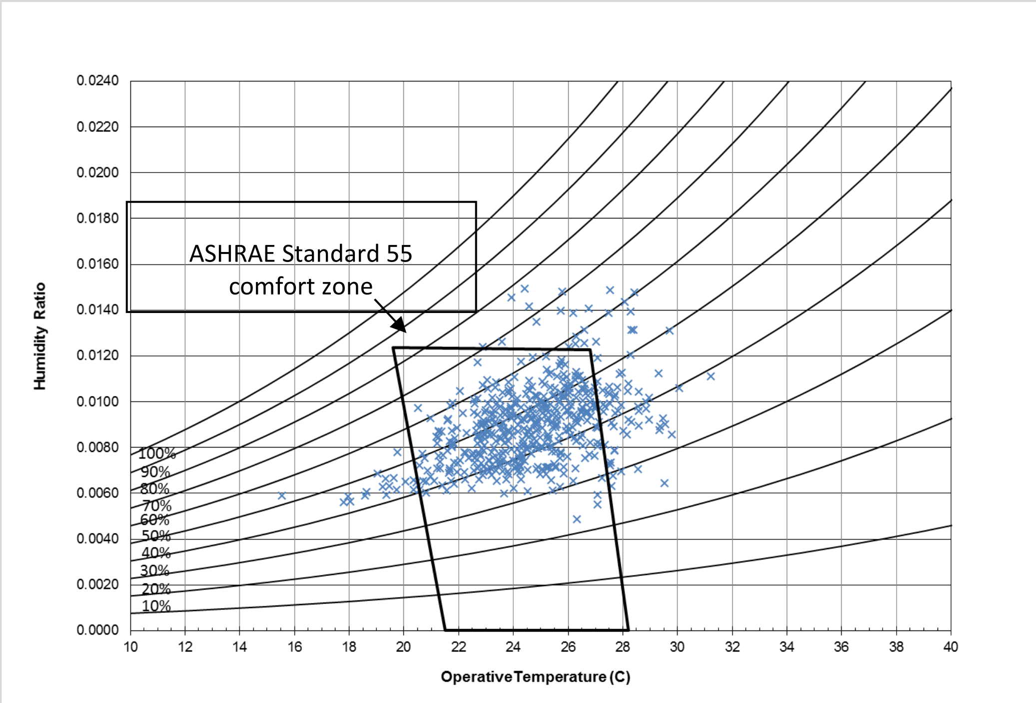


Figure 5-25: Psychrometric chart showing all qualifying neutral TSVs cast (n = 523) during the summer months (Dec–Feb) compared to the ASHRAE Standard 55 comfort zone

In contrast, of the TSVs cast during the winter months, 76% were outside of the comfort zone, all to the left of the predicted comfort zone. This means that thermal satisfaction is reported at temperatures lower than those considered satisfactory by the model (Figure 5-26). This confirms previous findings in this study that the participants will record a TSV that is warmer than predicted by the PMV model, despite cool conditions.

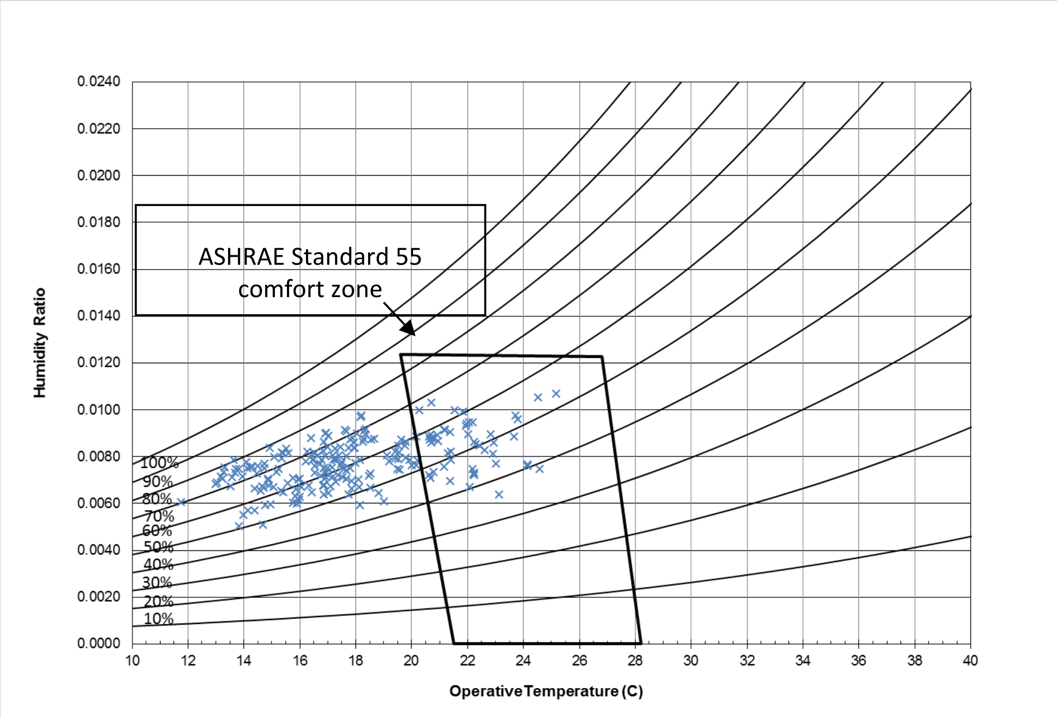


Figure 5-26: Psychrometric chart showing all qualifying neutral TSVs cast (n = 214) during the winter months (Jun–Aug) compared to the ASHRAE Standard 55 comfort zone

The ASHRAE Standard 55-2013 also includes a separate standard for naturally ventilated spaces. Most houses in South Australia do not rely on centralised heating and cooling systems that adjust the temperature in the same way that office and commercial building systems do. The heating and cooling is largely user-controlled in response to conditions in the house (as discussed in Chapter 4). Because of this, the adaptive model of thermal comfort can be applied to the votes during the study period where no heating or cooling was used. The same criteria as in the psychrometric chart were also applied—TSVs of ±1 where clothing and activity values were higher than those specified by the model were filtered out. The results of this comparison can be seen in Figure 5-27.

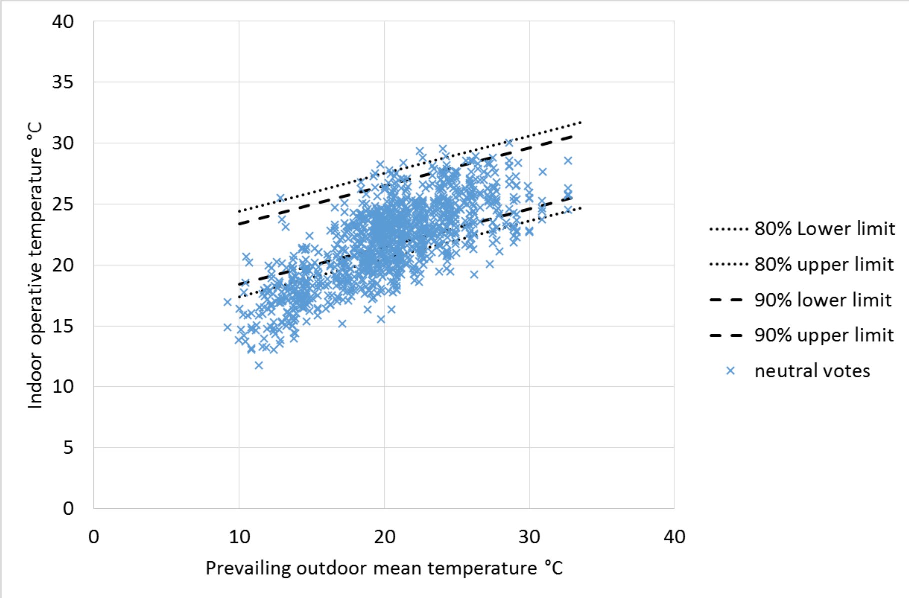


Figure 5-27: Qualifying neutral votes (n = 1153) compared to the Adaptive Thermal Comfort standard from ASHRAE Standard 55-2013

This result shows 31.6% of votes falling below the 80% lower limit and 45.5% of votes falling below the 90% acceptability limits of the model. Also interesting is that whilst the model predicts a linear relationship between prevailing outdoor mean and indoor operative temperature, the best fit for the study data is a non-linear curve, showing that there is a point at which the comfort votes plateau at higher temperatures, rather than continuing in the linear fashion. Only 2.6% of votes fell above the 90% upper limit. This again shows an overall trend to satisfaction at lower temperatures than predicted.

The final model considered for this data set is the European standard EN 15251–2007 which is the Comité Européen de Normalisation (CEN) standard for indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (CEN 2007) this model has different categories for different building types and uses. Category 1 (Cat 1) is for a 'high level of expectation only used for spaces occupied by very sensitive and fragile persons'. Category 2 (Cat 2) is 'normal expectation for new buildings and renovations' and Category 3 (Cat 3) is 'moderate expectation (used for existing buildings)' (CEN 2007, p. 13)

When comparing the votes from this study to the CEN standard, the exclusion criteria specified by the standard for the comfort votes were applied: only votes of ±1 or 0 were included at times when the activity level was reported as 1 or 2 (<1.5 met) and the clothing level was at or below 4 (<1 clo). This standard is applied to homes with no air-conditioning, but it does not exclude heating.

Whilst Category 3 is largely the most applicable in the case of the houses in this study, all categories are included in this comparison, shown in Figure 5-28. This is because it is likely that, at some point, many older people will fall into the Category 1 descriptor of 'sensitive and fragile', due to their advancing age and illness. This category is especially applicable to those living in homes designed specifically for older people, such as retirement villages and independent living units.

When compared to the CEN standard, it is clear that many votes fall outside the prescribed limits. Figure 5-28 therefore had to be adapted from the original standard, which has 19 °C as the minimum indoor operative temperature on the Y-axis, because otherwise many of the data points would not have appeared on the graph. In this case, 45.3% of neutral votes fall below the Cat 3 Lower Limit, 58.9% fall below the Cat 2 Lower Limit and 72.0% fall below the Cat 1 Lower Limit. This means that even for the healthiest individuals, satisfaction with the thermal environment was expressed when conditions were much colder than recommended by the standard.

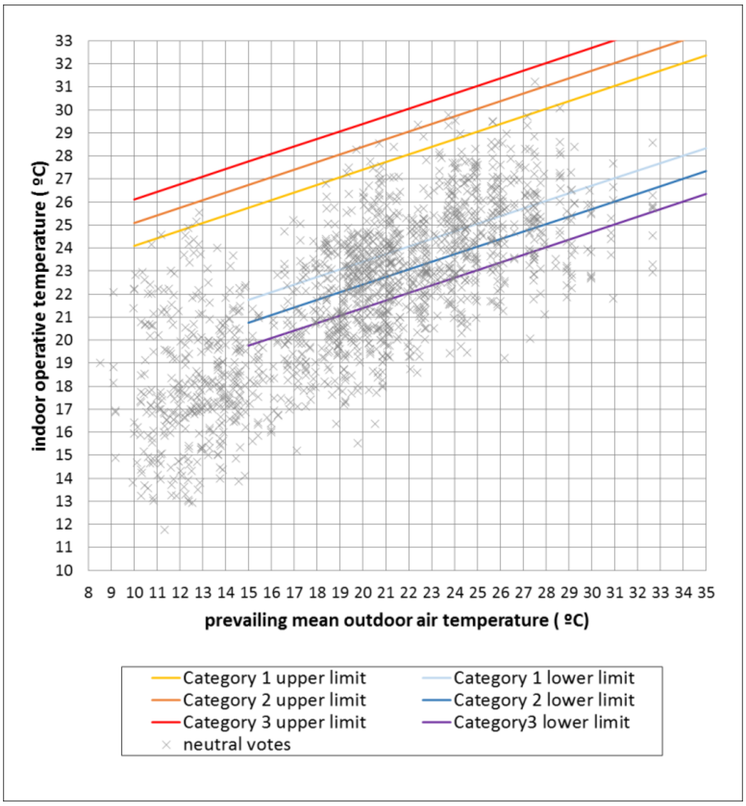


Figure 5-28: Qualifying neutral votes (n = 1151) compared to EN 15251–2007 standard for indoor environmental input parameters for design and assessment of energy performance of buildings

5.8 Thermal comfort, thermal conditions and health

During the study period, 256 thermal comfort votes included a symptom reported by the participant, which is equal to 9.6% of the total comfort vote forms returned. The breakdown of these symptoms can be found in Table 5-6.

There were also instances of participants not reporting symptoms on a comfort vote form the day the symptom occurred, but reporting in the comments that such symptoms had occurred on days when surveys were not filled out. This included instances of falls, which, although listed as a symptom on the form, were never recorded by participants on the day they occurred (Table 5-6).

Table 5-5: Breakdown of the symptoms reported

Headache	19
Dizziness	9
Racing heart	2
Unexplained tiredness	25
Coughing	13
Joint pain	76
Sleeplessness	100
Other	12
Total	256

To determine what relationship thermal comfort and indoor temperature may have with the frequency of symptoms, the TSV and the temperature that occurred at the time the votes were cast were compared as percentages. In terms of thermal comfort, the number of votes where symptoms were recorded is expressed as a percentage of the number of votes cast in total with that TSV (Figure 5-29). In regard to temperature, the logged measurements were binned in 1 °C bins, with each bin representing the temperatures –0.5 °C and +0.4 °C either side. The number of symptoms cast at each binned temperature was then compared with the total number of votes cast for each bin (Figure 5-30).

On initial examination of the votes where symptoms were recorded, there was an unexpected relationship between the percentage of people reporting symptoms and the TSV (Figure 5-29), indoor conditions at the time of completing the comfort vote form (Figure 5-30), and the indoor temperatures over the previous 24 hours (Figure 5-31). The 'neutral' votes actually had higher rates of symptoms than votes at the extreme ends of the thermal sensation scale, and votes cast during periods of colder (<15 °C) and hotter (>26 °C) indoor conditions also had fewer symptoms reported than those cast during more moderate conditions. Given that the indoor conditions showed a relationship to the outdoor conditions, and given that numerous studies have shown that outdoor temperatures are related to symptoms, morbidity and mortality (Analitis et al. 2008, Bi et al. 2011, Inglis et al. 2008, Rocklöv, Ebi & Forsberg 2011), this result was surprising and seemed contradictory to established trends.

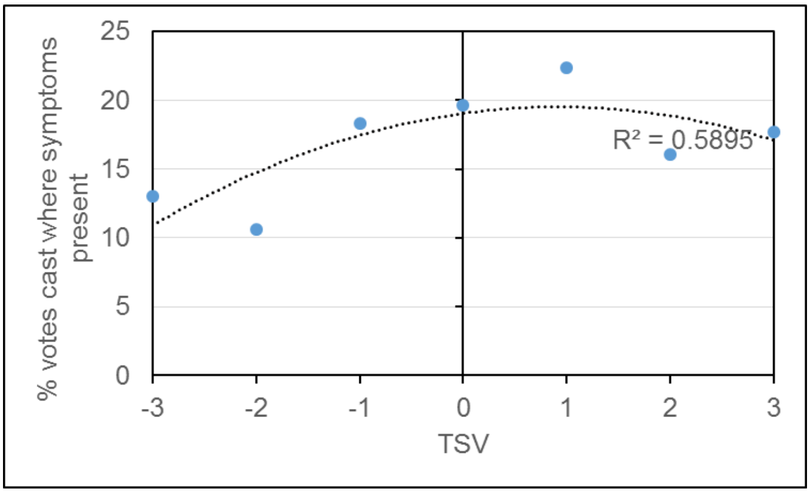


Figure 5-29: Percentage of votes where symptoms were reported at each thermal sensation vote score

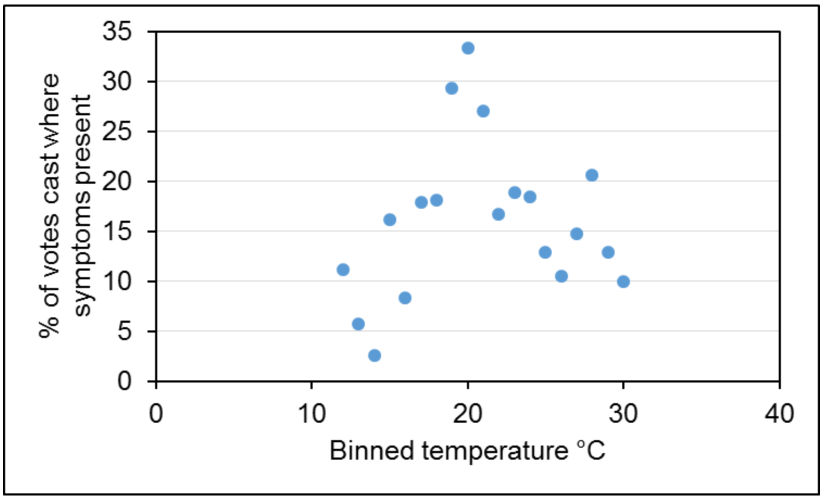


Figure 5-30: Percentage of votes at each binned °C at time of casting vote where symptoms were present in all participants

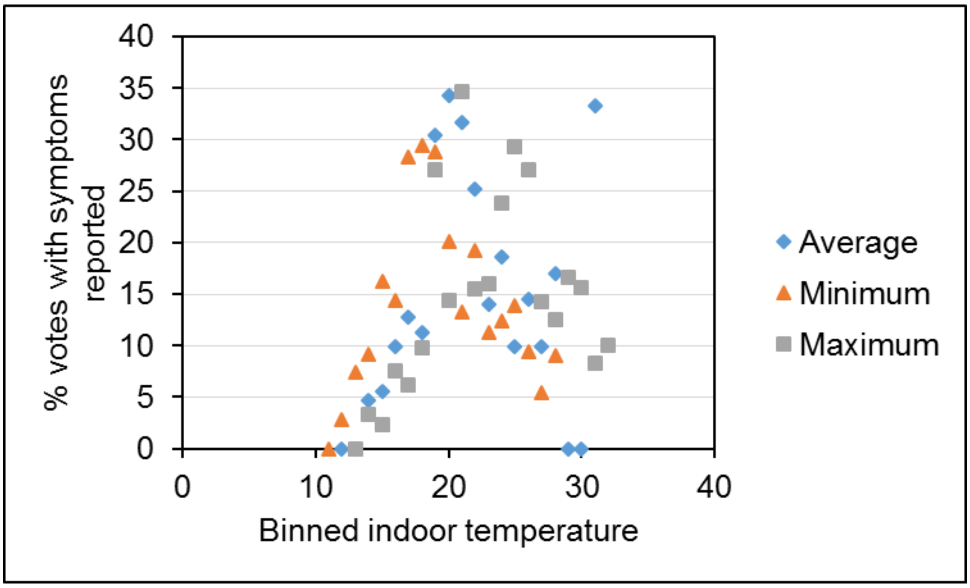


Figure 5-31: Percentage of votes with symptoms amongst all participants at binned average, maximum and minimum °C for the previous day

There were, however, a number of participants who suffered from chronic health conditions, which is not unexpected, given the age range of the cohort. Some of the conditions these participants had meant that they indicated suffering from symptoms every day, regardless of temperature. This meant that it was possible that these data were masking the effect of temperature on the participants who were otherwise healthy.

For this reason, to determine the effect, if any, that the indoor conditions were having on the frequency of symptoms, those suffering chronic symptoms (indicated by at least one symptom being indicated in every comfort vote form cast) were excluded from some analyses. This allowed the effect of indoor conditions on those who were otherwise largely healthy to be analysed and determined.

Figure 5-32 shows the results of the percentage of votes where symptoms were reported in 1 °C bins of indoor temperature at the time of the comfort vote being cast. With the symptoms of chronic sufferers removed, a curve emerges, indicating fewest symptoms at 17.2 °C, with the number of symptoms increasing on either side of this temperature.

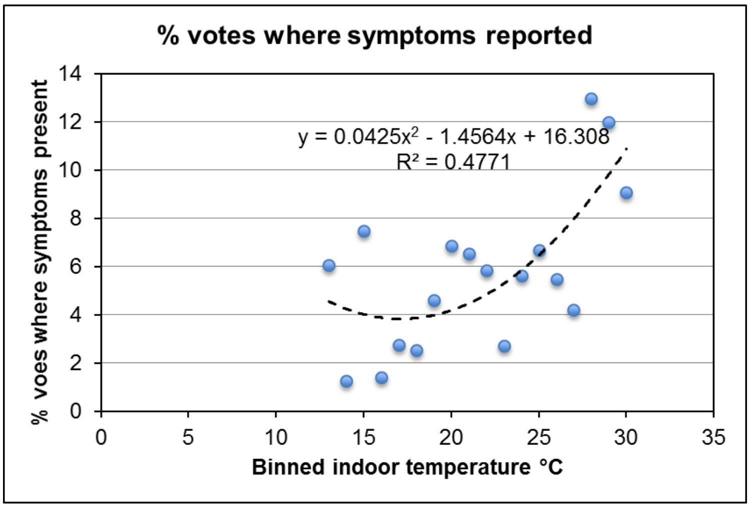


Figure 5-32: Percentage of votes at each binned °C at time of casting vote where symptoms were present in usually healthy participants

A similar result can be seen in Figure 5-33, which compares the percentage of votes reporting symptoms amongst healthy participants with the thermal sensation vote. A marked increase in symptoms can be seen when the TSV becomes positive, indicating slightly warm–hot sensations. There is also an increase in symptoms at times of negative thermal sensation votes; however, this curve is not symmetrical around the neutral vote of zero. The lowest point of the curve sits at –1.3, just to the left of the 'slightly cool' TSV. Regression analysis showed these results to be significant ($p<0.01$). To determine whether the curve see was an artefact of fewer votes being cast at the extreme ends of the 7-point scale, weighting was carried out but found the resulting line to be very similar to the unweighted line (Figure 5-34). This indicates the relationship is significant even though there were fewer total votes for cold (-3) and hot (3).

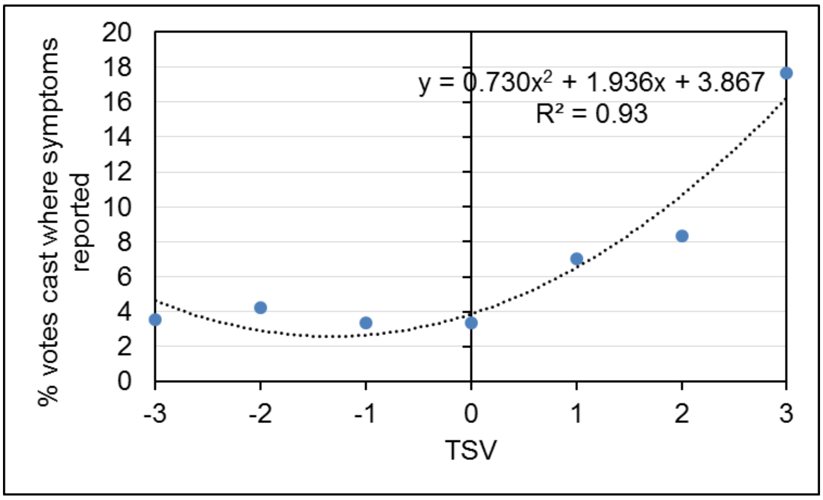


Figure 5-33: Percentage of votes where symptoms were reported at each thermal sensation vote score amongst otherwise healthy participants

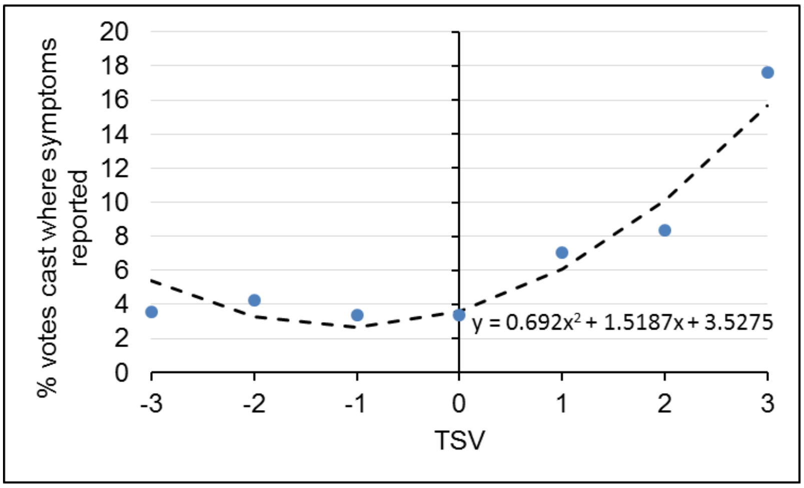


Figure 5-34: Percentage of votes where symptoms were reported at each thermal sensation vote score amongst otherwise healthy participants, with regression weighted to account for low numbers of votes at -3 and 3.

As the question in the survey covered 'any symptoms in the previous 24 hours', these measures at a single moment in time, whilst interesting, say little about what influence the conditions prior to casting the vote may have had on the health of the occupant. To further understand these influences, the daily minimum and maximum temperatures for the previous day were matched to those votes where symptoms were recorded, and binned by 1 °C. The results of this analysis are shown in Figure 5-35.

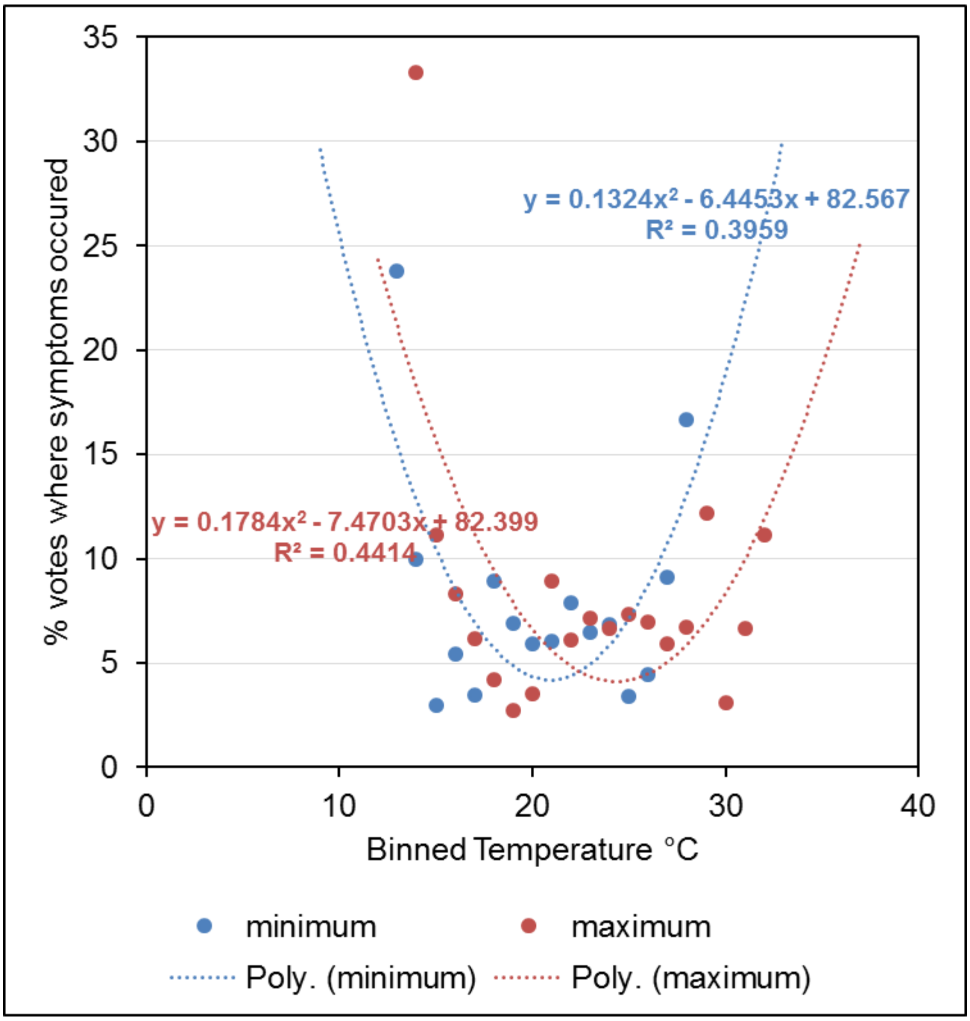


Figure 5-35: Percentage of votes with symptoms amongst otherwise healthy participants at binned maximum and minimum °C for the previous day

‘Poly. (minimum)’and ‘Poly. (maximum)’ refer to the trend lines that fit the data, with the equations of these lines in the colour that corresponds to the colour of the line. Regression analysis in Microsoft Excel found that, though the R-squared values are low, these results are statistically significant for both variables ($p<0.05$).

Overall, this analysis indicated that these findings demonstrate that participants were more likely to suffer symptoms at extremes of temperature, with hot and cold maximum and minimum temperatures both related to an increased incidence of symptoms being reported.

Because of the relatively small number of symptoms reported by those with non-chronic conditions, it was not possible to analyse the presence of symptoms in summer compared to winter. Instead, the indoor temperatures of the homes of those who did suffer symptoms were plotted, along with the occurrence of their symptoms. This allows the conditions in the house for each individual to be examined, in order to determine what trends (if any) might precede the occurrence of symptoms and thus give insight into what conditions should be avoided to best maintain good health. These plots of temperatures in individual houses (Figure 5-36,Figure 5-37, 5-34, Figure 5-39 andFigure 5-40) show different time periods, due both to the different times that monitoring was carried out and the different times that symptoms were recorded.

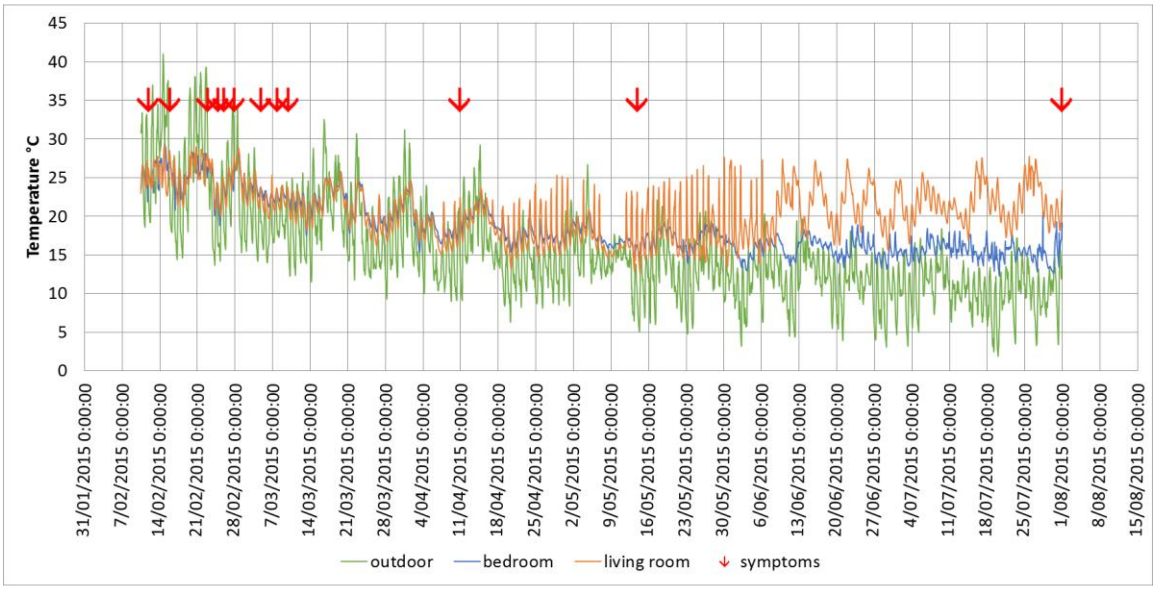


Figure 5-36: Temperatures and the occurrence of symptoms amongst occupant/s of House 13

In House 13 (Figure 5-36), a cluster of symptoms can be seen in February 2015, when Adelaide experienced several days with a maximum temperature of over 35 °C. The next time a symptom occurred was after a series of low outdoor minimum temperatures in April 2015. Later in April, the participant started using heating regularly, as indicated by the daily spikes in the living room temperatures. In early May, these temperatures plateau for around five days.

Plateaus like this typically indicate that the occupants are away, as—even when occupants are home but not using heating or cooling—there are still swings in temperature that are not seen when the house is unoccupied, due to the activities of the occupants. Following this period of absence, symptoms reappeared. The final occurrence of symptoms was in late July, after several days when the outdoor minimum temperature had fallen below 10 °C, with some days below 5 °C. Bedroom temperatures at this time remained between 15 °C and 18 °C, whilst living room temperatures were higher and fluctuated more widely. The pattern change in living room temperatures during June was probably due to a change in heating patterns. As this house had a slow-combustion heater installed, the participant may have started using it during June, thereby changing the rate at which the temperature oscillated.

The temperatures in House 7 (Figure 5-37) fluctuated much more widely in the living area than in the bedroom, for two main reasons. First, the main living area in this house was an addition, constructed of lightweight materials rather than the heavier double brick of the rest of the house including the bedroom. The living room therefore had less thermal mass than the rest of the house and consequently the temperature fluctuated more widely.

Second, this was the main living area for this occupant, who spent most of the day in this room. Over the winter period, the room relied heavily on heating to keep this occupant comfortable. In mid-July the occupant was away for a weekend, where a short plateau in temperatures occurred. Following this, the occupant reported symptoms. Later in July, a symptom occurred after a day that was warm by July standards, followed by a return to colder conditions, with maximums below 15 °C.

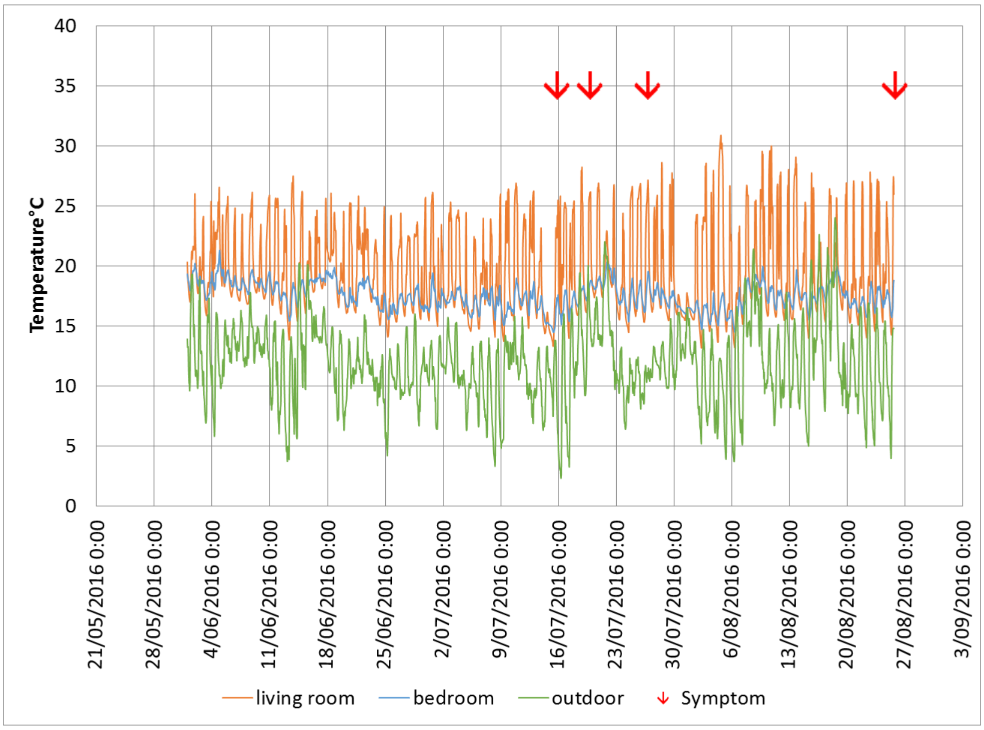


Figure 5-37: Temperatures and the occurrence of symptoms amongst the occupant/s of House 7 during cold months

In the same house during the warmer months, the variation in living room temperature is not as extreme as seen in winter (Figure 5-38). This suggests that in winter, the occupant used the heater a lot, but that heat was not retained well when the heating was off. In summer, there was less variation, as the occupant used air-conditioning only during periods of very hot weather, when outdoor temperatures exceeded 35 °C.

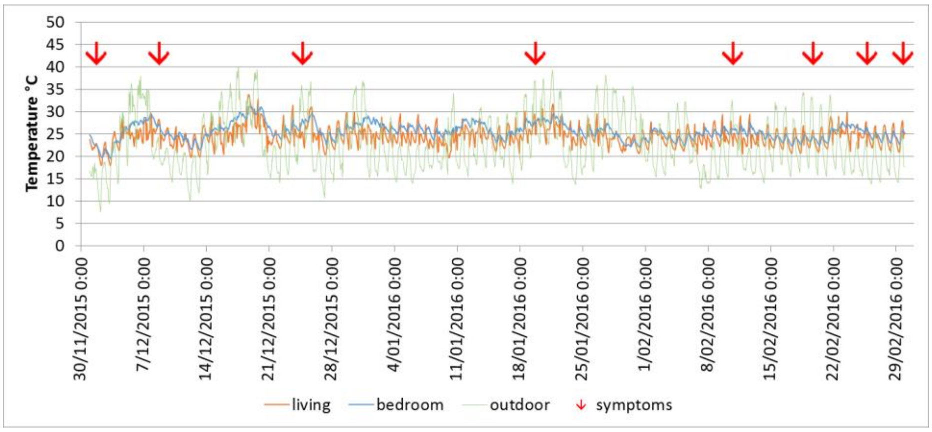


Figure 5-38: Temperatures and the occurrence of symptoms amongst the occupant/s of House 7 during warm months

In regard to the presentation of symptoms, the pattern is slightly irregular, but symptoms often occurred when the indoor living room temperature reached 30 °C. Of note here is that the bedroom temperature did not drop below 20 °C, and symptoms also occurred after periods when the bedroom temperature did not drop below 25 °C overnight. This is consistent with research that suggests that a lack of lower overnight temperatures which offer relief from high daytime temperatures can be more strongly related to health problems than high daily maximum temperatures (Loughnan, Carroll & Tapper 2015, Nicholls et al. 2008).

The temperature in House 12 remained fairly stable, with only small fluctuations, until early May 2015, when outdoor temperatures dropped and it is evident that the occupants had switched on the heating in the living room (Figure 5-39). There was a cluster of symptoms in April, when the outdoor temperature dropped suddenly after being moderate, with a maximum of 22 °C immediately followed by a maximum of 15.5 °C. There was a lag of a few days before symptoms appeared in this instance, which is not unusual where cold weather is concerned (Anderson & Bell 2009, Braga, Zanobetti & Schwartz 2001).

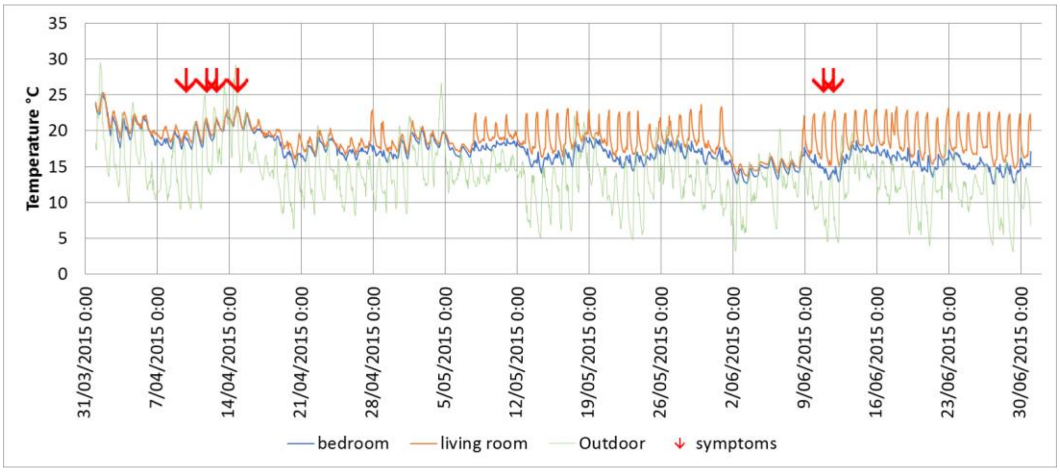


Figure 5-39: Temperatures and the occurrence of symptoms amongst the occupant/s of House 12

The consistent indoor temperatures in June indicate that the occupants were away for around 10 days, and this was confirmed in comments written in their comfort vote surveys. As previously noted, after a period of being away, when the house was not heated, symptoms appeared after a lag of two or three days.

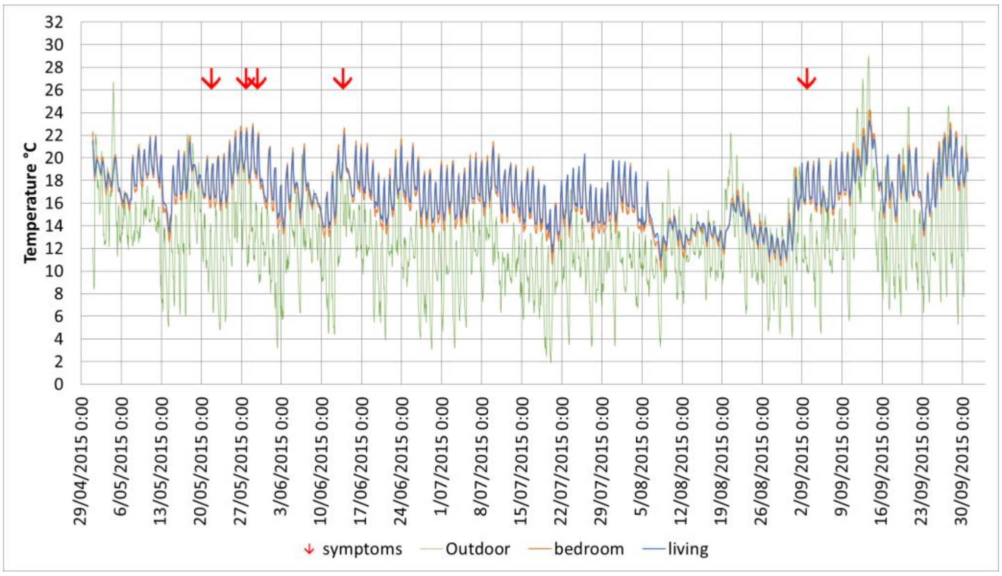


Figure 5-40: Temperatures and the occurrence of symptoms amongst occupant/s of House 3

The occupant of House 3 recorded his first symptoms during May and June (having reported no symptoms previously during summer), each time following a period of cold outdoor minimum temperatures despite relatively stable indoor temperatures. This participant was particularly active, and frequently out of his house during the day, which may explain an exposure to the outdoor temperatures which was less common amongst other older people. Again, the participant reported a symptom in September after an approximately month-long absence during which he had recorded being overseas.

This participant also noted that he was hospitalised immediately on his return, due to a deep vein thrombosis—a condition unrelated to the symptom he had reported just after returning. This shows the complications of examining reported symptoms using this method without taking into account other life events taking place.

A limitation of examining trends in symptoms in relation to both indoor and outdoor temperature is the reliance on self-reported symptoms for this information. This is problematic for a number of reasons. First, such analysis requires the participant to remember any instances of symptoms over the last 24 hours, however brief. Second, not all participants completed surveys daily, which could mean that symptoms occurred during the study period that did not get recorded, thus rendering the data set incomplete. The same can be said even for those who did complete votes every day, but who were away for a period of time: no survey data were recorded during these periods, and symptoms may have started whilst they were absent.

Despite these limitations, these data still provide an overall picture for each individual house. These act more as case studies, which give an overall sense of what was occurring in each house as a subjective explanation of the broader objective measures shown previously.

What these data show is that the relationship known to occur between outdoor temperatures and morbidity and mortality is likely to be linked to the indoor temperatures of older peoples' houses. Given the correlation between the outdoor and indoor temperatures shown earlier in this chapter, this is not surprising; however, it does suggest that houses may not adequately protect residents from extreme conditions. There is thus a need to examine why this is the case and what can be done to improve the conditions indoors in order to attempt to improve the health and comfort of the occupants.

5.9 Analysis of results

The analysis of the field study data is presented in two parts. First, in this section (Section 5.9), the results detailed above will be analysed in order to determine the range of conditions that can be considered both acceptable and healthy. These conditions will be presented as a model for the simulation experiments. Second, in Section 5.10 the differences between groups within the cohort—such as the differences between males and females, or between those who live alone and those who live in multi-person households—will be examined, in order to determine what differences exist and how they should be accounted for in the model conditions.

5.9.1 Optimising thermal comfort and health

In this study, three measures were used to ascertain comfort or satisfaction with the thermal conditions in the house: TSV, preference for change and thermal acceptability. In order to determine the best range of conditions for the comfort of the largest number of people, a binomial curve was fitted to each measure of satisfaction. Regression analysis showed these to be significant ($p<0.01$ for all cases). The resulting equations for each satisfaction measure were then modified using what-if analysis, so that the maximum of the curve was the same as the maximum satisfaction expressed in the field study data. These equations were then graphed. The results are shown in Figure 5-41.

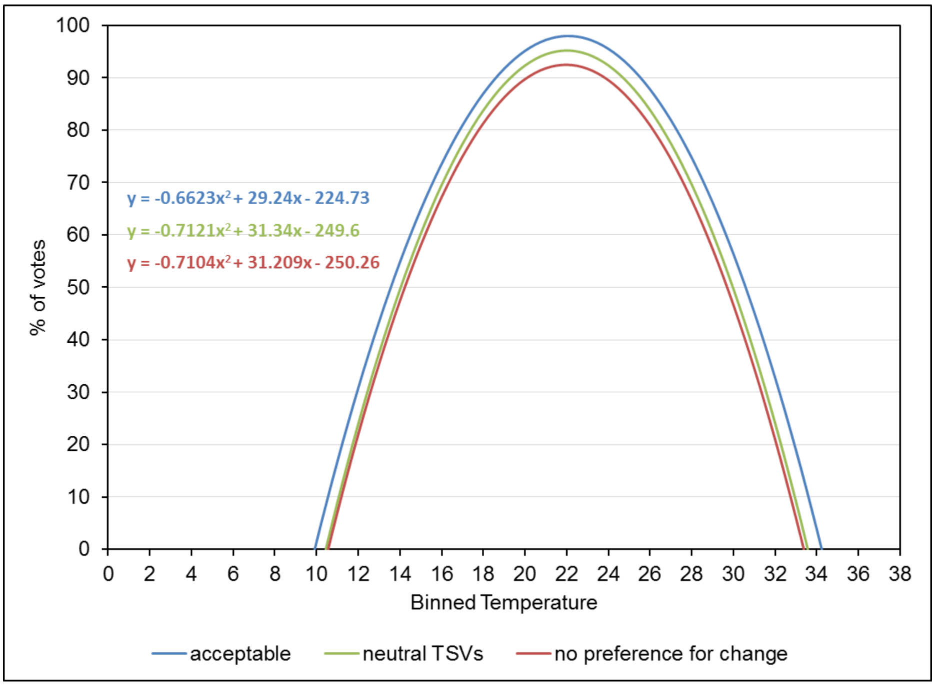


Figure 5-41: Binomial equations and resulting curves for measures of satisfaction in the comfort vote survey: neutral TSVs, acceptable conditions and no preference for change, expressed as percentage of satisfied votes at each binned °C of indoor temperature

Figure 5-41 illustrates the differences in levels of expressed satisfaction with the thermal conditions depending on how a question is worded in the comfort vote survey. A participant might prefer to feel cooler but still deem the conditions acceptable. Indeed, the 'acceptable' curve is the widest, indicating that a wider range of conditions might be deemed 'acceptable' than 'comfortable'.

Whilst this may appear to be simply an exercise in semantics, it is important to examine why these differences occur. Providing occupants with acceptable conditions may not always mean that they are comfortable, and when one considers the link between thermal comfort and the presence of symptoms shown in Section 5.8, this may pose a problem in regard to health.

By solving for *y* in each of the equations in Figure 5-41, the predicted temperatures at which a given percentage of votes would be 'satisfactory' can be determined for each of the measures. Results are shown in Table 5-6.

Table 5-6: Temperatures at which the given percentage of votes are predicted to be satisfactory

	90% satisfied		80% satisfied	
	Low temperature	High temperature	Low temperature	High temperature
Acceptable thermal conditions	18.6 °C	25.6 °C	16.9 °C	27.3 °C
Neutral TSV	19.3 °C	24.7 °C	17.4 °C	26.6 °C
No preference for change	20.1 °C	23.8 °C	17.8 °C	26.2 °C

To model the predicted effect of the thermal conditions on health, a similar protocol for the symptom data was followed to that used for the satisfaction data. The binomial equation generated from the data shown in Section 5.8 was used to predict the minimum and maximum temperatures at which the fewest symptoms were likely to occur (Figure 5-42).

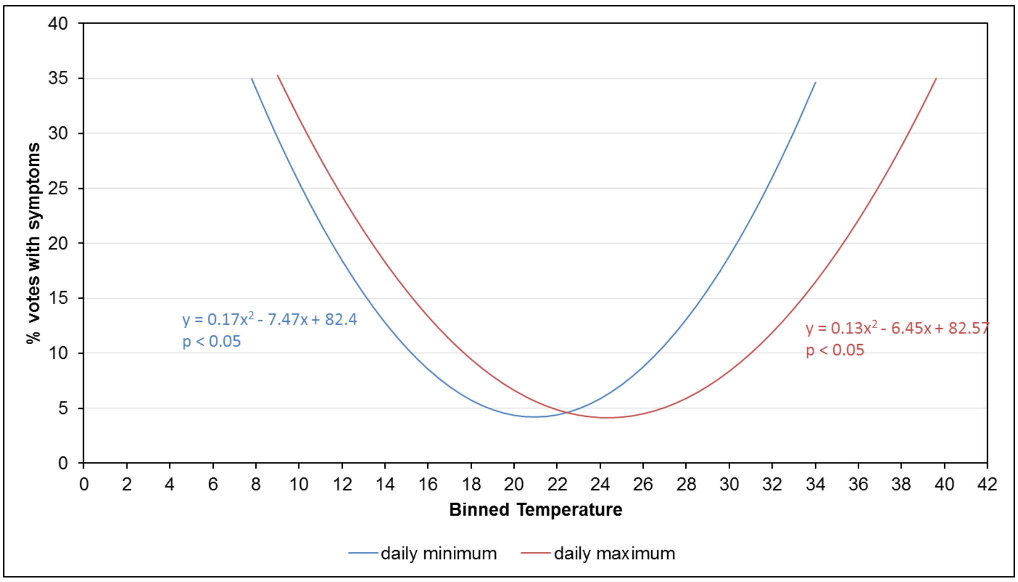


Figure 5-42: Binomial equations and resulting curves for the predicted percentage of votes with symptoms for minimum and maximum daily temperatures

The point at which the lines of the equations cross in Figure 5-42 represents the point at which a constant temperature would be related to the fewest symptoms. The intersection of these lines occurs at 22.4 °C, where it is predicted that 4.6% of votes would present with symptoms. This temperature falls within the ranges of predicted satisfactory conditions for each measure of satisfaction. It also falls within the range of temperatures suggested by the WHO as being healthy for mostly sedentary people (WHO Working Group 1982). This means that, for the most part, the conditions preferred by the participants in this study were not related to the presence of heat- and cold-related symptoms. It also means that using the predictions from the measures of satisfaction should create an environment with the lowest relationship to these symptoms (Figure 5-43).

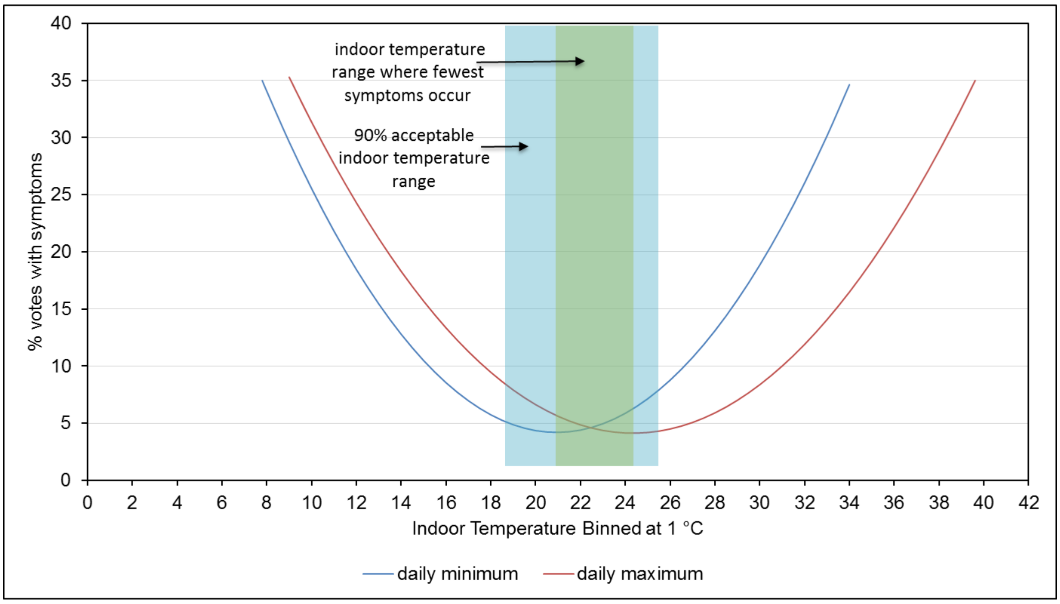


Figure 5-43: Acceptable conditions overlaid with the suggested temperature range found in this study

It is, however, simplistic to imply that all houses should be kept at 22.4 °C consistently throughout the year. For instance, when not relying on heating or cooling, the adaptive model of thermal comfort predicts that the comfortable indoor temperature is reliant on the outdoor temperature, indicating a change in thermal expectations across different seasons. Some shifting of indoor temperature will almost always occur naturally, due to warming from the sun during the day and cooling overnight.

If the lines in the equations in Figure 5-43 are solved for the lowest point on the curve, a range of temperatures which should minimise heat- and cold-related symptoms can be generated. The lowest point on the curve falls at 21 °C for the daily minimum, and the lowest point on the curve for daily maximum temperature falls at 24.3 °C. This model therefore suggests aiming for an indoor minimum temperature of 21 °C and an indoor maximum of 24.3 °C, so as to minimise the times when indoor thermal conditions linked to an increase in symptoms are present.

It is worth noting that the thermal comfort of sleeping individuals is more complex than that of those who are awake. The ambient temperature has less effect on the thermal comfort of a sleeping person than the immediate temperature of the bed environment, which is determined by the insulation of bedclothes. However, the ambient temperature of a room has been shown to have an effect on sleep quality, which may also influence thermal comfort whilst asleep and thermoregulation changes when entering different sleep cycles (Haskell et al. 1981, Muzet et al. 1983). It is also impossible to replicate the results of the current study with sleeping individuals.

For these reasons, the proposed range of 21 °C and 24.3 °C is a suggestion for the living area of the house only. As two-thirds of the votes where symptoms were reported were recorded in the living area, with a similar proportion of overall votes also recorded in the living area, this will be the focus of the simulation component of this study, which will be examined in Chapter 6.

5.9.2 **Current house conditions compared to proposed range**

Once a temperature range related to the fewest symptoms has been determined, it remains to examine how the houses in this study perform when compared to these parameters. The measured number of hours when the temperature was lower than 21 °C, between 21 °C and 24.3 °C, and above 24.3 °C, as recommended by the previous section, can be seen in Table 5-7.

This table shows that in most of the participating houses, temperatures were lower than recommended more often than they were either within the recommended range or higher than recommended. On average, houses had lower than recommended temperatures 47.8% of the time, with the temperature in eight of the houses being in this cold zone for more than half of the time. These readings are from typical occupant use of the house and therefore include any heating and cooling practices of the participants.

Only two houses had higher than recommended temperatures higher more often than they had lower than recommended temperatures, one of which housed an individual with specific heating needs due to a medical condition. The occupant of the other house was conscious of their HVAC use, wanting to remain in credit with their solar provider and not use much electricity. This occupant also lived alone and could therefore heat and cool the house to their individual desires without interference from anyone else.

From this point on in this research and moving forward, the aim is to determine whether it is possible to adapt these houses and the HVAC systems such that the temperature is within the recommended range for more time, with the temperature in the lower range, especially, for less time, but also in the higher than recommended range for less time.

Table 5-7: Percentage of hours during which the temperature was lower than, within, and higher than the temperature guidelines proposed by the study across all houses

House #	% hours at lower than recommended temperatures	% hours within recommended range of temperatures	% hours at higher than recommended temperatures
1	33.4	48.1	18.5
2	29.6	56.1	14.3
3	57.4	22.5	20.1
4	49.0	30.7	20.3
5	67.1	16.8	16.1
6	63.6	19.8	16.6
7	38.5	34.3	27.2
8	59.3	27.0	13.7
9	45.9	28.3	25.8
10	26.7	42.2	31.1
11	45.1	37.2	17.7
12	47.7	32.2	20.1
13	56.3	24.8	18.9
14	60.6	29.2	10.2
15	58.9	21.6	19.5
16	25.2	29.7	45.1
17	45.0	36.0	19.0
18	51.9	27.5	20.6
Average	47.8	31.3	20.8

5.10 Factors relating to comfort

Whilst the values in the previous paragraph have been calculated on the entire cohort, there are important factors which relate specifically to comfort amongst different groups. This section examines differences in comfort amongst those who live alone compared to those who live with a partner or other family members. It also examines some of the differences between males and females in terms of their comfort as well as in terms of their clothing and activity levels.

5.10.3 Living alone vs living with others

In a residential environment where the occupants have control of thermal conditions, it is possible that the thermal preferences of two or more occupants might not be the same. In this case, one person might sacrifice their comfort for the sake of another, or conditions might be set that offer a compromise between the occupants' preferences. These potential circumstances prompted an examination of the comfort of those who live alone compared with those who live with one or more other people. The average TSV, preference vote and acceptability vote for both groups was calculated and compared using a Student's t-test to determine whether any differences were statistically significant. The results of this are shown in Table 5-8.

Table 5-8: Student's t-test calculations showing measures of satisfaction in single households and multi-person households

	Single		**Multi-person**		***p***
	Mean	SD	Mean	SD	
TSV	0.09	0.99	-0.36	1.31	<0.01
Preference vote	0	0.45	0.09	0.51	<0.01
Acceptability vote	1.07	0.25	1.14	0.34	<0.01

Overall, those who live on their own have an average TSV closer to zero, indicating 'just right' conditions. They are also less likely to report a preference for change, and to have an average acceptability vote slightly closer to 1, the value assigned to 'acceptable' votes. The differences between the two groups are small but significant, indicating that those who live on their own are more likely to express satisfaction with their environment than those who live with one or more other people.

Given that a single occupant can keep a house 'how they like it', this seems an obvious conclusion. However, it can have drawbacks if a person who lives alone has a preference for conditions that are colder or warmer than is ideal for their health. In particular, there is a concern for the welfare of older women who live alone, for whom illness and death from cold-related causes is higher (Bright et al. 2014).

5.10.4 **Males vs females**

As mentioned in Section 5.5.3.2, there was no statistical difference between the neutral temperature of male and female participants. There was also no statistical difference between the average TSV of male and female participants, the means of which were –0.23 and –0.29 respectively (Figure 5-12). There were, however, small but significant differences in the average acceptability and average preference for change between the sexes. Males were slightly more likely to indicate that conditions were unacceptable, with an average vote of 1.14 (SD 0.34) compared to 1.09 (SD 0.29) for females—and, although small, this difference is statistically significant ($p<0.01$). There was also a statistically significant ($p = 0.016$) difference in the mean preference for change vote, with an average vote of – 0.09 (SD 0.52) for men and 0.05 (SD 0.47) for women.

A breakdown of the percentage of votes in each category can be found in Table 5-9.

Table 5-9: Percentages of votes at each point of the preference scale separated by sex

	Men	Women
No preference for change	72.1%	78.1%
Prefer to be warmer	9.2%	8.5%
Prefer to be cooler	18.6%	13.3%

Overall, men were more likely to express a preference for change than women, and this was twice as likely to be a preference for cooler conditions than warmer conditions. Women were also more likely to express a preference for cooler rather than warmer conditions than men, though the difference was smaller and fewer women overall expressed a desire for any change in conditions.

These results indicate that, overall, men are more likely to express dissatisfaction with the thermal conditions than women. The greater preference for cooler conditions than for warmer ones is consistent with the previous findings that, overall, the participants in this study preferred a cooler environment than predicted.

There are several reasons that might explain a difference between the thermal comfort for males and females. Some of these are physiological, which are beyond the scope of this study, as these measurements were not taken. However, factors such as activity level and clothing level were evaluated via the comfort vote survey and can also influence comfort.

Table 5-10 shows the differences between clo values and metabolic rate, as calculated from the participants' comfort vote surveys of their clothing level and activity level.

Table 5-10: Differences between clo values and met values of male and female participants

	Males		**Females**		**p**
	Mean	SD	Mean	SD	
Clothing (clo)	0.51	0.37	0.7	0.38	<0.01
Activity (met)	1.59	1	1.45	0.9	<0.01

Men on average had a lower clo value, suggesting that they typically had lower clothing insulation than women. Men also had a higher average metabolic rate, suggesting a greater level of physical activity than women on average. Once again, these differences are small but statistically significant. A higher metabolic rate and lighter clothing do make sense together; however, this does not explain the slightly higher neutral temperature previously calculated, or the greater level of dissatisfaction with the thermal environment. There were equal numbers of men who were living in multi-person households as there were women, so this does not account for the difference, either. It is possible that the observed differences lie in physiological or psychological differences not accounted for by the data available.

5.11 Summary

This chapter presents the results of a field study into the thermal comfort and health of a group of South Australians aged 65 or older. It examines how these participants experienced the thermal conditions of their houses and what their overall comfort preferences were. Through examination of average neutral temperatures, satisfaction and acceptability measures, it is concluded that, overall, older people in South Australia may prefer a slightly cooler indoor environment than predicted. The preferences of this cohort are cooler than predicted by the ASHRAE Standard 55-2013, the Adaptive Thermal Comfort standard and the European CEN standard.

Examination of the data collected regarding symptoms showed a binomial relationship between symptoms and both TSV and temperatures. In regard to temperatures, both minimum and maximum temperatures appear to have a relationship with the frequency of symptoms. Symptoms were fewest at a minimum indoor temperature of 21 °C and a maximum indoor temperature of 24.3 °C. These conditions fall within the range of conditions at which 90% of people are predicted to have no preference for change in thermal conditions as determined by the collected data. Thus, this temperature range will be what is aimed for in the building improvement component of this study, the results of which will be discussed in the next chapter.

An important caveat is that these statistics show correlation and not causation. It may well be that the indoor thermal conditions are only part of the story and that other unmeasured factors are influencing the presentation of symptoms in these participants. However, the conditions associated with the fewest symptoms will be aimed at from this point onwards, with the intention that they may reduce the presentation of symptoms. This reduction may not be as dramatic as the model predicts due to other related factors, but the author believes that it is in the best ethical interests to reduce the factors which are known to be related to the presentation of symptoms.

In practice, if these temperatures did not see a reduction in the number of symptoms presenting, further examination of the factors surrounding these symptoms would need to be undertaken.

CHAPTER 6

Results of a building improvement study

6.1 Overview

The results in Chapter 5 indicate that the houses in this study do not provide optimal thermal performance, with the temperature of most houses being lower than recommended between 30 and 67% of the time during the field study. Ideally, a house will be designed from the start of its life to create a healthy and comfortable thermal environment. However, when this is not the case, the retrofitting of features that can improve building performance is possible and may provide a cost-effective means of creating an optimal thermal environment.

This chapter presents an investigation into some of the houses from the field study and the predicted effects of building improvements, as studied through the use of building performance simulation. The aim of this research was to determine whether simple design changes to houses could bring about conditions more conducive to thermal comfort which were also related to conditions that may reduce the presentation of symptoms among the occupants. Ideally, these changes would bring with them less reliance on air-conditioning and heating, with an overall increase in energy efficiency, leading to lower energy costs. The intended outcome of the research was to produce recommendations regarding what kind of housing improvement should be conducted for preventive health measure purposes.

It is necessary to find a balance between the conditions favoured by older people (which Chapter 5 of this thesis found to be cooler than those predicted by existing thermal comfort standards) and conditions that are warm enough to prevent cold-related symptoms during the winter months. Any changes made also need either to be of low initial cost or to pay for themselves quickly in terms of energy savings, as older people typically have a fixed and often low income.

The housing conditions produced through building improvements will be compared to the range of healthy temperatures suggested in the previous chapter, and further compared to WHO guidelines (WHO Working Group 1982) about appropriate thermal conditions for older people. This range (18 °C to 24 °C) is related only to heating, and is not a recommendation for summer temperatures. Furthermore, a recent systematic review found no evidence that indoor temperatures higher than 24 °C pose any significant threat to health (Head et al. 2018). Therefore the WHO recommendations will be used only for comparisons of minimum temperature, below 18 °C. The range of temperatures that were predicted in the previous chapter (referred to from this point on as ‘study parameters’) to minimise the presence of symptoms was a minimum of 21 °C and a maximum of 24.3 °C. The guidelines from this study are a 24-hourly recommendation; however, there are some instances where it is appropriate to examine and alter only the occupied hours and yet still address the 24-hourly temperature recommendations.

6.2 Building improvement experiments

As detailed in Chapter 3, the process of testing the effect of building improvements via computer simulation involved four steps: modelling, calibration, base performance modelling, and analysis of building improvements. Buildings were modelled in the building simulated software and the resulting model was calibrated by comparing the predicted indoor temperatures to the measured indoor operative temperature in the case study buildings during the study period. Once the predicted indoor temperatures of a model matched with the measured data from the actual house modelled with an acceptable discrepancy (a CV(RMSE) of <10%), the calibrated model was then analysed in regard to how the house performed during a typical meteorological year; how frequently the indoor conditions were higher or lower than the temperatures recommended both in Chapter 5 and by the WHO; and what implications this had for electricity usage. Changes to the building fabric were then simulated within the calibrated model to examine the effect of design features such as increased insulation and double glazing on the internal temperatures and electricity use of the building. The impact of occupant behaviours on the needs of energy use due to patterns of heating, cooling and ventilation were also studied on their own and in combination with building improvements.

6.2.1 **Calibration of simulated houses**

Each of the five chosen houses was modelled and calibrated according to the method set out in Chapter 3. Where possible, houses were calibrated when they were unoccupied for an extended period, in order to minimise the effect of human behaviour on the modelled performance of the house. Further details about the appearance and material properties of each building can be found in Appendix F.

6.2.1.1 *Double brick attached independent living unit (House 4)*

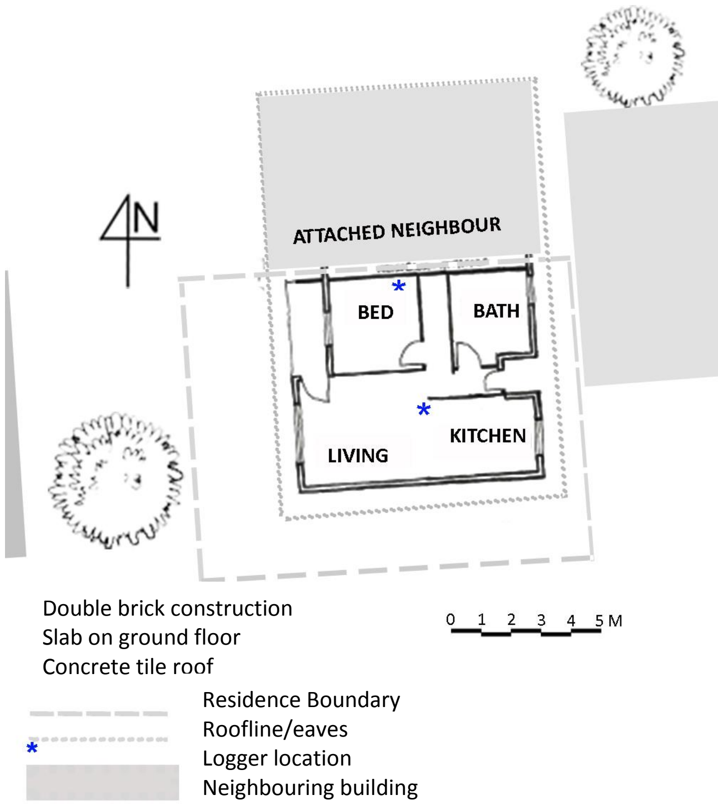


Figure 6-1: House 4

House 4 (Figure 6-1) was in the same complex as House 10 (Figure 6-4) and was essentially one half of the same plan. There are some important differences between the two houses, however. House 4 had a wall-mounted reverse cycle system installed in the living room, and this was the only heating or cooling available in the house, whereas House 10 had a ducted system. The main window of both the living room and the bedroom also faced west rather than north, as in House 10.

The occupant of this house was absent for some time in October 2015, which allowed for a very accurate simulation to be created with limited human activity affecting the building. Subsequently, the CV(RMSE) of the predicted vs measured temperaures in these rooms is very small, with values of 2.8% for simulated vs measured temperatures in the living room (Figure 6-2) and 3.3% for simulated vs measured temperatures in the bedroom (Figure 6-3). It should be noted that in this house and subsequent houses, the peaks of the simulated conditions are often sharper than the measured conditions. The simulation software consistently underestimated the thermal mass of the simulated buildings and the precise reason for this is unknown, however it may be due to factors such as furnishings.

Figure 6-2: Simulated and measured indoor temperatures of the main living area of House 4

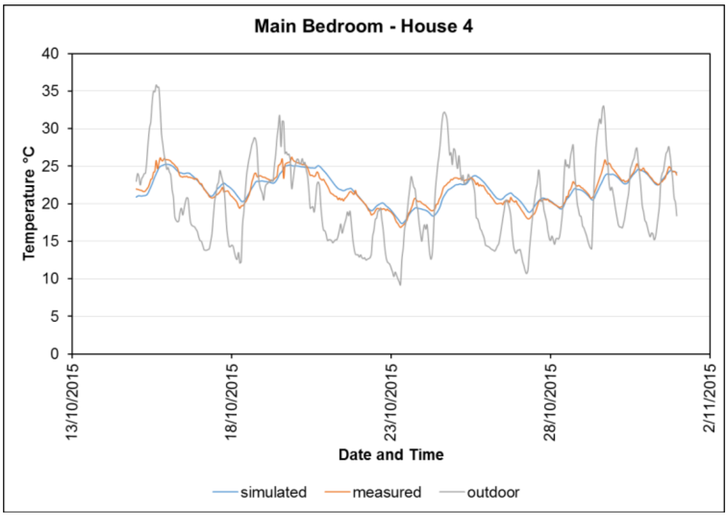


Figure 6-3: Simulated and measured indoor temperatures of the bedroom of House 4

6.2.1.2 *Double brick detached independent living unit (House 10)*

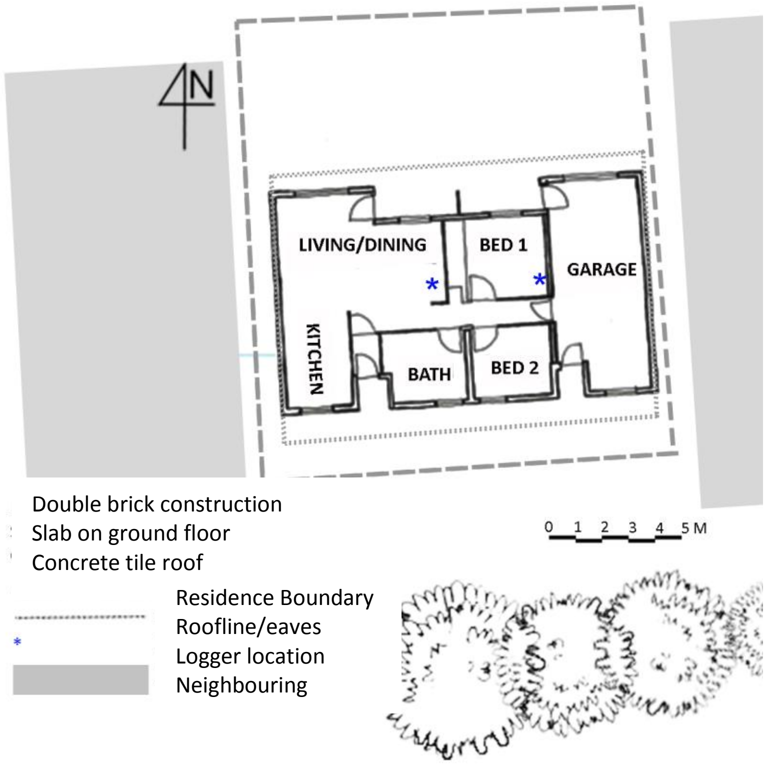


Figure 6-4: House 10

House 10 (Figure 6-4) was calibrated over a 10-day period in October 2015. During this time, no heating or cooling was noted on the comfort vote surveys. However, comfort votes were not completed every day during this time. One of the occupants of this particular house was very sensitive to cold, and it is possible from looking at the measurements in this house that heating was being used at some points during the calibration period which corresponded with lower outdoor temperatures. The places where heating was likely switched on (and where, therefore, the measured temperature deviated significantly from the simulated temperature) are indicated on the Figures 6-5 and 6-6 with a star (*).

As there was no period when the occupants were absent during the field study, it was not possible to calibrate this house during a true period of free running when no occupant behaviour would affect the results. Even so, this model is still calibrated within the acceptable margins, with CV(RMSE) results of 7.1% and 7.6% for simulated vs measured temperatures living room (Figure 6-5) and the bedroom respectively (Figure 6-6).

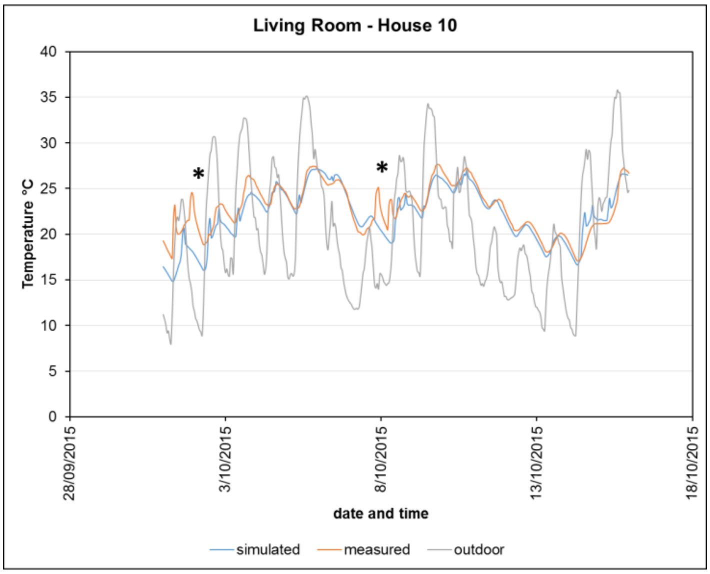


Figure 6-5: Simulated and measured indoor temperatures of the living area of House 10

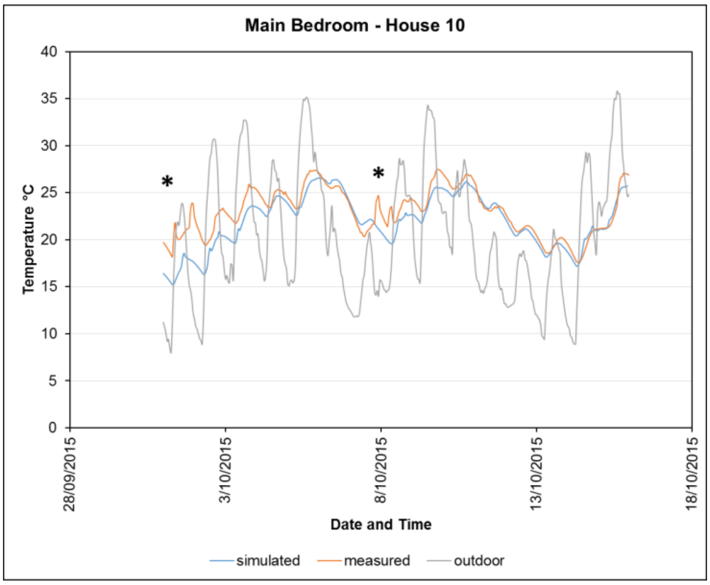


Figure 6-6: Simulated and measured indoor temperatures of the main bedroom of House 10

6.2.1.3 *Brick veneer detached house (House 12)*

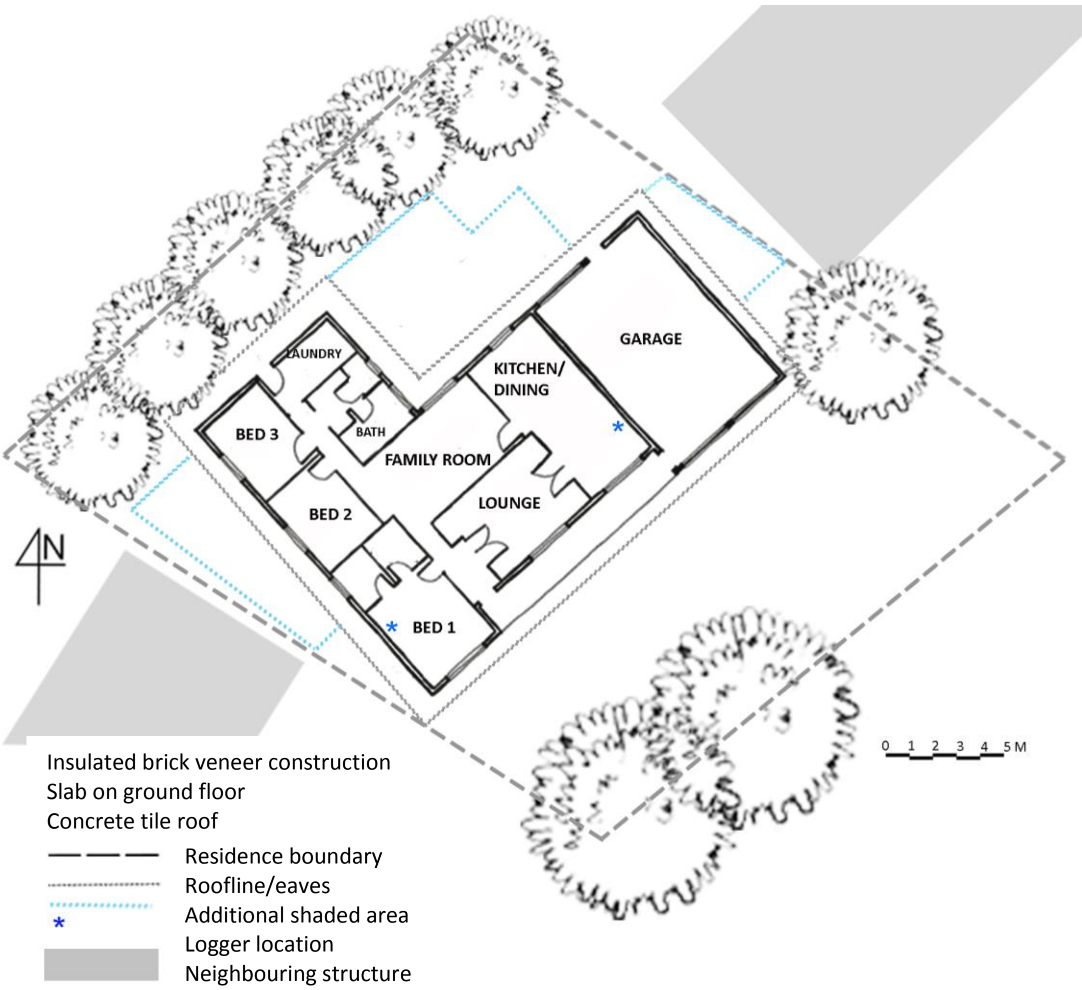


Figure 6-7: House 12

House 12 (Figure 6-7) was a three-bedroom house built in the 1990s which the occupants had owned and lived in from new. It was typical brick veneer construction with insulation specified on the house plans in both the walls (65mm rockwool batts) and the ceiling (85mm rockwool batts).

This house was the most difficult of the five to calibrate, despite very accurate plans from the occupants and daily comfort vote surveys being completed in both measured rooms. This is because there was no time during the dates available for calibration that the occupants were absent from the house, and it seems that occupant behaviour has a large effect on temperature in this house. On their surveys, the occupants did not mention having heating or cooling on during this period; however, they had mentioned opening and closing windows in the comfort vote surveys. This ventilation was integrated into the simulation via the profiles however assumptions had to made about which windows were opened, based on where the logging devices were placed and knowledge of the home gained during home visits. Further adjustments were made to the furniture mass factor within the thermal building profile, as it was observed during visits that the house was heavily furnished.

Despite these difficulties, the simulated house was able to be calibrated, with the difference between the simulated and measured temperatures falling within acceptable limits, with a CV(RMSE) of 8.8% for simulated vs measured temperatures in the living area (Figure 6-8) and 9.5% for simulated vs measured temperatures in the main bedroom (Figure 6-9).

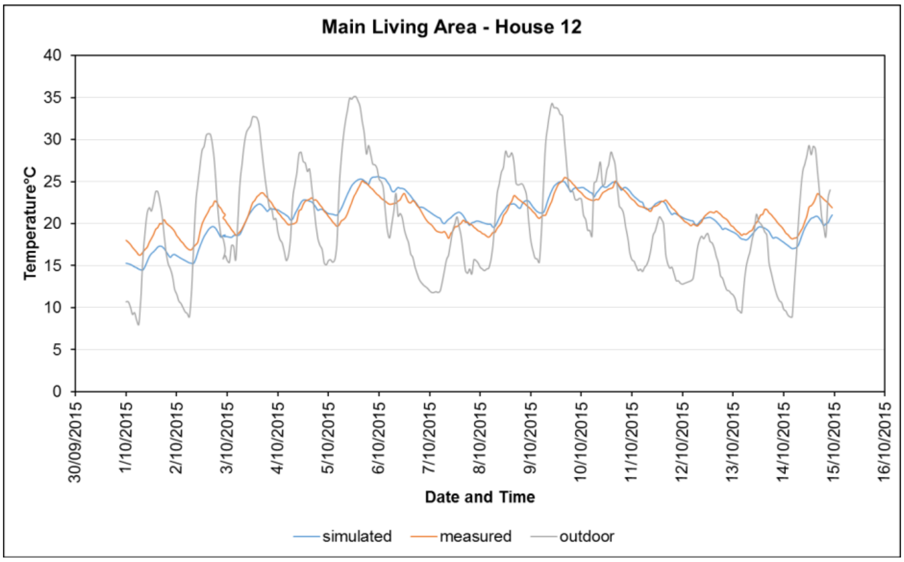


Figure 6-8: Simulated and measured indoor temperatures of the main living area of House 12

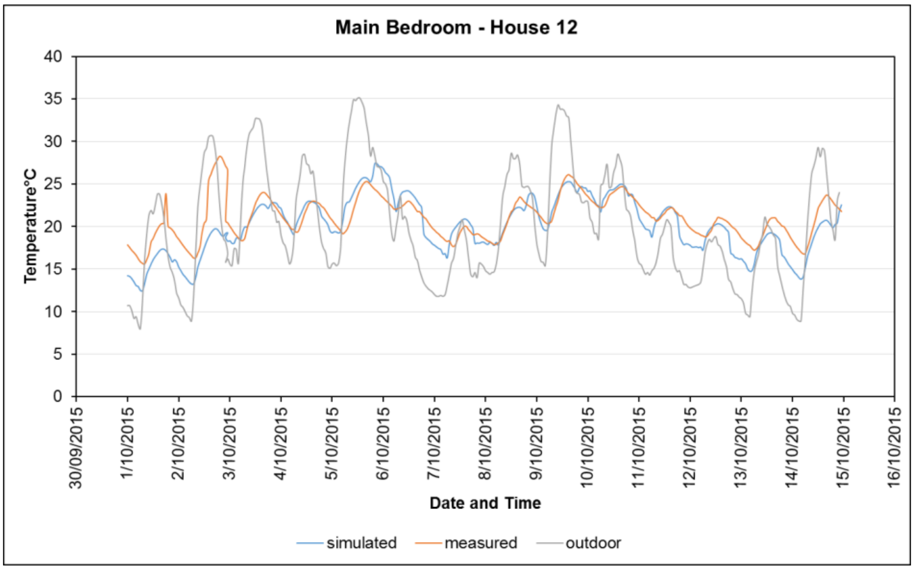


Figure 6-9: Simulated and measured indoor temperatures of main bedroom of House 12

6.2.1.4 *Concrete block detached house (House 16)*

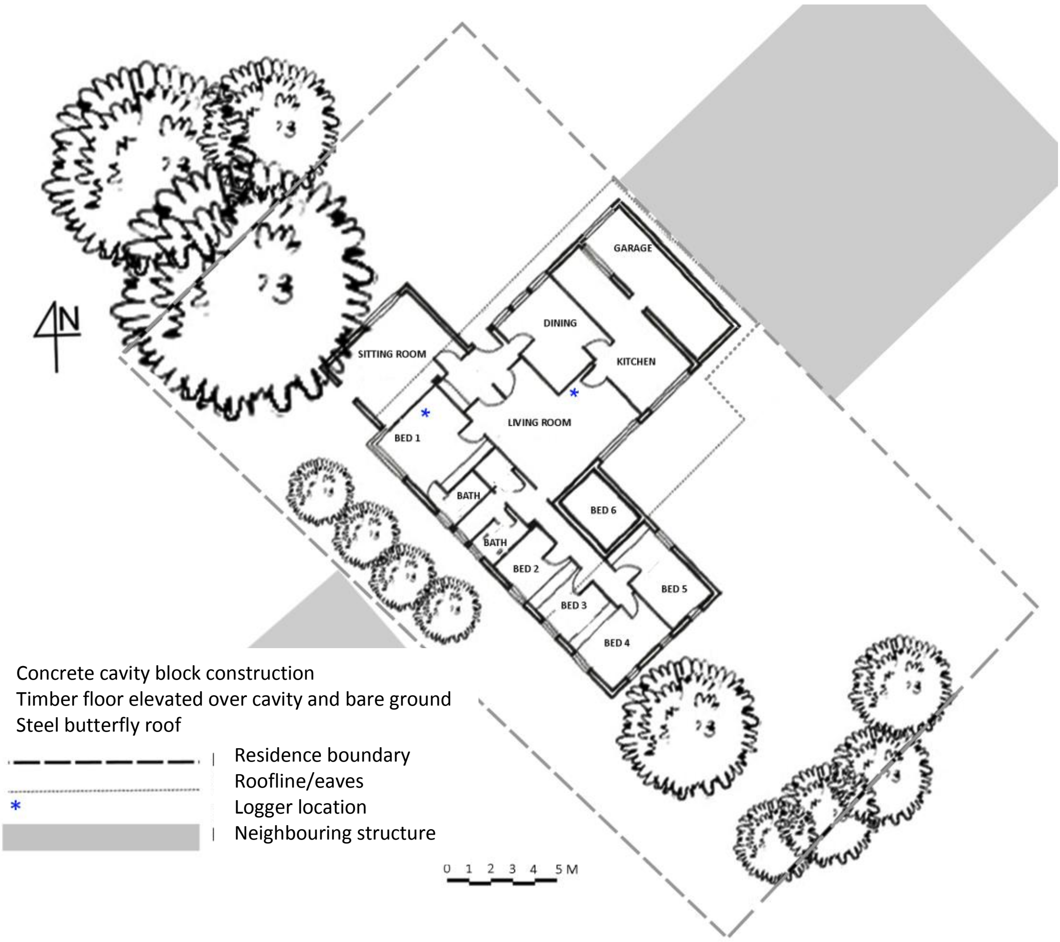


Figure 6-10: House 16

House 16 (Figure 6-10) was an interesting example to study due to its unusual status as an 'architect-designed' house. It was designed in the 1960s and featured concrete block construction, similar to a double brick cavity house. The house had a slow-combustion heater as well as a wall-mounted reverse cycle unit in the main living area. The latter was reported by the occupant as being used primarily for cooling, with the slow-combustion unit providing the main source of heating. For this reason, in all energy and HVAC analyses, this house had two sets of data—one relying on the slow-combustion heater, and one utilising the reverse cycle unit for heating.

There was again no period of occupant absence which would allow free-running performance to be calibrated, and thus occupant behaviours such as opening windows were adjusted within the simulation to attempt to match the information that could be gathered from the comfort vote surveys. This allowed calibrations to be completed with a CV(RMSE) of 6.6% for simulated vs measured temperatures in the main living area (Figure 6-11) and 8.5% for simulated vs measured temperatures in the main bedroom (Figure 6-12).

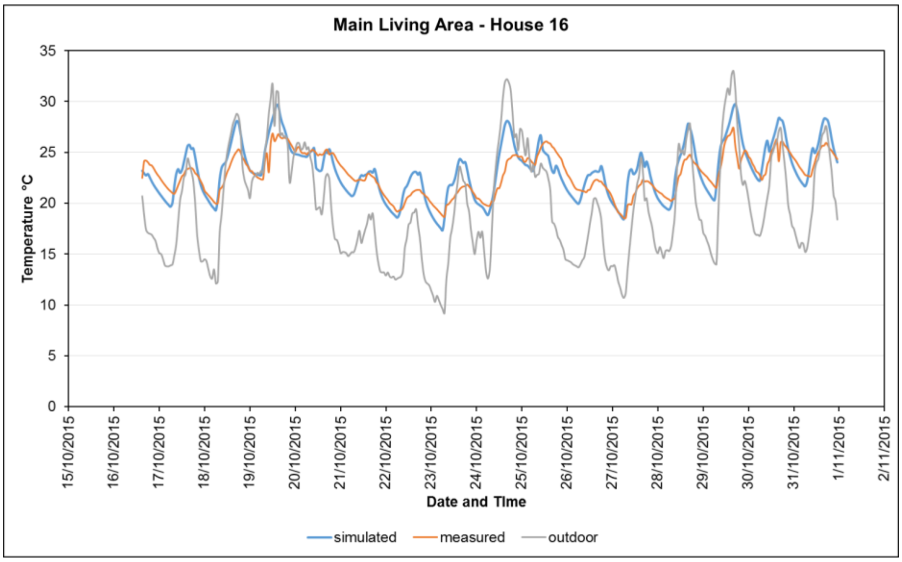


Figure 6-11: Simulated and measured indoor temperatures of the main living area of House 16

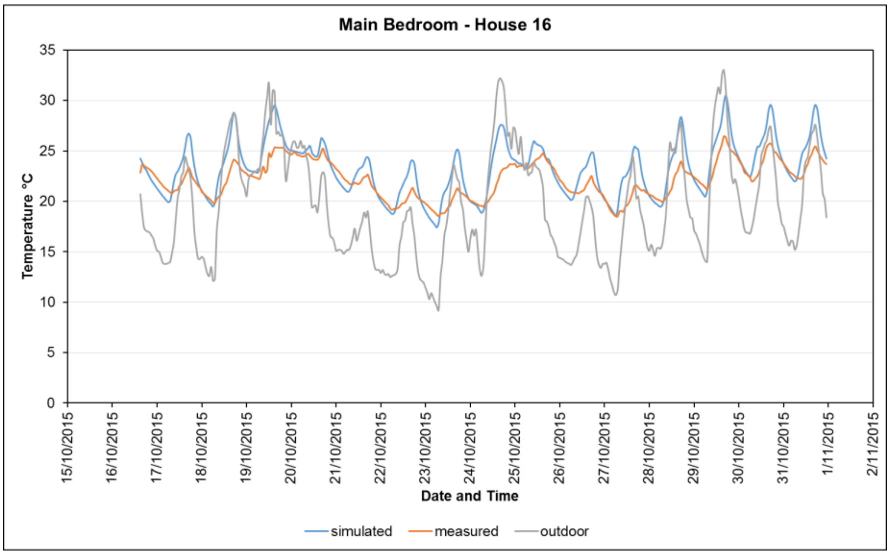


Figure 6-12: Simulated and measured indoor temperatures of the main bedroom in House 16

6.2.1.5 *Double brick detached house (House 18)*

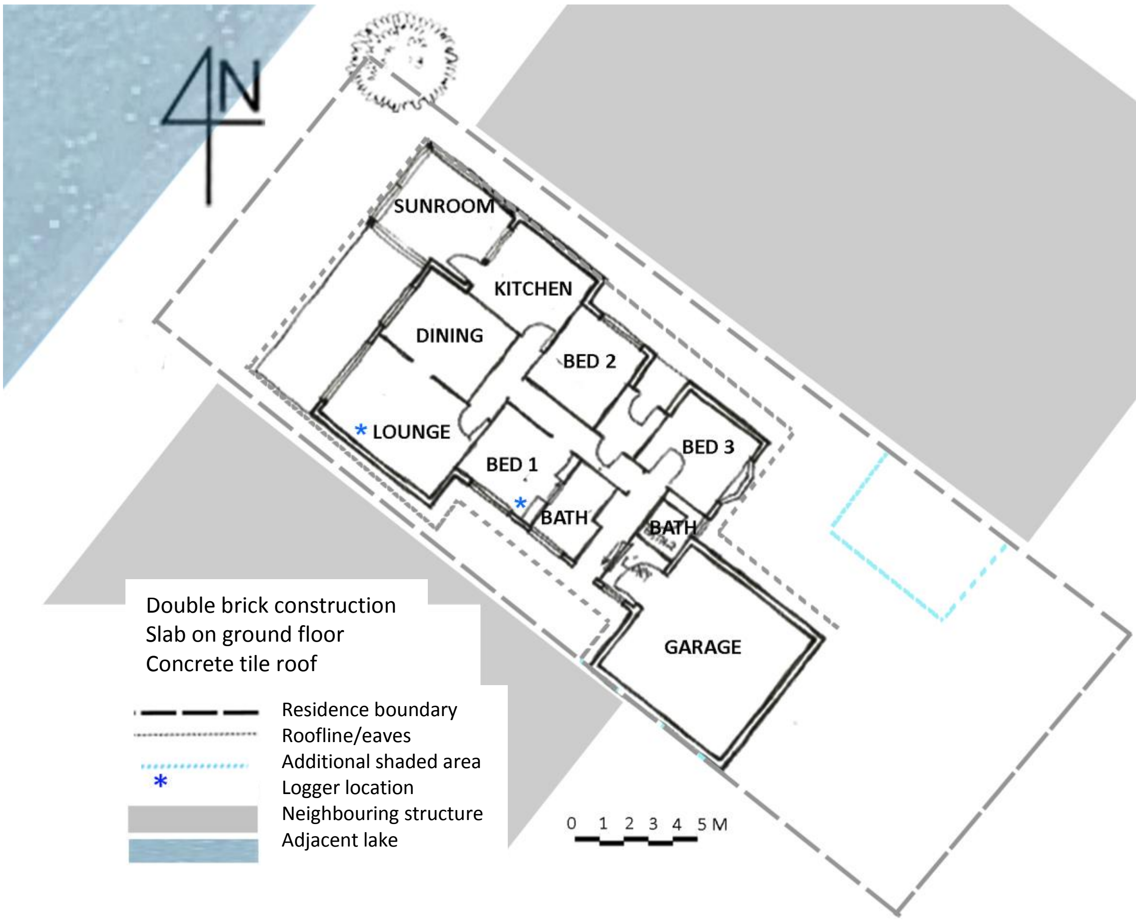


Figure 6-13: House 18

House 18 (Figure 6-13) was located in the north-west of Adelaide. It was a double brick home to which the occupants had added a sunroom area. This sunroom and the main living area both faced west over a lake, with the sunroom windows being tinted to keep some heat out during summer. The house was otherwise a three-bedroom home with insulation in the ceiling but not in the cavity brick walls.

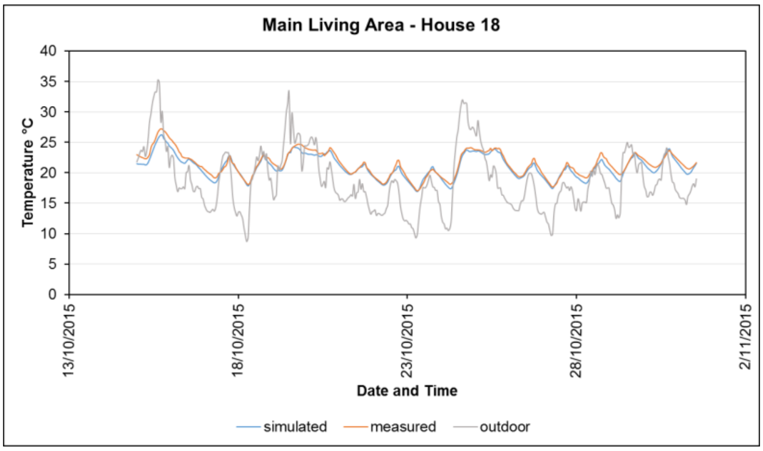


Figure 6-14: Simulated and measured indoor temperatures of the main living area of House 18

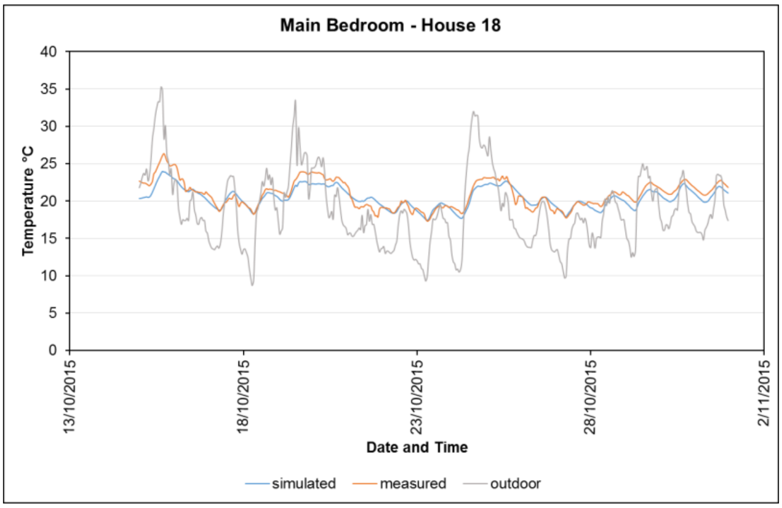


Figure 6-15: Simulated and measured indoor temperatures of the main bedroom of House 18

The occupants of this house travelled frequently, which meant there was ample opportunity to calibrate the house without their presence. Once again, this produced a very accurate result, with a CV(RMSE) of 2.9% in the living area (Figure 6-14) and 4.3% in the main bedroom (Figure 6-15).

6.3 Conditions before improvement

Following calibration, the simulation was used to predict the year-round hourly temperature from a file of TMY temperature data. Initially, each house was tested with no heating or cooling, to assess the performance of the house in free-running mode. The results of these experiments can be found in Table 6-1, along with the percentage of hours that the temperature of each house was within, lower than, and higher than the ranges recommended by the study, and lower than recommended by the WHO.

Table 6-1 shows that, in free-running mode, for a significant amount of time—more than 50%—the temperature of the houses was at a temperature lower than recommended by the study parameters, whilst it was within the range recommended by the study parameters for less than 20% of time. When compared to the WHO recommendations, the temperature of most houses was colder than recommended between 38% and 58% of time. In this free-running mode, the amount of time that the temperature in the house was higher than recommended varied, but all of the houses had lower temperatures than recommended for more time than they were higher than recommended.

Table 6-1: Year-round temperatures in free-running mode—original house design

House #		°C	Temperature range considered	% hours at lower than recommended temperatures	% hours within recommended range of temperatures	% hours at higher than recommended temperatures
4	max.	36.3	study parameters	59.7	15.0	25.3
	min.	8.9	WHO	43.3		
	ave.	19.6				
10	max.	35.2	study parameters	56.2	19.1	24.7
	min.	10.4	WHO	38.0		
	ave.	20.3				
12	max.	30.2	study parameters	75.4	16.7	7.9
	min.	7.4	WHO	58.4		
	ave.	17.0				
16	max.	36.4	study parameters	58.2	19.7	22.1
	min.	8.0	WHO	42.0		
	ave.	19.7				
18	max.	35.0	study parameters	67.7	17.7	14.6
	min.	8.2	WHO	42.9		
	ave.	19.4				

The reality is that all houses in this study did at some point use heating or cooling devices, as none of the houses provided year-round comfort without it. From thermostat and usage information provided in the occupants' initial surveys, as well as from analysis of the measured data from the houses, a profile of heating and cooling use was set up within the simulation software to give the closest possible approximation of the use of HVAC systems. These profiles included the thermostat set points shown in Table 6-2 as well as usage criteria such as systems being turned on when air temperature reached a certain threshold, but only during certain parts of the day. Building use profiles can be found in Appendix E. Hourly temperature was again simulated, and the number of hours that the temperature of the house was lower, higher and within recommended limits calculated, with the results shown in Table 6-3.

Table 6-2: Thermostat settings of the studied houses

House #	Construction type	Heating/cooling type	Summer thermostat setting	Winter thermostat setting
4	double cavity brick	R/C unit in living room	23 °C	21 °C
10	double cavity brick	ducted R/C	26 °C	22 °C
12	brick veneer	ducted R/C	23 °C	22 °C
16	concrete block cavity wall	slow-combustion heater	n/a	n/a
		R/C unit in living room	22 °C	22 °C
18	double cavity brick	ducted R/C	20 °C	18 °C

Table 6-3: Temperatures with HVAC—original house design

House #	HVAC type	Temperature range considered	% hours at lower than recommended temperatures	% hours within recommended range of temperatures	% hours at higher than recommended temperatures
House 4	R/C wall unit in living room	**study parameters**	41.4	34.6	23.9
		WHO	21.8		
House 10	ducted R/C	**study parameters**	55.0	31.4	13.7
		WHO	29.9		
House 12	ducted R/C	**study parameters**	67.0	23.5	9.5
		WHO	33.7		
House 16	slow-combustion stove	**study parameters**	56.6	27.5	15.9
		WHO	31.3		
	R/C wall unit in living room	**study parameters**	55.3	26.1	18.6
		WHO	38.3		
House 18	ducted R/C	**study parameters**	47.1	25.6	27.2
		WHO	27.3		

With heating and cooling usage included in the simulation, houses were within the temperature range recommended by the study more often, with an increase of between 8% and 19% of hours in this range. Most of this was because of a decrease in the amount of time that the temperature of the houses was lower than recommended. Despite most of the houses having thermostat settings above the minimum recommended temperatures (21 °C for the study parameters and 18 °C for the WHO), the usage patterns of the occupants meant that the temperature in these houses did not always stay at or above these temperatures, with most occupants typically switching heating on and off during the day depending on the time of the day and their own comfort, rather than allowing the thermostat to provide a constant temperature in the house.

6.3.2 **Electricity usage before improvements**

Using the same heating and cooling profiles that were used for the assessment of thermal performance of the building, annual electricity consumption for heating and cooling was simulated for each house. The results of these simulations can be found in Table 6-4.

It is worth noting that this is the heating and cooling electricity usage per house and it does not take into account the presence of any rooftop photovoltaic (PV) cells which feed electricity into the grid. Houses 18, 12 and 16 all had PV cells installed, and this was reflected in the bills they reported in the initial survey, but their presence does not change the overall heating and cooling electricity consumption of the house.

In addition, the data used for this study do not reflect the total energy used by a house, since this would include the use of kitchen appliances, laundry machines and other electrical equipment such as televisions and computers. An inventory of such appliances was not taken, as the focus of this study was on thermal comfort and the electricity required for heating and cooling.

House 16 had two modes of heating available, one of which burned wood for fuel, and therefore this mode of heating does not contribute to the electricity usage of the building. This house also had a reverse cycle unit installed in the living area, which the occupant claimed to use primarily for cooling. However, calculations were performed on the assumption that it could be used for heating if necessary, and these calculations aimed to take into account improvements in overall efficiency if it was used.

Participants in the study were not required to provide their electricity bills for analysis, and so all electricity usage numbers are predicted by the simulation. Should this study be expanded and repeated in the future, this is a limitation that should be rectified for more accurate results concerning electricity usage.

The energy type ‘other’ includes lighting energy of 2.5 W/m^2, as well as energy required to run the HVAC system beyond what is required to heat and cool the air coming from it (such as heat rejection fans). The lighting energy is approximated from the ABCB (ABCB, 2018) which stipulates a maximum of 5 W/m^2 indoors, with an assumption that most houses are not lit all over all of the time, and may utilise low energy bulbs. The HVAC system energy is calculated by the simulation and is determined by the type of system and its overall efficiency which come from the database within the software.

House 10 had the highest energy usage despite being one of the smallest houses in the study. This household included an occupant with very specific heating needs due to illness. Even mildly cool temperatures were poorly tolerated, which led to the higher than average usage of heating devices and electricity use.

House 4 had the highest usage per square metre, due to high heating loads associated with poor solar gains in winter. House 16 had the lowest electricity usage, especially when considering the profile, which relied only on the slow-combustion system for winter heating. The owner of this house mentioned that he was significantly in credit with his electricity company, due to his low electricity usage and the large PV system.

Table 6-4: Predicted energy usage with HVAC before improvements

House #	Construction type and HVAC system	Energy type	Energy usage (kWh)	kWh/m2
House 4	double brick cavity slab on ground clay tile roof with insulation R/C unit in living room	heating	1427.2	31.3
		cooling	324.8	7.1
		other	1920.5	42.1
		total	3672.5	80.5
House 10	double brick cavity slab on ground clay tile roof with insulation ducted R/C	heating	2632.3	39.3
		cooling	477.4	7.1
		other	872.9	13.0
		total	3982.6	59.4
House 12	brick veneer slab on ground clay tile roof with insulation ducted R/C	heating	1913.7	11.8
		cooling	42.8	0.3
		other	1274.7	7.9
		total	3231.2	19.9
House 16	concrete block cavity suspended timber floor steel roof with insulation slow-combustion heater	heating	0	0.0
		cooling	458.4	2.6
		other	897.1	5.1
		total	1355.5	7.6
	R/C unit in living room	heating	1172.5	6.6
		cooling	626.8	3.5
		other	706	4.0
		total	2505.3	14.1
House 18	double brick cavity slab on ground clay tile roof with insulation ducted R/C	heating	1581.7	12.3
		cooling	529.3	4.1
		other	1070.2	8.3
		total	3181.2	24.7

6.4 Effect of building fabric improvement

Since all houses required some form of heating and cooling, retrofitting to reduce the electricity used to run these systems is the primary concern of the building improvement simulations, rather than attempting to retrofit houses to run without air-conditioning or heating at all. For this reason, the effect of the improvements on the electricity usage was determined first, and the thermal conditions were considered once the best combination of improvements was determined. These simulations aimed to determine whether changes had significant effects on electricity usage and whether such effects could justify the cost of their installation.

Of the five houses studied, four had the potential for additional insulation in the walls, with the fifth house already having insulation as part of its brick veneer construction. All of the houses already had some insulation in the roof space; however, there was adequate roof space to increase the thickness and therefore the insulation value. As all of the houses in this study were currently fitted with single glazing (as is the case in most of Australia), the effect of installing double glazing was also considered, alongside increases to insulation.

Results of each of the simulations can be found in Table 6-5 and Table 6-6. In both tables, 'decrease' refers to the difference in electricity usage in the improved model compared to the base model (Table 6-4). For House 12 adding wall cavity insulation or both insulation types are not applicable, as the brick veneer construction meant that the house already had wall insulation.

Table 6-5: Predicted annual energy usage (kWh) after building improvement

House #	Energy type	Original (base) energy usage	Increase ceiling insulation	Add wall cavity insulation	Add both insulation types	Add double glazing	Add double glazing and insulation
4	heating	1427.2	1355.5	906.4	807.3	1325.2	655
	cooling	324.8	311.9	422.2	415.9	316	418.8
	other	1920.5	1916	1954.6	1952.5	1917.5	1953.4
	total	3672.5	3583.4	3283.2	3175.7	3558.7	3027.2
	decrease		89.1	389.3	496.8	113.8	645.3
10	heating	2632.3	2441.6	2141.5	1919.5	2592.8	1863.9
	cooling	477.4	399.5	416.8	334.2	453.8	311.9
	other	872.9	849.6	854.7	830	865.8	823.2
	total	3982.6	3690.7	3413	3083.7	3912.4	2999
	decrease		291.9	569.6	898.9	70.2	983.6
12	heating	1913.7	1773.1			1514.8	1352
	cooling	42.8	31.5			42	30.4
	other	1274.7	1265.2	n/a		1258.4	1247.6
	total	3231.2	3069.8			2815.2	2630
	decrease		161.4			416	601.2
16	heating	0	0	0	0	0	0
	cooling	458.4	433.9	447.1	432.3	398.4	382.1
	other	897.1	888.6	893.2	888	876.1	870.3
	total	1355.5	1322.5	1340.3	1320.3	1274.5	1252.4
	decrease		33	15.2	35.2	81	103.1
	heating	1172.5	829.4	904.4	532	896.1	253.1
	cooling	626.8	594.1	612.4	592.4	545.9	524.9
	other	706	696.1	701.6	695.8	681.7	675.4
	total	2505.3	2119.6	2218.4	1820.2	2123.7	1453.4
	decrease		385.7	286.9	685.1	381.6	1051.9
18	heating	1581.7	1338.6	1095.2	798.3	1443.9	598
	cooling	529.3	438.8	518.9	424.3	450.8	343.1
	other	1070.2	1030.3	1029.3	973.4	1051.7	927.4
	total	3181.2	2807.7	2643.4	2196	2946.4	1868.5
	decrease		373.5	537.8	985.2	234.8	1312.7

Table 6-6: Predicted annual electricity usage (kWh/m²) after building improvement

House #	Energy type	kWh/m2 Original (base) energy usage	Increase ceiling insulation	Add wall cavity insulation	Add both insulation types	Add double glazing	Add double glazing and insulation
4	heating	31.3	29.7	19.9	17.7	29.1	14.4
	cooling	7.1	6.8	9.3	9.1	6.9	9.2
	other	42.1	42.0	42.9	42.8	42.1	42.8
	total	80.5	78.6	72.0	69.6	78.0	66.4
	decrease	39.3	2.0	8.5	10.9	2.5	14.2
10	heating	7.1	36.4	32.0	28.6	38.7	27.8
	cooling	13.0	6.0	6.2	5.0	6.8	4.7
	other	59.4	12.7	12.8	12.4	12.9	12.3
	total	11.8	55.1	50.9	46.0	58.4	44.8
	decrease	0.3	4.4	8.5	13.4	1.0	14.7
12	heating	7.9	10.9	0.0	0.0	9.4	8.3
	cooling	19.9	0.2	0.0	0.0	0.3	0.2
	other	0.0	7.8	0.0	0.0	7.8	7.7
	total	2.6	18.9	0.0	0.0	17.4	16.2
	decrease	5.1	1.0			2.6	3.7
16	heating	7.6	0.0	0.0	0.0	0.0	0.0
	cooling	6.6	2.4	2.5	2.4	2.2	2.2
	other	3.5	5.0	5.0	5.0	4.9	4.9
	total	4.0	7.5	7.6	7.4	7.2	7.1
	decrease	14.1	0.2	0.1	0.3	0.5	0.6
	heating	12.3	4.7	5.1	3.0	5.0	1.4
	cooling	4.1	3.3	3.5	3.3	3.1	3.0
	other	8.3	3.9	4.0	3.9	3.8	3.8
	total	24.7	11.9	12.5	10.3	12.0	8.2
	decrease		2.2	1.6	3.9	2.1	5.9
18	heating		10.4	8.5	6.2	11.2	4.6
	cooling		3.4	4.0	3.3	3.5	2.7
	other		8.0	8.0	7.5	8.2	7.2
	total		21.8	20.5	17.0	22.8	14.5
	decrease		2.9	4.2	7.6	1.8	10.2

Of the improvements examined singularly, the addition of wall insulation into the houses with cavity brick or cavity block construction made the largest difference in energy consumption when averaged over the four houses to which it was added. This is due to the fact that less heat is lost through the walls, as the air gap, which itself is not very conductive, is replaced with an even less conductive material such as rockwool. Increasing ceiling insulation or replacing single glazing with double glazing each had about the same effect on electricity usage. Adding both types of insulation together had a greater effect than the sum of the two individual interventions on their own, due to an overall decrease in heat conductivity.

In three of the houses this was also true for the replacement of single glazing with double glazing, although in the two other houses the total sum of electricity usage saved was not as high as the sum of different types of interventions. This may be due to a number of factors. For example, building orientation might not allow adequate solar gains, and the house would therefore either require more heating or, conversely, have high solar gains and therefore require greater cooling. Decreasing the rate at which heat leaves a house is good in winter, but a house with high solar gains may then cool down more slowly in hot weather.

Overall decreases in electricity usage obviously depended on the kind of house and the interventions that were possible. On average for the five houses studied, the combined improvements gave a decrease of 918.9 kWh, which, at $0.35 per kWh, equates to a saving of $321.63 a year in electricity costs (Table 6-7). This figure was typically higher in houses in which cavity insulation could be added to the walls. House 12, which already had insulated walls, had a smaller decrease in overall electricity expenditure, as it was already more energy-efficient than an uninsulated cavity brick or block construction. House 4 also had lower savings, owing to the fact that it was already expensive to heat and cool—the house had very poor solar gains in the winter months due to a total lack of northern exposure, and had high solar gains in the summer through inadequately shaded western windows.

Table 6-7: Average decrease in annual energy usage and expenditure of each intervention

Improvement type	Average decrease in energy use (kWh)	Nominal average saving on annual electricity bill (AUD)
Increase ceiling insulation	260.3	$91.11
Add wall cavity insulation	445.9	$156.07
Add both insulation types	766.5	$268.28
Add double glazing	243.3	$85.15
Double glazing and insulation	918.9	$321.63

In terms of thermal performance, improvement varied considerably between the houses (Figure 6-8, 6-9 and 6-10) . The temperature in House 18 was higher for much less time than previously, being higher than recommended by the study parameters for 14.3% fewer hours. The temperature in House 12 was also higher than recommended for fewer hours than before, but these hours were reduced by only 2.67%. In contrast, in the other houses there was an *increase* in the number of hours in which the temperature would be higher than recommended. This is a side effect of increased insulation, which prevents heat loss—a factor that is necessary in winter but may be undesirable in summer. There are simple changes which can counteract this effect, however, and these will be discussed later in the chapter.

The temperature in all but one house had lower temperatures than recommended for fewer hours following the improvement in insulation.

The house in which the temperature was lower for slightly more hours—House 12—was already fitted with wall insulation, and thus the changes seen after improving insulation were less dramatic. This house also had extensive shading of the northern windows by means of a patio structure, which, whilst preventing excess heat in summer, was large enough that it also prevented most solar gains in the winter.

The net result of this is that the temperature in all houses except House 12 was within the recommended range of temperatures for more time than recorded in the previous chapter of this study However, the percentage of hours during which the temperature of the houses was in this range was still low—below 50% for most of the houses. This is due in part to the fact that thermostat settings were below the recommended temperature; in these simulations, the houses were still essentially functioning in the way the occupants currently used them.

In the next section of this chapter, changes in the behaviour of the occupants in regard to thermostat settings and ventilation will also be taken into account, rather than simply the changes to the building fabric.

Table 6-8: Percentage of time during which the temperature in the house was lower than the recommended range before and after improving insulation and glazing using HVAC.

House #	HVAC type	Temperature range considered	% hours spent cooler than guidelines		
			before improvements	after improvements	% change
4	R/C unit in living room	study parameters	41.4	29.5	-11.9
		WHO	21.8	4.7	-17.1
10	Ducted R/C	study parameters	55.0	38.0	-17.0
		WHO	29.9	7.3	-22.6
12	Ducted R/C	study parameters	67.0	70.7	3.7
		WHO	33.7	37.2	3.4
16	Slow combustion	study parameters	56.6	47.7	-9.0
		WHO	31.3	20.2	-11.2
	R/C unit in living room	study parameters	55.3	47.7	-7.6
		WHO	38.3	28.8	-9.6
18	Ducted R/C	study parameters	47.1	45.1	-2.1
		WHO	27.3	11.9	-15.4

Table 6-9: Percentage of time during which the temperature in the house was within the recommended range before and after improving insulation and glazing using HVAC.

House #	HVAC type	% hours at temperatures within recommended guidelines (annual)		
		Before improvements	After improvements	% change
4	R/C unit in living room	34.6	38.8	4.2
10	ducted R/C	31.4	46.9	15.5
12	ducted R/C	23.5	22.4	−1.1
16	slow-combustion	27.5	29.6	2.2
	R/C unit in living room	26.1	26.6	0.5
18	ducted R/C	25.6	42.0	16.4

Table 6-10: Percentage of time during which the temperature in the house was higher than recommended before and after improving insulation and glazing using HVAC

House #	HVAC type	% hours at higher than recommended temperatures (annual)		
		Before improvements	After improvements	% change
4	R/C unit in living room	23.9	31.7	7.8
10	ducted R/C	13.7	15.1	1.5
12	ducted R/C	9.5	6.9	−2.7
16	ducted R/C	15.9	22.7	6.8
	Slow-combustion	18.6	25.7	7.1
18	R/C unit in living room	27.2	12.9	−14.3

6.5 Effect of heating, cooling and ventilation use changes

Section 6.4 dealt with changes only to the building fabric. What has become apparent as a result of this study is that this is inadequate for creating thermal conditions that are within the recommended ranges. Because of this, further interventions in relation to thermostat settings, heater and cooler usage and ventilation were also simulated, in order to determine whether the combination of these changes with the design interventions would bring indoor conditions within the recommended ranges more often.

6.5.1 Thermostat settings and heating and cooler use

The first, and likely most easy, change is altering the thermostat settings on HVAC systems in both summer and winter. For most houses, the cooling thermostat temperature was adequate to keep temperatures within the recommended ranges. However, the system was not always used in such a way that the temperatures were consistent: occupants tended to turn systems on and off during the day rather than relying on the thermostat setting alone.

During summer, the thermostat should be set at a maximum of 24 °C to create the optimum daily maximum temperature, as suggested by the model outlined in the previous chapter. In these models, occupants would still be free to switch their air-conditioning on according to their own preferences. A better scenario would have occupants relying on the thermostat setting on their HVAC systems to turn on the cooling when required. This been added into the cooling profiles for the purposes of examining the difference it makes.

In regard to the winter temperatures, the reduction in heat conductivity from insulation and double glazing is a good start in terms of increasing the indoor temperature and reducing the electricity required to keep the house warm. However, most occupants in this study did not use their heating systems continuously, which meant that the temperature oscillated during the day, frequently dipping below the recommended 21 °C (the optimum minimum temperature suggested by the study parameters) despite most having a thermostat setting above this. An increased reliance on the heating thermostat to maintain a constant temperature should thus go a long way towards reducing the number of hours during which the temperature of a house is lower than recommended.

6.5.2 **Building ventilation**

The challenge when designing houses that lose less heat in winter through the use of insulation and double glazing is that in summer it has the unwanted side effect of preventing heat loss, thereby causing the temperature of the houses in this study to be higher than recommended after the improvements for more time. There are various ways in which this can be counteracted, the easiest of which is opening windows at times when the air outside is cooler than the air inside. This tends to happen at night and is an effective way to naturally cool a house and keep the night-time temperatures lower. It is, however, acknowledged that some older people prefer to close their windows at night due to security and noise concerns (Mishra & Ramgopal 2013, Rajasekar & Ramachandraiah 2010).

In this instance a mechanical system of air exchange could be installed. A night-time ventilation system removes hot air from the house and roof cavity when the air outside is cooler than the air inside. Such a system allows both for tight controls on when the ventilation system operates with thermostat controls and for the ability to program the system for only certain times of the year, or for certain outdoor temperatures. These mechanical ventilation systems do use some electricity, but much less than a typical air-conditioning system. Thus, whilst systems such as these use more electricity than natural ventilation via windows, they are a better option than running air-conditioning at night to reduce the temperature of the house. A system was included in the simulation on a thermostat profile to remove hot air during appropriate outdoor conditions using the auxillary ventilation function in IES with an air exchange rate of 6 times per hour as per the information available from a commercial manufacturer (CSR Edmonds 2018)

6.5.3 **Changes to heating, cooling and ventilation in the simulated houses**

The ultimate aim of HVAC alterations was to reduce the number of hours during which the temperature of the house was lower or higher than recommended to below 10% at each end of the scale. To address the fact that many of the colder hours happen at night, and that this is remedied by turning on the heating before the room is occupied, night-time hours were discounted in the final calculation of the hours during which the temperature was within recommended ranges. Table 6-11 shows the results of these simulated changes. The percentages presented in this table are the occupied hours and exclude the hours between 11 pm and 7 am.

Table 6-11: Number of hours during which the temperature in the house was higher than, lower than and within the guidelines after changes to thermostat settings and HVAC profiles

House #	Heating/cooling type		% higher	% within	% lower
4	R/C unit in living room	study parameters	4.2	87.6	8.2
		WHO	0.8		
10	ducted R/C	study parameters	5.2	88.2	6.6
		WHO	1.7		
12	ducted R/C	study parameters	0.3	81.0	18.7
		WHO	5.4		
16	R/C unit in living room	study parameters	6.3	91.3	2.4
		WHO	0.1		
18	ducted R/C	study parameters	4.0	88.6	7.4
		WHO	2.0		

Almost all the houses were brought within the guidelines suggested by the study for more than 85% of the time after these interventions. However, despite the same interventions being applied to House 12, the temperature of the house was still lower than recommended by the study parameters for more than 18% of the time. Many of these hours were during the spring months of October and November, when the profile did not include heater use. Further analysis showed that this was also evident in other houses, likely due to HVAC profiles being set to cooling rather than heating in the warm pre-summer months of October and November. In October 2015, when the field study was occurring, temperatures over 35 °C were recorded in Adelaide and nights were warmer than usual (BOM 2015b). However, in a typical meteorological year, there may be cooler weather in these months as well, which could trigger heating use in a real-life scenario, but such a scenario was not included in the HVAC profile for these months.

House 12 was also the coldest in the first round of building improvements. There was significant shading to the north of the house, both from a gazebo and tall trees. The trees acted partly as a sound barrier to a major transit corridor near the house. However, when this shading was removed from the simulated house, the temperatures were still lower in this house compared to other houses. There were also few north-facing windows in House 12, and the main living areas faced south. In addition, House 12 had the highest energy usage after both building improvements and changes to HVAC usage.

That said, energy usage increased in all of the houses when the HVAC usage was changed in addition to the building improvements, compared to when the houses were improved only. This was due to the need for increased heating in order to keep the temperature within the recommended range. Nonetheless, because of the housing improvements, two of the houses ended up using less energy than they had with the original house design, even with the increased HVAC use. The energy usage of one of the houses increased by only 50 kWh over the unimproved building, and in two of the houses, the energy usage increased substantially compared to energy usage of the base house.

The total energy usage following changes to the house and HVAC use can be seen in Table 6-12.

Table 6-12: Predicted annual energy usage after housing improvements and changes to HVAC settings

House #	Heating energy (kWh)	Cooling energy (kWh)	Total energy (kWh)	Current PV offset (kWh)	Total billed energy (kWh)	Change in billed energy from unimproved house (kWh)
4	1522.6	295.6	3595.5	none	3595.5	–77
10	1856.6	415.6	3126.6	none	3126.6	–856
12	4961.1	430	5942.1	–1959	3983.1	2710.9
16	2755.2	878.2	4414.9	–5250.6	–835.7	3059.4
18	1972.1	396.4	3231.2	–3358.7	–127.5	50

Whilst the total energy after housing improvements was similar to, or in some cases higher than, the unimproved house, further analysis showed that if the thermostat changes and changes to heating and cooling use and ventilation were made *without* the housing improvement, the average electricity usage would have been 2000 kWh higher, equating to approximately $700 in electricity charges. The combination of the HVAC changes and building improvement interventions that bring the temperature of the house to within the recommended ranges at least 80% of the time must be considered together if they are to be of benefit to the occupants.

However, ideally, the two combined should not cost the occupants more than they are currently paying, despite increased heating and cooling usage. With the exception of House 12, this is currently the case in the studied houses. Even with increased heating and cooling use, the two households which completely offset their current energy costs with installed PV cells still had overall negative billed energy, meaning that they were still producing more energy than they were using.

The simulated change in the number of hours during which the house used air-conditioning or heating is shown in Table 6-13. This table shows that, despite the occupants in some cases having to double the hours of HVAC use in their house, their energy costs were kept almost the same through the use of housing improvement strategies. This further reinforces the need for changes both to the house itself as well as to HVAC, in order to create an environment which should minimise the presence of heat- and cold-related symptoms in the occupants.

Table 6-13: Hours of HVAC use before improvements, after improvements and after improvements with changes to HVAC settings

House #	Intervention type	% total hours with HVAC use	% occupied hours with HVAC use
4	House improvements + HVAC changes	38.4	57.6
	House improvements	27.4	41.1
	Base design	22.2	33.3
10	House improvements +HVAC changes	40.9	61.3
	House improvements	26.4	39.6
	Base design	26.9	40.3
12	House improvements + HVAC changes	38.4	57.6
	House improvements	17.1	25.6
	Base design	15.8	23.8
16	House improvements + HVAC changes	45.7	68.5
	House improvements	11.8	17.7
	Base design	18.3	27.5
18	House improvements + HVAC changes	48.7	73.1
	House improvements	30.0	45.0
	Base design	31.6	47.4

Ultimately, creating a thermally comfortable environment that also fits within the study parameters shown to be related to the lowest number of symptoms is possible, but it is expensive because it requires both house improvements and changes in HVAC usage. The houses studied in this chapter do not perform well enough without both these changes to avoid large amounts of electricity expenditure on heating. Whilst a combination of retrofits and changes to heating and cooling use can create the specified conditions, it does so without reducing electricity use and therefore costs to occupants, a situation that is not a persuasive argument to spend money on both home improvements and electricity.

The next section a different approach is presented, which may offer a viable alternative to housing improvement. It considers whether small-scale domestic electricity production is a cost-effective alternative, allowing occupants to heat and cool their homes to the recommended levels without excessive electricity costs.

6.6 Photovoltaic systems to reduce household electricity costs

Since the start of the 21st century, there has been increasing interest in the use of photovoltaic (PV) cells as a small-scale power source for residential buildings. Prior to this, solar system use was limited largely to properties in remote areas, where access to the electricity grid and other fuels is difficult (Watt 2001). The Australian Government first established Renewable Energy Targets in 2001, which saw the introduction of incentives for renewable energy production (Climate Change Authority 2012). This led to an increase in residential solar PV systems through government incentives and rebates.

Whilst these rebates have tapered off somewhat in recent years (Simpson & Clifton 2015), the result is that around 20% of homes in Australia have solar energy systems, with over 50% of households in some urban areas having some sort of solar PV system installed (Johnston 2018). In Adelaide in particular there has been a high uptake of solar PV technology, due to the climate as well as to state government incentives tied to a goal of 50% renewable energy by 2020 (Sivaraman & Horne 2011). A map (Figure 6-16) produced by the Australian PV Institute shows the percentage of houses with solar PV systems by local government area.

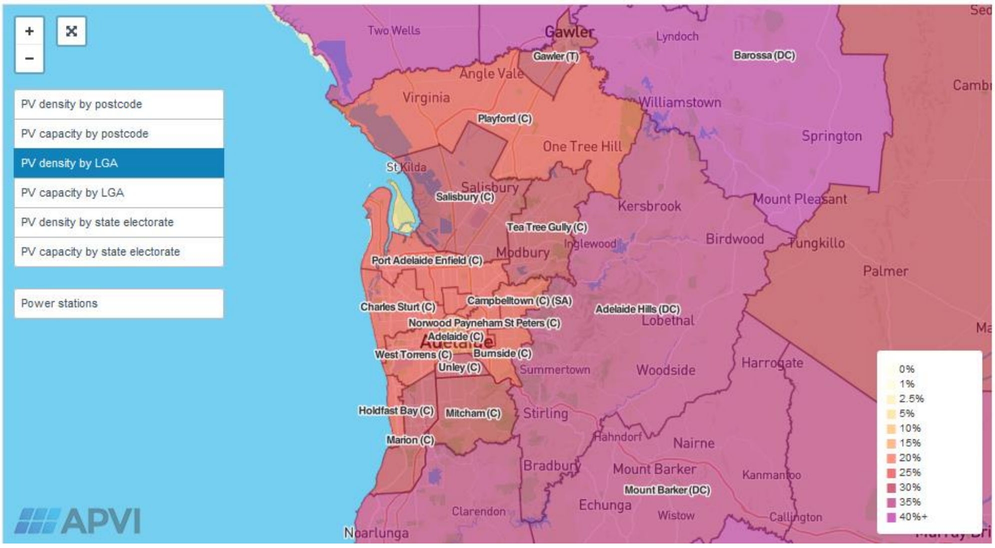


Figure 6-16: Percentage of households with PV solar systems by local government area (Australian PV institute, 2019)

In the Adelaide metropolitan area, between 20% and 35% of homes already have some solar PV capacity. This suggests that it represents a feasible way to reduce electricity bills. These systems work by feeding electricity produced into the grid to offset the energy used by the household. The exact mechanisms are complicated and beyond the scope of this study, but most simple explanations suggest that if a household produces as much electricity as it uses, its power bills are neutral, and a feed-in tariff applies for any energy it returns to the grid in excess of what it uses. Depending on the value of this feed-in tariff and the amount of electricity fed into the grid at various times, this can lead to significant savings and in some cases a negative energy bill, in which the energy company ends up paying money to consumers. One participant in the field study had taken advantage of generous rebates and locked in a high feed-in tariff, mentioning that he was several thousands of dollars in credit with his energy provider.

Both the increase in popularity of the systems as well as advances in technology mean that the purchase price for solar PV systems has decreased significantly. For instance, the cost is significantly lower than the cost of installing double glazing, which has a small impact on energy efficiency and a relatively long payback period. The payback period for a solar PV system, in contrast, can be as short as two years. The life cycle cost analysis of installing such systems will now be discussed in the context of the houses used in the building improvement study.

6.6.1 Houses 10 and 4—No existing solar PV system

Houses 4 and 10 were small independent living units located within the same complex. Whilst the current reality for these householders is that they have no means to improve their buildings due to the conditions of their lease, they have been included for the purposes of this study, as they have no solar PV system installed. The ramifications of this analysis to the owners of the complex rather than the leaseholders will be discussed following the life cycle costing.

In Adelaide, as in other southern hemisphere locations, it is best to locate panels on the northernmost aspect of the roof, in order to get maximum solar exposure. House 10 has approximately 46 m^2 of roof space facing almost exactly north, which is ideal for solar installation. House 4, in contrast, has none of its own roof space facing north; any north-facing roof is attached to the unit next door. It does, however, have a large amount of roof space facing directly west and east which could be utilised to capture solar radiation for most of the day, especially in summer when the sun is higher in the sky.

For each of these houses, 20 m^2 of solar PV panels were simulated, facing due north in the case of House 10, and due west in the case of House 4. This does not quite equate to a full 5 kW system, which is what has been priced below, however the roofspace available for House 4 did not allow for more than the 20 m^2 simulated. These houses were simulated with the same area of panels to illustrate the difference the orientation of a building can make to both its heating needs and the available roof space for solar electricity generation. The simulation software is able to calculate the electricity produced by these systems, which can then be compared to the electricity used by the household, and thus the resulting savings can then be determined.

House 10 currently uses 3982.5 kWh of electricity per year. Despite the small size of the dwelling (around 70 m^2 liveable space), it has the highest heating use of any of the houses due to a medical condition suffered by one of the occupants. At $0.37 per kWh, this house currently has an annual electricity bill of $1473.56 before discounts and concessions, but the temperature of the house still falls outside the temperature zone recommended by the study for a high percentage of hours. If the heating and cooling settings are changed within the simulation to create a more optimal environment, as outlined earlier in this chapter, the annual electricity usage goes up to 4326.1 kWh, at a cost of $1600.66 per year.

The exact pricing of solar PV systems is complicated, with the number of small-scale technology credits given changing with location and year. The current estimate for a 5 kW system in Adelaide is between $5000 and $9000. Assuming an average of $7000 for the system, and a discount based on the value of small-system technology credits of just over 50%, a value of $3400 was used to estimate the cost of installing the solar PV system in this case.

Table 6-14 shows the Present Value of the cost of electricity vs the cost of installing a solar system and paying a decreased electricity bill amount. This is based on the simulation, which predicts that the 20 m^2 system will produce 3699 kWh annually. This leaves the household paying for 622.6 kWh at a cost of $232.03 per year. This is a saving of $1368.63 per year, meaning that the cost of the solar PV system is paid back in 2.48 years.

Table 6-14: Present Value of original costs, costs with solar installation and the value of savings for House 10

Years	Present value of energy costs without solar (what the household would pay)	Present value of system + electricity costs (what the household pays now)	Present value of energy savings (value of the savings to the household)
5	$7125.85	$4432.96	$6092.90
6	$8390.88	$4616.33	$7174.55
7	$9607.25	$4792.66	$8214.59
8	$10,776.84	$4962.20	$9214.64
9	$11,901.44	$5125.22	$10,176.22
10	$12,982.79	$5281.97	$11,100.82
15	$17,796.76	$5979.80	$15,216.96
20	$21,753.49	$6553.36	$18,600.13

House 4 is smaller again than House 10, with a total liveable area of around 45 m^2. This house has only a single reverse cycle unit to heat and cool the living and kitchen area, with no heating or cooling in the bedroom. Because of the lack of north-facing glazing, the house is very cold and thus also has a high heating bill. The total electricity bill for this house was $1358.83 for 3672.5 kWh, and it was also at a lower temperature than recommended for much of the time. After simulated changes to the usage and settings of the heating and cooling unit, the total electricity use for this house increased to 4543 kWh, which would cost $1680.91.

The installation of 20 m^2 of solar PV panels in this house would equal 3387.1 kWh of generated electricity. This leaves the household paying for 857.3 kWh at a cost of $427.68. This equals a $1142.78 reduction in the annual electricity bill, and a payback period of 2.98 years on the cost of panel installation. The present values of the energy with and without solar, as well as the present value of the potential energy savings, can be found in Table 6-15.

Table 6-15: Present value of original costs, costs with solar installation and the value of savings for House 4

Years	Present value of energy without solar (what the household would pay)	Present value of system + electricity (what the household pays now)	Present value of energy savings (value of savings to the household)
5	$6991.45	$5303.96	$5581.38
6	$8232.62	$5641.96	$6572.22
7	$9426.05	$5966.96	$7524.96
8	$10,573.57	$6279.46	$8441.04
9	$11,676.97	$6579.94	$9321.90
10	$12,737.92	$6868.87	$10,168.87
15	$17,461.09	$8155.11	$13,939.46
20	$21,343.20	$9212.31	$17,038.60

The differences in the payback time as well as electricity savings are due largely to the different orientations of the houses. House 10 has north-facing windows in the living area, which capture solar radiation and slightly reduce the heating needed, whilst the north-facing panels on the roof are able to generate slightly more electricity than the panels facing west. Whilst, overall, both households will pay less with a solar system than without, this is a noteworthy finding when planning and building new housing with solar PV systems.

In the real world, the occupants of these houses are unable to make changes to the physical structure of their building due to the fact that they are leaseholders and not owners. It could be argued that, as providers of housing for older people, the owners of such complexes have a moral obligation to build houses that provide affordable healthy environments for the occupants. However, the private aged care sector is still a for-profit entity and the moral argument may not be sufficient for such companies to provide solar PV systems to their occupants.

The occupants of these units do, however, pay a bond as leaseholders, and the price of the panels could be added to this bond with essentially the same payback to the occupants. The unit owners would get their costs back and the new leaseholders would enjoy lower electricity bills and a comfortable living environment. Given that the occupation of such independent residential units does turn over when the occupants move out or pass away, a premium could be added to the price of a unit with solar PV, which would allow the housing provider to continue to make a profit, with the new leaseholder still having an overall advantage in terms of the ratio of the bond paid to electricity saved, especially if the new leaseholder lives there for five years or more.

What these results show, however, is that there is a significant cost benefit to installing a solar PV system where none currently exists, with a short payback period and significant savings over the life of the system. Those who plan to stay in their current dwelling and who have the capital available would soon benefit and would also have lower long-term electricity costs, which would be additionally beneficial when they have retired and are on a fixed income that may be lower than the amount they earned whilst working. People planning on moving or downsizing should therefore factor the installation of a solar PV system into the cost of moving, whether that means installing a new system or purchasing a property with an existing one. If they purchase a property with an existing system, the property may need to be upgraded in order to achieve the internal temperatures suggested by this study.

The next section examines houses which already have a solar energy system installed and what would be required to maintain the current costs of living if heating and cooling use were increased.

6.6.2 **Houses 12, 16 and 18—Upgrading the existing solar PV system**

Three of the houses studied in the building improvement section of this thesis already had solar PV systems installed. These systems varied in size from eight panels for a relatively small system to 18 panels; and for two of the households these systems provided sufficient power to negate their electricity costs as they currently stand. One householder had installed the system at a time which allowed for a generous feed-in tariff and mentioned being significantly in credit with their electricity provider.

The challenge, however, is that even the large 18-panel system would not produce enough electricity for the house if the changes to heating and cooling use suggested by this study were applied. In this section, each house will be examined separately in order to determine what benefit installing an additional system would bring in terms of savings in electricity costs.

6.6.2.1 *House 12*

House 12 had a small existing solar PV system installed on the northwest-facing roof. This was a system of only eight panels, producing 1959 kWh per year for a house which currently requires 3231 kWh per year. This equates to a saving of $724.83 per year, with a remaining annual electricity spend of $470.64. This house was, however, one of the coldest ones studied, due to extensive shading on the north-western side, which allowed for very limited solar gains through the glazing on this side of the house.

To heat and cool this house enough to create the indoor temperatures suggested by this study, an additional 5074 kWh of electricity would be required, more than doubling the current electricity consumption and costing an additional $1877 a year. The present value of this electricity over five years is $13,679.96, which takes into account the electricity produced by the existing system. If this house were to be kept heated and cooled to the levels suggested by this study, there would be an enormous ongoing cost to the occupants (Table 6-16).

The addition of 24 m^2 of additional PV cells on the roof of this house would generate an additional 5599 kWh per year, bringing the total amount of electricity generated to 7559 kWh per year, which represents a saving of $2796.65 on electricity, leaving the occupants with a bill of only $276.24 per year. On its own, the additional system would save the household $2071.82, which, assuming an installation price of $3400, would give a payback time of 1.6 years.

Table 6-16: Present value of original costs, costs with new additional solar installation and the value of savings for House 12

Years	Present value of energy without solar (price paid if no additional solar installed)	Present value of system + electricity (price paid of new electricity bill plus system cost)	Present value of total energy savings (total saved after installing additional system as well as savings from existing system)	Present value of new savings (amount saved by installing the new system)
5	$13,679.96	$4629.77	$12,450.19	$9223.37
6	$16,108.51	$4848.09	$14,660.42	$10,860.76
7	$18,443.65	$5058.01	$16,785.65	$12,435.18
8	$20,688.98	$5259.85	$18,829.13	$13,949.04
9	$22,847.96	$5453.94	$20,794.02	$15,404.67
10	$24,923.89	$5640.55	$22,683.34	$16,804.32
15	$34,165.58	$6471.34	$31,094.24	$23,035.30
20	$41,761.58	$7154.19	$38,007.39	$28,156.71

This house provides a prime example of how compensating for the hot sun and extreme heat conditions of the summer can impact the ability of the house to use passive solar gains as a source of heat in the winter. In the case of this house, some of the shading is from trees which are part of a sound barrier between the house and a noisy automated bus line. If these trees were removed so as to allow greater solar gains, the sound comfort of the house would change. There is therefore a degree of compromise required here.

However, there is also significant shading over most of the north-western-facing glazing, which should be reconsidered in addition to increasing the solar PV system. Whilst this would assist with some solar radiation gains in the winter, it is worth noting that the PV system would still be cost-effective in this instance. It is unlikely that such a change would completely eliminate the need for more electricity for heating in the winter, however. Therefore the solar system would be of a benefit in terms of reducing, but not eliminating, the electricity costs needed to keep the house warm.

6.6.2.2 *House 18*

This house has a significant solar system already installed, which produces enough electricity to completely cover the existing bills at the current electricity usage. There are 18 panels mounted on the north-east-facing roof area, which currently produce 4870 MWh of electricity annually. Currently, the house uses only 3181 MWh of electricity, but, again, it is quite cold in the winter. In the cold weather, the occupants typically utilise a sun room, which is built on the western side of the house. This room is largely a glass box with some tinting, but the solar gains are enough to keep this room comfortable in otherwise cold weather, so long as there is some sun.

The occupants of this house also spend considerable time travelling, so the annual usage has the potential to be lower than the predicted amount due to less energy being used, particularly for heating and cooling, when the house is unoccupied.

Whilst currently the occupants travel frequently, it is likely as they get older that they will be at home more often, due to the illnesses that frequently come with increasing age. Thus, it is important that the house can provide adequate thermal comfort all year round in the future for an affordable price. Creating the thermal conditions suggested as ideal by this study would increase the energy use in this house by 2531 MWh a year. This 2531 MWh is greater than the excess currently produced by the solar panels (1689 MWh), taking the household's annual spend from being negative (after a feed-in tariff from their electricity provider) to $311.76 per year.

Whilst this is not a significant power bill, given that the average private metropolitan house has a bill of $1800 annually (ABS 2018b), it does represent a change to the cost of living, which may mean that the occupants are less likely to want to implement the changes to their heating and cooling usage in order to keep their electricity bill effectively zero.

Table 6-17: Present value of original costs, costs with new additional solar installation and the value of savings for House 18

Years	Present value of electricity costs without additional solar	Present value of system + electricity costs	Present value of total energy savings	Present value of new savings
5	$1387.94	$3400.00	$13,805.28	$5783.41
6	$1634.34	$3400.00	$16,256.08	$6810.11
7	$1871.26	$3400.00	$18,612.61	$7797.33
8	$2099.07	$3400.00	$20,878.51	$8746.58
9	$2318.11	$3400.00	$23,057.26	$9659.31
10	$2528.73	$3400.00	$25,152.21	$10,536.95
15	$3466.38	$3400.00	$34,478.56	$14,444.01
20	$4237.06	$3400.00	$42,144.15	$17,655.33

There is roof space facing north-west where additional panels could be installed to make up for the current shortfall in PV-generated electricity. Table 6-17 shows the present value of what the householders would pay if they changed their heating and cooling behaviours but did not install additional solar. Over time, the costs would be smaller compared to the other houses, and it seems on the surface that the cost of the system (which is the only cost for this household, as the additional system would generate enough electricity to completely cover the new needs of the house) is not worth it, given the small amount of electricity paid for, as well as the relatively long payback period compared to the other houses, which is around 11 years.

However, what this table does not take into account is the excess energy produced and fed back into the grid, for which electricity companies will pay the household. With this new solar PV setup, the household would feed 2668.5 KWh back into the grid. Feed-in tariffs are currently anywhere between $0.07 and $0.11 per KWh, meaning that the system would earn the household between $180.80 and $293.54 a year. Thus, the household would earn money from their system which would make the yearly benefit between $492.57 and $605.31 total, giving payback times of between 5.6 and 6.9 years, depending on the feed-in tariff paid.

For the sake of simplicity, from this point on the feed-in tariff amount of $0.11 will be used for calculations. In Table 6-18 it becomes clear that if the feed-in tariff amount is taken into account as a negative amount paid by the household, the present value of the system plus savings decreases to the point that the present cost after 20 years is in fact negative. The amount saved by the household over time with the installation of the new system is also significant.

Table 6-18: Present value of the remaining electricity costs without additional solar, the cost of the system with feed-in tariffs applied, and the present value of the money saved by the additional solar PV system for House 18

Years	Present value of energy without additional solar	Present value of system + electricity produced	Present value of new savings
5	$1387.94	$2093.21	$5783.41
6	$1634.34	$1861.22	$6810.11
7	$1871.26	$1638.16	$7797.33
8	$2099.07	$1423.67	$8746.58
9	$2318.11	$1217.43	$9659.31
10	$2528.73	$1019.13	$10,536.95
15	$3466.38	$136.31	$14,444.01
20	$4237.06	−($589.30)	$17,655.33

The biggest challenge in a household like this is that going from relatively low electricity usage and no electricity bills to high usage (but still potentially no electricity bills) may not seem like the best use of their money. Convincing a household that they need to increase their electricity usage in times when people are wanting to decrease their power bills (and when they have already done so through the installation of a solar PV system) is counterintuitive, to say the least.

In a house like this, therefore, further research into the health economics of increasing the usage of heating and cooling may be required in order to provide a more convincing argument to the occupants. One recommendation from this study is that such work be carried out in order to show households, and potentially policy makers, that to spend money on solar PV is actually a way to save money in the long run, both for the household and for the health sector, which is funded by the tax dollars of the householders in the first place.

6.6.2.3 *House 16*

This house presented an interesting case in terms of existing solar PV cells, heating and cooling use, and house design. The house has what is known as a butterfly roof, where the angles are the inverse of what is seen on a typical hip or gable roof. For this reason, the majority of the solar PV cells of the house are situated on southeast roof area, but because of the inverted slope they actually capture the north-westerly sun. There are some solar PV cells on the north-west wing which face slightly south-east, but the orientation of this house is such that they will absorb the morning easterly sun. This house has a total of 21 panels already installed. It also currently relies largely on a slow-combustion fire for heating in the winter, although there is a reverse cycle unit on the wall in the main living area.

Due to the narrow range of temperatures that, according to this study, are conducive to the reduction of symptoms in older people, it is recommended that devices such as reverse cycle units are used in preference to the slow-combustion style heating, because of the fluctuating and unpredictable heating of the latter. Thus, in order for this house to remain at the temperatures recommended by the study, much larger amounts of electricity would need to be used. The occupant of this house mentioned being in significant credit with his electricity supplier due to the timing of the installation and the generous feed-in tariff he was guaranteed at the time, coupled with low heating energy from the use of the slow-combustion heater.

Again, as in House 18, it would potentially be difficult to convince a householder in this position to increase their electricity consumption and possibly lose this financial advantage.

The PV system currently installed on this house produces 5514 kWh per year, with a current energy use of only 2505.3 KWh. Heating and cooling this house to the level suggested by this study would take 6813.4 KWh per year. This would leave the householder with a modest electricity cost of $480.77 per year. Again, whilst this figure is significantly lower than that paid by most households, it is not what the householder is used to, and he is unlikely to be willing to change his heating and cooling behaviours for such a cost.

Despite the large number of panels already installed on this house, there is still room for some additional panels on the roof of the garage. The addition of 20 m^2 of panels on this house would allow it to generate an additional 2800 kWh per year, taking the total

PV-generated electricity to 8314 kWh per year. This would once again create an excess of electricity which would be fed back into the grid.

The calculations in Table 6-19 are based on a feed-in tariff of $0.11/kWh; however, it is possible, as this householder originally signed on for a higher rate, that the savings from the feed-in tariff would be greater. Thus Table 6-19 suggests a 'worst case' scenario and the actual present value of the system + electricity may thus be even lower. Note that unlike House 18, the present value after 20 years is not negative, as the annual amount of electricity fed into the grid is not as high. In this scenario, the additional system has a payback period of 5.2 years.

Table 6-19: Present value of the remaining electricity costs without additional solar, the cost of the system with feed-in tariffs applied, and the present value of the money saved by the additional solar PV system for House 16

Years	Present value of energy without additional solar	Present value of system + electricity produced	Present value electricity produced by new system
5	$2140.35	$2665.14	$4612.09
6	$2520.31	$2534.68	$10,622.67
7	$2885.67	$2409.24	$12,162.56
8	$3236.97	$2288.63	$13,643.23
9	$3574.76	$2172.65	$15,066.96
10	$3899.56	$2061.13	$16,435.92
15	$5345.50	$1564.69	$22,530.30
20	$6533.96	$1156.64	$27,539.44

Despite a lower amount of electricity being fed into the grid than in the previous example, the present value of the electricity that would be produced by a new system is significantly higher than the present value of energy bills.

Once again, this house represents a challenge when the numbers are in for the cost/benefit of adding addition solar PV cells to the house. There is still going to be a capital outlay, even if the payback period is short: it would therefore be much simpler for the occupant to maintain the status quo. This is especially true in the case of winter heating, where the current reliance on a wood-burning slow-combustion heater creates cheap (if not free, depending on the source of the fuel) warmth, despite that warmth being unpredictable and changeable. This presents not only a financial obstacle to change, but also an obstacle related to an occupant's habits, which only become more set the longer a person stays in their own home. As the addition of solar PV cells is part of the goal of creating a healthy thermal environment, this is a significant hurdle that cannot be ignored.

6.6.3 **Summary of solar PV as an aid to creating a healthy thermal environment**

The results from the previous section show that in houses with little or no current solar PV system, there are distinct advantages to investing in such a system, as it allows for additional heating and cooling to be utilised whilst the occupants save enough money on electricity bills to negate the initial capital expenditure in less than three years. For houses with systems already installed, the addition of more capacity to the existing system will see the capital expenditure returned, but over approximately twice as long as for houses with limited or no existing solar PV capacity.

An overall summary of the electricity and monetary savings as well as the payback period for each house can be found in Table 6-20. The main finding is that through the use of solar PV systems, older people can increase their use of heating and cooling to create the thermal conditions recommended by this study in a cost-neutral fashion.

Table 6-20: Electricity and monetary savings and payback period for new systems

House #	Current energy produced (kWh)	Energy produced by new system (kWh)	Total energy produced (kWh)	Total energy required (kWh)	Difference between electricity produced and electricity requirements (kWh)	Electricity cost before new solar ($)	New electricity cost (including $0.11 feed-in tariff)	Payback period for system (years)
4	0	3387.1	3387.1	4543	1155.9	$1,680.91	$427.68	2.71
10	0	3699	3699	4326.1	627.1	$1,600.66	$232.03	2.48
12	1959	5599.5	7558.5	8305.1	746.6	$2,348.06	$276.24	1.64
16	5514	2800	8314	6813.4	–1500.60	$480.78	–$165.07	5.26
18	4870.1	3511.1	8381.2	5712.7	–2668.50	$311.76	–$293.54	5.62

6.7 Summary

This chapter examines the benefits of building improvements on a range of variables. Improving the fabric of a building can improve the thermal conditions inside; however, these improvements must be coupled with changes to how the HVAC systems are used and how the house is ventilated in order to maximise the time during which the temperature of the house is within the range of temperatures conducive to good health as indicated in Chapter 5. When the building fabric is improved and the behaviours of the occupants change to increase HVAC usage and take advantage of summer night-time ventilation, these healthy conditions can be attained with similar electricity costs to the original building.

This chapter also raises questions as to the affordability of energy and the possibility of government subsidies to assist in making building improvements and energy efficiency accessible to older people, especially those on low fixed incomes. Using two examples from the study, it shows the effectiveness of home PV systems in offsetting the cost of electricity, and it indicates that such a system can fully negate all electricity costs, even when running HVAC systems for more hours than occupants currently do.

This chapter further examines the feasibility and cost-effectiveness of the installation and use of solar PV cells to reduce electricity costs for households, which in theory should allow people to heat and cool their homes to the levels that the field study results indicate are related to the fewest heat- and cold-related symptoms. Life cycle cost analysis shows that for the homes of older people with no existing solar PV system, or with a limited solar PV system, the installation of a new system would lead to significant savings on electricity, even when the occupants increase their use of heating and cooling.

In houses with larger existing systems, there may be more resistance to increasing the heating and cooling usage, because these houses currently produce an excess of electricity that is fed to the grid, meaning that they effectively incur negative energy bills. This could be overcome with an expansion of the existing system for a relatively small capital outlay; however, the payback period for houses with larger existing systems is longer than it is for a house with no existing system. Given that these householders have already outlaid significant capital for their existing systems, they may not receive the idea of further costs well. However, the evidence presented in this chapter shows a cost benefit in the long term, whilst allowing greater amounts of electricity to be used to for heating and cooling.

These results raise questions such as how best to inform older people about the need to heat and cool their houses, and how best to ensure that they are able to afford to do so. Large-scale health economics are outside of the scope of this study, but a cursory look at the costs of home improvement versus the potential for savings in the health system suggests that further investigation is warranted, in order to determine the potential for home improvement as a preventive health measure.

CHAPTER 7

Discussion

7.1 Overview

This chapter will discuss the implications of this research and recommendations for a variety of stakeholders, including future researchers, policy makers and individual householders. It will also compare the findings of this study to those of other studies and discuss what similarities and differences exist.

The predominant findings of the research indicate that

- the temperature of the houses in the study is lower than recommended for a significant amount of time
- the occupants of these houses typically find cooler conditions more thermally comfortable than expected, but temperatures between 21 °C and 24.3 °C would be comfortable for these participants and are also associated with the fewest presenting symptoms
- there is a heavy reliance on electricity for the provision of heating and cooling, which makes reaching the recommended temperatures difficult without significant increases in electricity usage and subsequent utility bills.

Thus, this chapter will examine the implications for householders faced with increased heating needs, as well as the priorities of housing design in the future.

7.2 Cold homes in a warm climate

The challenge of creating a healthy but comfortable thermal environment is twofold. First, the temperature in the houses in this study was lower than recommended for much of the time, even when the houses were occupied and there were heaters and coolers in use (under the control of the occupants). Second, this research found that the older people who occupied these homes had an overall preference for conditions that were cooler than predicted by thermal comfort models.

Australian houses are frequently either designed with features that keep the house cool, such as wide eaves, verandas and natural ventilation, or else they are designed to meet the minimum standard required by the building code to meet energy efficiency guidelines. This often results in homes being built which, in order to provide conditions that allow for the thermal comfort of the residents, rely on heating and cooling systems for much of the year, rather than passive systems utilising natural ventilation and solar gains.

In South Australia, residents are aware of the need to remain cool during the heatwaves that have become the norm during the summer months (and occasionally beyond, with heatwaves having been recorded in March). It would appear from the data collected during the field study that the participants were generally successful; the temperature in the houses was higher than 25 °C for only about 15% of hours, and higher than 24.3 °C, the maximum temperature recommended by Chapter 5 of this study, for only 20% of hours.

However, when it comes to lower temperatures, the results of the study show a pattern of under-heating across most of the houses. The temperature of the 18 houses in the study was lower than 21 °C, the minimum temperature associated with fewest symptoms in this group, for 50% of the time and lower than 18 °C, which is the minimum temperature advised by WHO as being healthy for sedentary people, for 25% of the time. All but one of these houses had access to some form of electrical heating, but the occupants either chose not to use it or had its thermostat set below the recommended temperature.

Despite temperatures being below 18 °C much of the time, the occupants were largely satisfied with the thermal environment of their house. They rated conditions acceptable 88% of the time; they expressed no preference for a change in conditions 75% of the time; and they recorded neutral TSVs 70% of the time. Participants were also more likely to express dissatisfaction with warmer conditions than with the cold. The combination of low indoor temperatures in the homes of older people coupled with their rating of these conditions as comfortable may be putting their health at risk, and this provides a challenge in terms of education regarding the health hazards of cold indoor temperatures, even in a 'warm' climate such as that in Adelaide.

Examination of the Housing and Health survey data, as discussed in Chapter 4, also reveals trends about behaviour during cool vs warm weather. Whilst the numbers of respondents who avoided using their heating was the same as those who avoided using their cooling, there were a greater number of responses about behavioural adaptations to the cold. Some people mentioned putting on an extra layer of clothing or using blankets to stay warm, or being more active in order to increase their body temperature. Whilst these adaptations may make the participants feel warmer, the air temperature, rather than the feeling of comfort, is what is most closely associated with the presence of symptoms (or the lack thereof), and thus these strategies may not be as beneficial for the occupants' health as increasing the room temperature in the colder months would be.

7.3 Preventing an increased reliance on increasingly expensive electricity

The results shown in Chapter 4 of this study show a very high reliance on electricity, especially for heating. Over 60% of the survey respondents utilised a reverse cycle system for their cooling, whether ducted or single-unit type, with around 25% relying on gas heating. The most recent data from the ABS (2014a) show that reliance on electricity for heating has increased dramatically, with 53.7% of households in South Australia relying on electrical systems for heating, which is an increase of 11.7% since 2005 (ABS 2011). This is also considerably higher than the national reliance on electricity for heating, which is 40.4% (ABS 2014a).

This increased reliance on electricity, especially for heating, has significant ramifications for the thermal comfort and health of the occupants of a house. As reported in Chapter 5, the temperature in the homes in this study was cold for significant amounts of time. The temperature in the houses in this study was lower than the temperature recommended by the study for the minimisation of cold-related symptoms for 50% of total hours, and for 47% of occupied hours. An examination of both the measured data and the simulated data from Chapter 6 shows that despite the relatively mild winters experienced in Adelaide and the propensity for extreme heat events during the summer months, heating is needed more often than cooling.

Should the recommended heating and cooling schedules proposed by Chapter 6 be implemented by a household, this would further increase the electricity usage of these houses (as all houses relied on reverse cycle systems) and significantly increase their electricity bills.

The challenge of increasing the amount of electricity used by older South Australians is further impacted by the rising cost of electricity. Wholesale electricity prices in Australia increased by 130% between 2015 and 2017, with household bills increasing by 20% in 2017 alone (Wood, Blowers & Percival 2018). The increase in wholesale electricity prices has hit South Australians particularly hard, because the wholesale cost of electricity makes up a larger proportion of the total bill than in other states, other parts of the bill including network costs, retail margins, environmental levies and so on (Wood, Blowers & Percival 2018).

Essentially, the findings of this study are that older people need to use more electricity to keep their homes warmer in an economy where electricity is already expensive and may continue to increase in cost. Even with the building improvements outlined in Chapter 6, which can help increase energy efficiency, the ability to keep houses adequately warm may well be out of reach for older people. If electricity costs are already a concern, the capital required to increase insulation and install new double glazing may not be available and, as demonstrated, these changes allow for increased heating at the same cost as houses are currently paying in electricity bills. This, for some households (but not necessarily those in this study), may already be more than the occupants can afford.

The recommendations of this study are thus as follows:

- It should be ensured that people know the risks of cold and hot indoor temperatures, with a particular emphasis on the dangers associated with winter cold.

- It should be ensured that households are able to keep their house at a comfortable and healthy temperature in an affordable manner.

7.3.1 The impact of photovoltaic cells and other energy concessions

The examination into the effect of both improving the house and changing occupant behaviour in regard to heating and cooling shows that creating a healthy thermal environment can be cost-effective, especially if the housing improvements are subsidised. The final data on total billed energy make evident the impact that having a system of photovoltaic cells installed has on the total amount paid for electricity. Despite doubling the hours of HVAC usage, the two houses which were already in energy credit remained so. Beyond the houses presented for improvement in this chapter, other participants in the field study also mentioned the use of PV systems, and typically claimed less worry or concern over the use of heating and cooling devices because they knew that at least some of their energy bills were offset by feeding energy into the grid.

The installation of PV cells on Australian houses, and especially in South Australia, has been encouraged in the past by generous government rebates at both state and federal levels (Simpson & Clifton 2015, Sivaraman & Horne 2011). Those who have been able to take advantage of these schemes have the long-term benefit of lower power bills and, in some cases, they feed more electricity into the grid than they produce and thus are in credit with their energy supply companies. Currently, the rebates and feed-in tariffs are not as generous as they have been in the past (Poruschi, Ambrey & Smart 2018). In light of the data from this chapter, one suggestion for making a thermally comfortable and healthy home possible for older people is the reintroduction of these more substantial rebates and tariffs.

One of the biggest challenges in encouraging increased use of heating and cooling is the cost of electricity, which is higher in South Australia than in other parts of the country (Harmsen 2017). There are some concessions available to older people through both government and energy providers. In South Australia there is an annual concession of $223.01 available to eligible pension holders and low income earners (Government of South Australia 2019). The South Australian Government has also partnered with a major electricity supplier to provide a discount of 18% on electricity supply up to a $531 a year for eligible pension holders (Government of South Australia 2019). This study suggests that more heating is required than is currently being used, and therefore more action will need to be taken in order to make the electricity required affordable, especially for older people on a fixed low income. As suggested previously, this could be in the form of subsidies for housing improvements, PV cell installation or both.

For a typical 150 m^2 double brick house, with 125m^2 of exterior wall and 20m^2 of glazing, the cost of adding wall insulation ($27.90/sqm), increasing ceiling insulation by 100mm ($10.60/sqm) and adding double glazing ($537.00/sqm) is approximately $15,000 (Rawlinsons Group 2018). With current concessions, the cost of a 5 kW solar PV system is approximately $3400 (Infinite Energy 2018). Either or both of these interventions would ensure that a house was warmer in winter and cooler in summer, which this research suggests could have an effect on the burden of the cost of illness amongst older people.

Data from the Australian Institute of Health and Welfare show that as a person ages the average cost of a hospital admission increases from around $4000 from ages 65–69 up to over $10,000 by ages 85–89 (AIHW 2017a). Another AIHW report in the same series shows that just under 23.5% of people aged over 65 are admitted to hospital each year, with as many as 31% of people aged 85 and over being admitted each year (AIHW 2017b). If, in the lifetime of the improvements, two hospitalisations are prevented by creating an optimal thermal environment, there is an overall saving to the health sector if the cost is completely covered by government subsidy, and there is an even bigger saving if there is a partial subsidy. The occupant could pay for some of the upgrades to their house, and would recoup these costs through cheaper electricity bills and feed-in tariffs from a home PV system. Further cost-benefit analysis by health economists could be of benefit to determine the exact savings available if hospitalisations are prevented.

There have been some limited studies examining the behaviours of older people in homes which have been retrofitted and the thermal conditions they experience. Following the installation of extra insulation and new reverse cycle HVAC units, most occupants continued their practice of turning their heater off overnight, and levels of under-heating of the home did not change (Willand, Maller & Ridley 2017a). Upon examination as to why this was the case, fear of high electricity bills was still found to be the major factor, despite the energy-efficient retrofits. In another study older people expressed dissatisfaction with energy companies and electricity bills, with some householders considering the installation of a solar PV system to alleviate high electricity costs (Willand & Horne 2018).

These findings show that whilst, theoretically, energy-efficient retrofits should make it easier to keep a house at a temperature which minimises heat- and cold-related symptoms, the reality is that once heating and cooling is increased after a retrofit, electricity bills will reduce only a small amount. For many householders, this means that there will still be stress related to the cost of electricity. For this reason, it is more important to make the changes in thermostat settings and patterns of heating and cooling affordable for older households than it is to simply increase energy efficiency.

7.3.2 **Emerging technology**

Production of electricity via photovoltaic cells and then feeding the electricity produced into the grid is well established in Australia as a means of both lowering electricity costs and reducing some of the reliance on fossil fuels. The feed-in system has changed over time and tariffs have dropped substantially since they were first introduced (Poruschi, Ambrey & Smart 2018). The feed-in tariff system also has limitations in terms of the times when electricity is being produced versus the times when it is most needed.

Until recently, storage of PV-generated electricity was expensive and unwieldy on a domestic scale. However, new technology has emerged which provides home electricity storage at increasingly affordable prices. Research shows that there is consumer interest in such storage, which would enable almost complete independence from the energy grid (Agnew & Dargusch 2017).

Whilst the price of such units has dropped, they still have a long payback period and require significant capital investment by the home owner. A recent study has shown that state governments have discussed subsidy arrangements to make battery storage more accessible (Agnew & Dargusch 2017), and increased production of these units will lead to decreasing prices, which will lower payback periods in the future. Battery storage may therefore offer a new way of decreasing electricity costs in the future and it may thus enable better winter warming practices without high electricity costs.

There are other technological solutions that are still largely in the developmental phase, or that have not seen a wide consumer take-up, which may also offer solutions to home thermal comfort into the future (Anvari-Moghaddam, Monsef & Rahimi-Kian 2015). Increasingly, so called smart homes and 'the internet of things' allow networked control of many household devices. Smart phone technology allows users to turn on heating and cooling devices when they have been out and are on their way home, for instance, which means a recommended thermal environment can be created without leaving heating or cooling running whilst the occupant is absent (Anvari-Moghaddam, Monsef & Rahimi-Kian 2015). With the increasing availability of home sensors and smart devices, these smart homes will likely play a part in creating a thermally comfortable home, in combination with home energy production and storage.

It is unlikely these technologies will evolve into common home use individually: a combination of some or all of these devices and materials will probably be integrated into residences in the future. Whilst this has promise for the ageing population as it increases in the future, it is not good enough to rely on future technology to solve the problems of houses that are under-heated currently. This thesis therefore has studied more immediate solutions that can be implemented with existing technology, whilst indicating awareness that these recommendations may evolve in the future.

7.4 Comparisons with other studies

This study sits between a number of research areas: ageing and thermal comfort, health and thermal comfort, and indoor environment and health. Whilst the indoor environment is related to thermal comfort, there have been few if any studies which directly associate both of these areas with health, even before considering the effect on older people specifically.

As discussed in Chapter 2, the literature has mixed results when considering the thermal comfort of older people. Studies across climate chambers differ from field studies, with the latter typically resulting in larger differences in the preferences of older people compared to thermal comfort standards (Soebarto, Zhang & Schiavon 2019). In the home, participants typically have the ability to control the factors related to thermal comfort, and this sense of control has been attributed to feelings of comfort outside of what is predicted. This control is over both the heating and cooling systems as well as adaptive mechanisms such as clothing levels and ventilation, all of which are typically fixed in a climate chamber study. This should perhaps come as no surprise, given the early studies of Rohles and others (Heijs & Stringer 1988, Rohles 1971, Rohles 1980) into environmental psychology and what role factors such as control and appearance have on the experience of thermal comfort.

In this study, the thermal comfort of the participants was again found to be different to that predicted by the various thermal comfort models. In this older cohort, feelings of comfort were frequently experienced at much lower temperatures than expected. This is in line with studies that have shown delayed physiological responses amongst older people, with lower temperatures needed to elicit a thermoregulatory response. Such physiological measurements were not taken in this study, but they nonetheless exist as a possible explanation for these findings.

Similar results of comfort in cooler than predicted conditions have been found amongst older people in some regions of China, specifically the rural areas (Fan et al. 2017, Jiao et al. 2017). Like the cohort studied in this thesis, these older Chinese people had similar thermal preferences to younger people. Interestingly, in these Chinese studies, those who lived in urban areas had similar thermal preferences to younger people. The authors of these studies list life experience and acclimatisation as primary factors; those in urban centres are typically more accustomed to using heating and cooling whilst these appliances are not always available in rural areas, or may be a newer addition to the house.

Some of the older people studied in this thesis mentioned past experience, especially of heating, as a factor in their winter warmth practices. They mentioned having not had heating in their homes as children, and having always survivied without it before, they didn't feel the need to use it now. This narrative would go someway to explaining the acclimatisation to and expectation of lower temperatures in their houses. It is similar to the reasoning in the Chinese studies, and warrants further investigation as the acceptance of cold houses may pose more of a threat to the health of older people than to younger people.

This study has filled a knowledge gap, in that as well as examining thermal comfort and preferences, it examined how these preferences may be influencing the health of the older people studied. Acceptance of colder than predicted temperatures is linked with the presence of cold related symptoms when homes are below 21 °C. High temperatures were also associated with the presence of symptoms but importantly older people typically did not show a preference for hotter than predicted conditions. They are more likely then to avoid heat related symptoms due to adaptive behaviours than they are to avoid cold related symptoms. Future research should aim to determine why the preference for lower temperatures persists to better target messages about the danger of winter cold.

7.5 Limitations and considerations

This research has covered the thermal experiences of a very small group of South Australian older people. It is by no means a comprehensive examination of the experiences of all older people, or even of all older Australians and therefore the results cannot be generalised to represent all older people. It does, however, show alarming trends about the conditions in Australian houses which present a potential health risk, not just for older people but for the population more broadly. In essence, Australian houses are not typically designed to maintain heat in winter, and the high costs of living and, in particular, high energy costs can lead to other factors that affect a person's health, such as their inability to afford medical treatment.

This leads to one of the limitations of this project: the socioeconomic status of the participants, in particular those who participated in the field study. Participants were largely self-funded retirees, living without a mortgage. Some received a part pension in addition to their superannuation income. However, this represents a group of people who typically have incomes slightly higher than is average for older people, and this makes them slightly less vulnerable to challenges such as energy poverty. Very few of these participants represented the most vulnerable of older people—who are typically single women who live only on the Age Pension of less than $20,000 a year.

It is possible that those in this situation have even colder homes than the ones studied in this research, due to a lack of funds to enable them to heat their homes even at a basic capacity, let alone to the levels required to keep them in the healthy temperature zone. Future research examining the homes specifically of those in lower socioeconomic brackets should be considered, so as to enable recommendations and policies to be put into place to support these more vulnerable older people. In this study, efforts were made to include a wider range of socioeconomic groups, but access to more vulnerable people was limited, by both ethical and practical considerations.

Another consideration that is worth further examination than was possible in this study is the sacrifice that one person may make for another in regard to their thermal comfort. One household in particular gave a good representation of this: a healthy woman and her husband with Alzheimer's disease. His condition progressed over the course of the study, and one of his symptoms meant he could not tolerate the feeling of air blowing on him, which meant that their ducted system could not be used to heat or cool the house. This house had other heating systems available, but during summer the wife suffered in the heat because her husband's behaviour became unmanageable if the air-conditioning was used.

This sort of situation was seen in one other house, where one member of the household suffered an illness requiring high levels of heating to remain comfortable, thereby leaving the other occupant warmer than preferred.

Whilst it would seem logical that comfort is maximised for the frailer person in a relationship, the healthier individual is not immune from the effects of discomfort and extremes in temperature. Should a carer suddenly fall ill, whether from temperature-related illness or otherwise, there is a shift in dynamic in the relationship in the household. One or both people may now, for instance, require a level of care they are unable to give to each other and they may require hospitalisation or a move into a residential care facility. This phenomenon warrants further investigation, in order to determine how prevalent the sacrifice of comfort is amongst older carers, and whether this is putting their health at risk.

A further shortfall in this study was that in some instances only one person in a two-person household completed the surveys. From conversations with couples during home visits and from the comments recorded on the surveys in other houses, it became clear that there were instances of ill health amongst such households that were not formally recorded in the comfort vote data. There were, for instance, at least two instances where the wife of the husband who was completing the survey had had a fall.

Fall data, in particular, is something that it would be beneficial to capture, as it is one of the symptoms that is not only shown to be exacerbated by cold but also often has poor recovery and long-term complications. Two of the female participants in the study reported more than one fall in the study period; however, the numbers of participants in this survey is not enough to examine the data surrounding falls and indoor temperature in any great detail.

This represents another area for further study, which could focus on the prevalence of falls in regard to indoor temperature and the possible means of prevention.

7.6 Recommendations arising from the research

Despite the possibility of retrofitting and proven cost-effectiveness, it is likely that people may still not choose this option. Some older people may not have the capital available, or they may not have the ability to make such changes to their dwelling. The recommendations from this analysis of the heating and cooling needs of older people and the subsequent life cycle cost analysis are thus as follows:

V. There should be targeted education of people approaching retirement age (50–65) of the dangers to their health of heat and cold and of the optimum temperature for good health. This education could include information about the installation of home energy systems such as solar PV, the cost:benefit of such systems, and the recommendation that people think about their future electricity requirements whilst they are still earning and have the capacity to install potential solutions.

VI. More should be done for people who are already retired and lack the capital to install their own home energy systems, in order to make electricity more affordable for them. Whilst there are currently some concessions in South Australia, these are limited to discounts of only 18%, up to a value of $531 per year, and only through one energy provider as negotiated by the state government. Those on low or fixed incomes may be eligible for a further $223.01 in concessions; however, this concession is means-tested and only available to those on the Age Pension.

    For example, for House 10 in this study, making the required changes to their heating and cooling results in an electricity bill of $1600.67 per year. An 18% discount and a $223.01 government concession reduces their yearly bill to $1089.53, much higher than it would be with even a small solar PV system installed. There is also an energy concession available via the federal pension scheme of $14.10 per fortnight for singles and $21.20 per fortnight for couples. Whilst for the occupants of House 10 this equals approximately half of the annual energy bill left after the other concessions, it is worth noting that this is received with the pension, and, whilst it is intended to cover electricity costs, it may easily be absorbed into other expenses. Also, for a single person it represents only $366.60 annually. However as shown by House 4, a smaller house with only one person can use nearly as much electricity as a household of two people.

All of these concessions and discounts come with eligibility requirements that may rule out a person even on a small income. Providing home energy generation systems would provide a permanent means of reducing electricity bills, making it possible for older people to achieve healthy thermal conditions indoors.

VII. Further research should be conducted into the health economics of creating a thermal environment more conducive to the good health of older people. The broad scope of this research thesis is whether housing can be a form of preventive health care; the cost/benefit of this should be examined from the perspective of preventing hospitalisations and entry into aged care. Obviously, this would require further study into the relationship between indoor temperature and the health of the occupants, particularly in other states and other climate zones. Given the many links between housing and health that have been discussed in this thesis, particularly in Chapter 2, it is not a vast leap to suggest that housing improvement, done in a targeted and well-informed manner, will result in better health of the occupants, regardless of age but especially in vulnerable populations such as older people and people with a disability.

These recommendations all come with a caveat that this research has covered only a small number of households and participants. Ideally, this research can be expanded in the future, to cover a wider group of participants, including different socioeconomic groups, ethnicities and living situations. There are a number of specific needs that are not examined in this research relating to, for example, older people with dementia or other illnesses, and these may complicate the experience of temperature and thermal comfort. These should be examined further before universal recommendations about the thermal environment for older people are made, as these conditions may have specific requirements not yet explored in this research.

7.7 Summary

This chapter includes a discussion surrounding the increasing reliance of Australian households on electricity to heat and cool their homes. With this increased usage comes increased costs, and yet the results of the field study and housing improvement show a need for increased heating and cooling, even once houses are improved in terms of insulation and glazing.

This chapter further recommends greater means of making electricity affordable for older people than are currently provided, including the possibility of providing financial assistance to install solar PV systems or other small-scale electricity generators in the homes of older people, in order to make the electricity bills more affordable. A final recommendation is to examine the cost benefit of housing improvement to the health system overall, and to examine whether housing improvement as a preventive health measure is cost-effective and beneficial to the hospital and residential care systems.

This chapter includes some discussion of the shortfalls of this study, along with issues arising from the study that warrant further investigation. Ideally, a study examining any kind of health issue would have more participants over a greater range of locations and socioeconomic groups; however, this was not possible within the scale and time frame of this study. Further research into these links, especially in lower socioeconomic groups and different climactic zones, is recommended.

Finally, this chapter lists a number of recommendations, which include acknowledging the need to educate people about the dangers of heat and cold inside their homes, and what can be done to prepare a house as an occupant enters older age. Because of concerns around capital for home improvement, it is suggested that this education target those in their 50s and 60s, who may be planning their retirement but who are still in an employment-type situation, which means that they are more likely to be financially able to make the suggested improvements.

CHAPTER 8

Conclusions

Housing for older people presents a challenge to Australian policy makers. A house not only represents a place to live, but also creates an environment that has flow-on effects to the comfort and health of the occupant. There is thus a largely untapped potential for houses to be utilised as a tool for ageing well—a tool that can potentially be altered in order to increase the quality of life for those who live in them.

This chapter begins by taking the findings from the different parts of this study and using them to address the research aims posed in Chapter 1. It will then outline the findings that have implications for the health and comfort of older people and how such issues might be addressed.

8.1 Addressing the research aims

In order to ascertain the success of this research, the stated aims will be revisited and conclusions drawn from the findings of the different parts of the studies.

8.1.1 **Research Aim 1**

To investigate the relationship between the indoor thermal environment of the home, the comfort perception of older people, and their health

Overall, this study found that older people found that their houses provided adequate thermal comfort, with participants noting an acceptable thermal comfort vote (between –1 and 1 on the ASHRAE 7-point scale) approximately 65% of the time in the surveys and 77% of the time in the field study. The field study showed that this level of thermal comfort is experienced at lower temperatures than predicted by models of thermal comfort, such as Fanger's PPD/PMV model and the Adaptive Thermal Comfort model. This may be due to a change in perception with ageing, but the physiological tests required to confirm this were outside the scope of this research.

The field study revealed that there is a relationship between the indoor temperatures and the presentation of heat- and cold-related symptoms in otherwise healthy older people, which is binomial, and therefore the symptoms in these data were related to both low and high indoor temperatures, for both the daily indoor minimum and maximum temperatures. This result suggested that an indoor range of temperatures which would be related to the fewest symptoms was between 21 °C and 24.3 °C. This range is narrower than that suggested by the World Health Organization (18 °C to 25 °C). Houses in this study were lower than 21 °C for 47.8% of the time. This is evidence that older people are being exposed to conditions that may be related to the presence of cold-related symptoms.

Symptoms were also related to heat, with high indoor minimum temperatures as well as high indoor maximum temperatures being related to the increased presence of symptoms. This suggests that high overnight temperatures may be related to the presence of symptoms, and that night-time ventilation or cooling may thus be related to a reduction in the presentation of symptoms, as well as staying cool during the day.

The fact that the houses in this field study were at temperatures lower than recommended for much of the time despite heating being used indicates that

- the house on its own was not providing an ideal thermal environment and
- heating usage was inadequate in these houses, either due to patterns of usage or the thermostat settings.

Information from both the survey and the field study suggests that, rather than relying on a thermostat to maintain a comfortable indoor temperature, most participants turned their systems on and off in relation to their comfort. For instance, if they felt too cold they would turn the heating on until such time as they were comfortable, and then they would switch it off again.

8.1.2 **Research Aim 2**

To investigate ways to create a more thermally comfortable, healthy and low-energy environment to accommodate older people in their homes

As shown in Section 8.2.1, the houses in the field study component of this research did not provide an ideal thermal environment. Whilst the occupants were comfortable for a majority of the time, they were comfortable at temperatures which were lower than recommended by the results of the field study as well as by those suggested by thermal comfort models. Thus, a building improvement study was undertaken to see what changes could be made to the indoor conditions by changing aspects of the building fabric.

The improvement study found that whilst changes such as increasing insulation and adding double glazing do make a difference to the amount of time that the temperature of a house is within recommended temperatures, such improvements will not replace the need for heating and cooling. Even with building fabric changes, occupants would need to increase the heating in their house in winter, and change the way they cool and ventilate their house in summer, in order to create an environment in line with the recommendations from the study. Doing so would mean that their current electricity usage would, at a minimum, remain the same, and it might possibly increase if the improvements were not enough to offset the increased heating and cooling usage. Given the high costs of electricity and the concerns of some older people in the study about its affordability, it is unlikely that these people would make the suggested changes either to their house or to their heating and cooling usage.

What is needed, therefore, is a means of increasing heating and cooling use without an increase in electricity bills. This study examined the feasibility of rooftop photovoltaic cells as a means to produce electricity that can be returned to the grid for a feed-in tariff, thereby offsetting energy costs to the household. It found that for those without photovoltaic systems in place, the payback time is relatively short (2.5–3 years), and even with a small roof area enough electricity can be generated to offset most if not all of the household’s electricity bill.

For a house which already has some photovoltaic cells installed, upgrading this system may be an option to cover the extra electricity needed to heat and cool the house to the recommended temperatures. This is complicated by the feed-in tariff system and the way it has changed over time: occupants who installed photovoltaic cells between five and eight years ago get a larger feed-in tariff than those with newer systems. Many who already have such systems are in credit with their energy providers because of the high rate they are paid for energy fed to the grid and they are unlikely to want to sacrifice this. Installing any additional cells would likely mean that their feed-in tariff would drop to the rate for new systems, and even though the payback period for the cost of the system might be as short as 1.5 years, the loss of the high feed-in tariff and negative energy bills would likely dissuade occupants from investing in a larger PV system.

8.2 Recommendations and conclusion

The primary issue that arises from this study is that many older people live in housing that may be under-heated. Whether this is due to thermal comfort preferences, lifelong heating practices or concerns about electricity costs needs to be investigated further to provide an appropriate intervention. It is clear, however, that the current housing stock cannot provide appropriate thermal conditions without significant redesign and remodelling, as simple interventions alone will not provide the warmth needed in winter.

In the short to medium term, older people should be made aware of the dangers of living in a cold house and given the means to be able to appropriately heat it. These means could be in the form of significant energy concessions that acknowledge the specific needs of older people, their heating requirements, and their often limited incomes. They could also come in the form of small-scale electricity production at the household level, with photovoltaic cells providing a means of reducing power bills with a relatively short payback period.

Longer-term recommendations should address a need for thermal comfort guidelines within the National Construction Code for residential buildings, with a greater emphasis on the need for warmth in winter than is currently provided for in the energy efficiency sections of the code. This may include the use of new technologies in areas such as building materials and battery storage of household-generated electricity.

For existing homes, building improvements such as increased insulation and double glazing do not provide adequate means for improving the thermal environment. This means that a 'low-energy' strategy for creating a thermally comfortable environment with temperatures that relate to fewer symptoms was not achieved in this study. By installing photovoltaic systems, occupants could, however, potentially have lower energy costs, despite using more electricity overall to heat and cool their house to recommended temperatures. Investment in home electricity production such as via the use of photovoltaic systems thus represents a better return than investments in building fabric improvements. If adequate funds were available or provided through housing improvement subsidies for both, the quality of the indoor environment would be more in line with the recommendations for temperature, and this might then be related to a resulting decrease in the presentation of heat- and cold-related symptoms.

References

ABCB 2004. BCA 2004. *Building Code of Australia.* Australian Building Codes Board.

ABCB 2010. Information handbook. *Energy Efficiency Provisions for BCA 2010*

Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., Adger, W. N. & Raine, R. 2009. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. *Journal of public health,* 31**,** 119-126.

ABS. 1999. *Australian Housing Survey - Housing characteristics, costs and conditions* [Online]. Canberra. Available: http://www.abs.gov.au/Ausstats/abs@.nsf/0e5fa1cc95cd093c4a2568110007852b/53af1d370fc826feca256988007bf6a9!OpenDocument.

ABS. 2009. *Feature article: heating and cooling* [Online]. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1345.4Feature%20Article1Aug%202009 [Accessed 30 June 2014].

ABS. 2011. *4602.0.55.001 - Environmental issues: Energy use and conservation, Mar 2011* [Online]. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4602.0.55.001Main+Features1Mar%202011?OpenDocument [Accessed 14/11/18.

ABS. 2012a. *Still on the move* [Online]. Canberra: ABS. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/2071.0Main%20Features702012%E2%80%932013?opendocument&tabname=Summary&prodno=2071.0&issue=2012%962013&num=&view= [Accessed 10/1/17 2016].

ABS 2012b. *Year Book Australia,* Canberra, Australian Bureau of Statistics.

ABS. 2013a. *Australian Health Survey: Biomedical Results for Chronic Diseases, 2011-12: Diabetes Prevalence* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/9769589F9E465EE6CA257BBB00121648?opendocument [Accessed 16/1/2017.

ABS. 2013b. *Australian Health Survey: Health Service Usage and Health Related Actions, 2011-12* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4364.0.55.002Main+Features12011-12?OpenDocument [Accessed 16/1/17.

ABS. 2013c. *Australian Health Survey: Updated Results, 2011-2012* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4364.0.55.003Chapter2002011-2012 [Accessed 9/1/17 2017].

ABS. 2013d. *Household Energy Consumption Survey, Australia: Summary of Results, 2012* [Online]. Canberra: Australian bureau of statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4670.0main+features132012 [Accessed 5/1/17 2017].

ABS. 2013e. *Population projections, Australia, 2012 (base) to 2101* [Online]. Canberra: ABS. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3222.0main+features52012%20%28base%29%20to%202101 [Accessed 18 March 2014].

ABS. 2013f. *Reflecting a Nation: Stories from the 2011 Census, 2012–2013 Where and how do Australia's older people live?* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/2071.0main+features602012-2013 [Accessed 16/1/17 2017].

ABS. 2014a. *4602.0.55.001 - Environmental Issues: Energy Use and Conservation, Mar 2014* [Online]. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4602.0.55.001Main+Features1Mar%202014?OpenDocument [Accessed 13/11/2018.

ABS. 2014b. *Environmental Issues: Energy Use and Conservation, Mar 2014* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4602.0.55.001Main+Features1Mar%202014?OpenDocument 2017].

ABS. 2015a. *Disability, Ageing and Carers, Australia: Summary of Findings, 2015* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4430.0main+features302015 [Accessed 22/3/2017 2017].

ABS. 2015b. *Household Income and Wealth, Australia, 2013-14* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/6523.0~2013-14~Main%20Features~Key%20Findings~1 [Accessed 16/01/2017.

ABS. 2016a. *Greater Adelaide (GCCSA)* [Online]. Canberra: Australian Bureau of Statistics. Available: http://stat.abs.gov.au/itt/r.jsp?RegionSummary&region=4GADE&dataset=ABS_REGIONAL_ASGS&geoconcept=REGION&measure=MEASURE&datasetASGS=ABS_REGIONAL_ASGS&datasetLGA=ABS_REGIONAL_LGA&regionLGA=REGION&regionASGS=REGION [Accessed 19/1/2017.

ABS. 2016b. *Household Use of Information Technology, Australia, 2014-15* [Online]. Canberra: Australian Bureau of Statistics. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/8146.0Main+Features12014-15?OpenDocument [Accessed 1/3/2017.

ABS. 2016c. *South Australia (S/T)* [Online]. Canberra: Australian Bureau of Statistics. Available: http://stat.abs.gov.au/itt/r.jsp?RegionSummary&region=4&dataset=ABS_REGIONAL_ASGS&geoconcept=REGION&measure=MEASURE&datasetASGS=ABS_REGIONAL_ASGS&datasetLGA=ABS_REGIONAL_LGA&regionLGA=REGION&regionASGS=REGION [Accessed 16/1/2017.

ABS. 2017a. *2016 Census Community Profiles* [Online]. Available: https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/communityprofile/4?opendocument [Accessed 7/6/2019.

ABS. 2017b. *Census of population and housing: Reflecting Australia - Stories from the Census, 2016* [Online]. Available: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2071.0~2016~Main%20Features~Ageing%20Population~14 [Accessed 09/10/2018.

ABS. 2018a. *3222.0 - Population Projections, Australia, 2017 (base) - 2066* [Online]. Available: https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3222.0 [Accessed 2/6/2019.

ABS. 2018b. *6401.0 - Consumer Price Index, Australia, Jun 2018* [Online]. Canberra: ABS. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6401.0Jun%202018?OpenDocument [Accessed 3/12/2018.

Agnew, S. & Dargusch, P. 2017. Consumer preferences for household-level battery energy storage. *Renewable and Sustainable Energy Reviews,* 75**,** 609-617.

AIHW 2007. Older Australia at a glance: 4th edition. Canberra: Australian Institute of Health and Welfare.

AIHW 2013. The desire to age in place among older Australians. Canberra: Australian Institute of Health and Welfare.

AIHW 2014. Arthritis and other musculoskeletal conditions across the life stages. Canberra: AIHW.

AIHW 2016. Australia's hospitals 2014 - 15 at a glance. Canberra: Australian Institute of Health and Welfare.

AIHW 2017a. Australian health expenditure—demographics and diseases: hospital admitted patient expenditure 2004–05 to 2012–13. *Health and welfare expenditure series.* Canberra, ACT.

AIHW 2017b. Health care use by older Australians. Canberra.

AIHW 2017c. Older Australia at a glance.

Akompab, D., Bi, P., Williams, S., Grant, J., Walker, I. & Augoustinos, M. 2013. Awareness of and Attitudes towards Heat Waves within the Context of Climate Change among a Cohort of Residents in Adelaide, Australia. *International Journal of Environmental Research and Public Health,* 10**,** 1.

Aktacir, M. A., Büyükalaca, O. & Yılmaz, T. 2010. A case study for influence of building thermal insulation on cooling load and air-conditioning system in the hot and humid regions. *Applied Energy,* 87**,** 599-607.

Analitis, A., Katsouyanni, K., Biggeri, A., Baccini, M., Forsberg, B., Bisanti, L., Kirchmayer, U., Ballester, F., Cadum, E. & Goodman, P. 2008. Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. *American journal of epidemiology,* 168**,** 1397-1408.

Anderson, B. G. & Bell, M. L. 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology,* 20**,** 205.

Anderson, G., Meneilly, G. & Mekjavic, I. 1996. Passive temperature lability in the elderly. *European journal of applied physiology and occupational physiology,* 73**,** 278-286.

Anderson, J. J. 1982. Guarded window test apparatus for determining the insulation value of interior window coverings. *Textile Research Journal,* 52**,** 643-651.

Anvari-Moghaddam, A., Monsef, H. & Rahimi-Kian, A. 2015. Optimal smarthome energy management considering energy saving and a comfortable lifestyle. *IEEE Transactions on Smart Grid,* 6**,** 324-332.

ASHRAE 2013. *ANSI/ASHRAE standards 55-2013, thermal environmental conditions for human occupancy,* Atlanta, GA, ASHRAE.

Australian Competition and Consumer Commission 2017. Retail electricity pricing inquiry: preliminary report. Canberra: Commonwealth of Australia.

Australian Council of Social Service 2018. Energy stressed in Australia. NSW: Australian Council of Social Service.

AutoDesk Inc 2016. AutoCAD Architecture. 7.8.44.0 ed.

Babich, F., Cook, M. J., Loveday, D. L. & Cropper, P. C. 2016. Numerical modelling of thermal comfort in non-uniform environments using real-time coupled simulation models.

Bailie, R. S. & Wayte, K. J. 2006. Housing and health in Indigenous communities: Key issues for housing and health improvement in remote Aboriginal and Torres Strait Islander communities. *Australian Journal of Rural Health,* 14**,** 178-183.

Baker, E., Bentley, R. & Mason, K. 2013. The mental health effects of housing tenure: causal or compositional? *Urban Studies,* 50**,** 426-442.

Baker, E. & Lester, L. 2017. Multiple housing problems: A view through the housing niche lens. *Cities,* 62**,** 146-151.

Baker, E., Lester, L., Bentley, R. & Beer, A. 2016. Poor housing quality: Prevalence and health effects. *Journal of Prevention & Intervention in the Community,* 44**,** 219-232.

Bastow, M. D., Rawlings, J. & Allison, S. P. 1983. Undernutrition, hypothermia, and injury in elderly women with fractured femur: an injury response to altered metabolism? *The Lancet,* 321**,** 143-146.

Becker, R. & Paciuk, M. 2009. Thermal comfort in residential buildings–failure to predict by standard model. *Building and Environment,* 44**,** 948-960.

Bentley, R., Baker, E. & Mason, K. 2012. Cumulative exposure to poor housing affordability and its association with mental health in men and women. *Journal Epidemiology and Community Health,* 66**,** 761-766.

Berkhout, P. H., Muskens, J. C. & Velthuijsen, J. W. 2000. Defining the rebound effect. *Energy policy,* 28**,** 425-432.

Bi, P., Williams, S., Loughnan, M., Lloyd, G., Hansen, A., Kjellstrom, T., Dear, K. & Saniotis, A. 2011. The effects of extreme heat on human mortality and morbidity in Australia: implications for public health. *Asia-Pacific journal of public health***,** 1010539510391644.

BOM. 2015a. *Adelaide in July 2015: Below average temperatures; average rainfall* [Online]. Available: http://www.bom.gov.au/climate/current/month/sa/archive/201507.adelaide.shtml [Accessed 07/11/2017.

BOM. 2015b. *Adelaide in October 2015: Dry overall with above-average temperatures* [Online]. Available: http://www.bom.gov.au/climate/current/month/sa/archive/201510.adelaide.shtml [Accessed 23/8/2018 2018].

BOM. 2017a. *Climate Data Site - Mount Lofty* [Online]. Available: http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p_stn_num=023842&p_prim_element_index=0&p_nccObsCode=122&period_of_avg=&normals_years=&redraw=null&p_display_type=enlarged_map.

BOM. 2017b. *Climate Data Sites - Adelaide (Kent Town)* [Online]. Available: http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p_stn_num=023090&p_prim_element_index=0&p_nccObsCode=123&period_of_avg=&normals_years=&redraw=null&p_display_type=enlarged_map.

BOM. 2017c. *Climate Data Sites - Adelaide Airport* [Online]. Available: http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p_stn_num=023034&p_prim_element_index=0&p_nccObsCode=122&period_of_avg=&normals_years=&redraw=null&p_display_type=enlarged_map.

Bonnefoy, X. 2007. Inadequate housing and health: an overview. *International Journal of Environment and Pollution,* 30**,** 411-429.

Braga, A. L. F., Zanobetti, A. & Schwartz, J. 2001. The time course of weather-related deaths. *Epidemiology,* 12**,** 662-667.

Brager, G., Fountain, M., Benton, C., Arens, E. A. & Bauman, F. 1993. A comparison of methods for assessing thermal sensation and acceptability in the field.

Bridge, C. & Flynn, M. Home maintenance and modification information needs and evidence-based practice solutions in NSW. National Housing Conference 2003 Adelaide, Australia.

Bright, F. M., Winskog, C., Walker, M. & Byard, R. W. 2014. A Comparison of Hypothermic Deaths in South Australia and Sweden. *Journal of Forensic Sciences,* 59**,** 983-985.

Byrd, H. & Matthewman, S. 2012. Warm up New Zealand: Heat smart-a critical overview. *New Zealand Sociology,* 27**,** 54.

Campbell, A. J., Spears, G., Borrie, M. & Fitzgerald, J. 1988. Falls, elderly women and the cold. *Gerontology,* 34**,** 205-208.

Cao, B., Luo, M., Li, M. & Zhu, Y. 2016. Too cold or too warm? A winter thermal comfort study in different climate zones in China. *Energy and Buildings,* 133**,** 469-477.

Cao, B., Zhu, Y., Ouyang, Q., Zhou, X. & Huang, L. 2011. Field study of human thermal comfort and thermal adaptability during the summer and winter in Beijing. *Energy and Buildings,* 43**,** 1051-1056.

CEN 2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. EU: European Commitee for Standardisation (CEN).

Chandola, T. & Jenkinson, C. 2000. Validating self-rated health in different ethnic groups. *Ethnicity and Health,* 5**,** 151-9.

Chapman, R., Howden-Chapman, P., Viggers, H., O'dea, D. & Kennedy, M. 2009. Retrofitting houses with insulation: a cost–benefit analysis of a randomised community trial. *Journal of epidemiology and community health,* 63**,** 271-277.

Chester, L. 2014. The Growing Un-affordability of Energy for Households and the Consequences. *International association for energy economics newsletter,* Second quarter 2014**,** 23-27

Chester, L. & Morris, A. 2011. A new form of energy poverty is the hallmark of liberalised electricity sectors. *Australian Journal of Social Issues,* 46.

Climate Change Authority 2012. Renewable energy target review. *Final Report. Commonwealth of Australia. www. climatechangeauthority. gov. au*.

Collins, K., Exton-Smith, A. & Doré, C. 1981. Urban hypothermia: preferred temperature and thermal perception in old age. *British Medical Journal (Clinical Research Edition),* 282**,** 175-177.

Collins, K. & Hoinville, E. 1980. Temperature requirements in old age. *Building Services Engineering Research and Technology,* 1**,** 165-172.

Commonwealth of Australia 2015. 2015 Intergenerational Report: Australia in 2055. *In:* Treasury (ed.). Canberra: Commonwealth of Australia.

Conti, S., Meli, P., Minelli, G., Solimini, R., Toccaceli, V., Vichi, M., Beltrano, C. & Perini, L. 2005. Epidemiologic study of mortality during the Summer 2003 heat wave in Italy. *Environmental Research,* 98**,** 390-399.

Cooper, G. 2002. *Air-conditioning America: engineers and the controlled environment, 1900-1960*, JHU Press.

Crawford, V. L. S., McCann, M. & Stout, R. W. 2003. Changes in seasonal deaths from myocardial infarction. *QJM: An International Journal of Medicine,* 96**,** 45-52.

CSR Edmonds 2018. Odyssey technical data sheet. NSW: CSR Edmonds.

Cumming, R. G., Nevitt, M. C. & Cummings, S. R. 1997. Epidemiology of Hip Fractures. *Epidemiologic Reviews,* 19**,** 244-257.

Daniel, L., Baker, E. & Lester, L. 2018. Measuring housing affordability stress: can deprivation capture risk made real? *Urban Policy and Research,* 36**,** 271-286.

Daniel, L., Baker, E. & Williamson, T. 2019. Cold housing in mild-climate countries: A study of indoor environmental quality and comfort preferences in homes, Adelaide, Australia. *Building and Environment,* 151**,** 207-218.

Daniel, L., Soebarto, V. & Williamson, T. 2015. House energy rating schemes and low energy dwellings: The impact of occupant behaviours in Australia. *Energy and Buildings,* 88**,** 34-44.

Daniel, L., Williamson, T., Soebarto, V. & Chen, D. 2015. Learning from thermal mavericks in Australia: comfort studies in Melbourne and Darwin. *Architectural Science Review,* 58**,** 57-66.

Davie, G. S., Baker, M. G., Hales, S. & Carlin, J. B. 2007. Trends and determinants of excess winter mortality in New Zealand: 1980 to 2000. *BMC Public Health,* 7**,** 263.

Davis, S. L., Wilson, T. E., White, A. T. & Frohman, E. M. 2010. Thermoregulation in multiple sclerosis. *Journal of Applied Physiology,* 109**,** 1531-1537.

Day, R. 2015. Low carbon thermal technologies in an ageing society–What are the issues? *Energy Policy,* 84**,** 250-256.

Day, R. & Hitchings, R. 2011. 'Only old ladies would do that': Age stigma and older people's strategies for dealing with winter cold. *Health & Place,* 17**,** 885-894.

de Dear, R. & Brager, G. 1998. Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions,* 104(1)**,** 145-167.

de Dear, R. & Brager, G. 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and buildings,* 34**,** 549-561.

De Vries, R. & Blane, D. 2013. Fuel poverty and the health of older people: The role of local climate. *Journal of Public Health,* 35**,** 361-366.

DeGroot, D. W. & Kenney, W. L. 2007. Impaired defense of core temperature in aged humans during mild cold stress. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology,* 292**,** R103-R108.

DPTI 2017. Land administration data (extract). *In:* DPTI (ed.).

Dufour, A. & Candas, V. 2007. Ageing and thermal responses during passive heat exposure: sweating and sensory aspects. *European Journal of Applied Physiology,* 100**,** 19-26.

Eccles, R. 2002. An Explanation for the Seasonality of Acute Upper Respiratory Tract Viral Infections. *Acta Oto-Laryngologica,* 122**,** 183-191.

Epstein, Y., Albukrek, D., Kalmovitc, B., Mora, D. & Shapiro, Y. 1997. Heat intolerance induced by antidepressants. *Annals of the New York Academy of Sciences,* 813**,** 553-558.

Evans, G. W., Wells, N. M., Chan, H.-Y. E. & Saltzman, H. 2000. Housing quality and mental health. *Journal of Consulting and Clinical Psychology,* 68**,** 526.

Ezzati, M., Lopez, A. D., Rodgers, A., Vander Hoorn, S. & Murray, C. J. L. 2002. Selected major risk factors and global and regional burden of disease. *The Lancet,* 360**,** 1347-1360.

Fabbri, K. 2015. A Brief History of Thermal Comfort: From Effective Temperature to Adaptive Thermal Comfort. *Indoor Thermal Comfort Perception: A Questionnaire Approach Focusing on Children.* Cham: Springer International Publishing.

Fan, G., Xie, J., Yoshino, H., Yanagi, U., Hasegawa, K., Wang, C., Zhang, X. & Liu, J. 2017. Investigation of indoor thermal environment in the homes with elderly people during heating season in Beijing, China. *Building and Environment,* 126**,** 288-303.

Fanger, P. O. 1970. *Thermal Comfort: Analysis and applications in environmental engineering,* United States, McGraw-Hill Book Company.

Fanger, P. O. 1973. Assessment of man's thermal comfort in practice. *Occupational and Environmental Medicine,* 30**,** 313-324.

Fanger, P. O. & Toftum, J. 2002. Extension of the PMV model to non-air-conditioned buildings in warm climates. *Energy and Buildings,* 34**,** 533-536.

Faulkner, D. 2017. Housing and the Environments of Ageing. *Ageing in Australia.* Springer.

Fausset, C. B., Kelly, A. J., Rogers, W. A. & Fisk, A. D. 2011. Challenges to aging in place: Understanding home maintenance difficulties. *Journal of Housing for the Elderly,* 25**,** 125-141.

Foster, K., Ellis, F., Dore, C., Exton-Smith, A. & Weiner, J. 1976. Sweat responses in the aged. *Age and Ageing,* 5**,** 91-101.

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Guihenneuc-Jouyaux, C., Clavel, J., Jougla, E. & Hémon, D. 2006. Excess mortality related to the August 2003 heat wave in France. *International Archives of Occupational and Environmental Health,* 80**,** 16-24.

Fountain, M. E. & Huizenga, C. 1996. A thermal comfort prediction tool. *ASHRAE journal,* 38.

Fries, J. 1980. Aging natural death and the compression of morbidity. *New England Journal of Medicine,* 303**,** 130-135.

Garssen, J., Harmsen, C. & Beer, J. d. 2005. The effect of the summer 2003 heat wave on mortality in the Netherlands. *Eurosurveillance,* 10**,** 165-167.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M. L., Guo, Y.-L. L., Wu, C.-f., Kan, H., Yi, S.-M., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P. H. N., Honda, Y., Kim, H. & Armstrong, B. 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet,* 386**,** 369-375.

Gibson, M., Petticrew, M., Bambra, C., Sowden, A. J., Wright, K. E. & Whitehead, M. 2011. Housing and health inequalities: a synthesis of systematic reviews of interventions aimed at different pathways linking housing and health. *Health & place,* 17**,** 175-184.

Gilbertson, J., Grimsley, M. & Green, G. 2012. Psychosocial routes from housing investment to health: Evidence from England's home energy efficiency scheme. *Energy Policy,* 49**,** 122-133.

Gilbertson, J., Stevens, M., Stiell, B. & Thorogood, N. 2006. Home is where the hearth is: Grant recipients' views of England's Home Energy Efficiency Scheme (Warm Front). *Social Science & Medicine,* 63**,** 946-956.

Goromosov, M. S. 1968. *The physiological basis of health standards for dwellings,* Geneva, World Health Organization.

Government of South Australia. 2019. *Energy concession discount offer* [Online]. Available: https://www.sa.gov.au/topics/care-and-support/financial-support/concessions/energy-bill-concessions [Accessed 01/05/2019.

Greenburg, L., Field, F., Reed, J. I. & Erhardt, C. L. 1964. Asthma and temperature change: An epidemiological study of emergency clinic visits for asthma in three large New York hospitals. *Archives of Environmental Health: An International Journal,* 8**,** 642-647.

Greenburg, L., Reed, J. I. & Erhardt, C. L. 1966. Asthma and temperature change: II. 1964 and 1965 epidemiological studies of emergency clinic visits for asthma in three large New York City hospitals. *Archives of Environmental Health: An International Journal,* 12**,** 561-563.

Grimes, A., Denne, T., Howden-Chapman, P., Arnold, R., Telfar-Barnard, L., Preval, N. & Young, C. 2012. Cost benefit analysis of the warm up new zealand: Heat smart programme. *Wellington: University of Wellington*.

Han, J., Yang, W., Zhou, J., Zhang, G., Zhang, Q. & Moschandreas, D. J. 2009. A comparative analysis of urban and rural residential thermal comfort under natural ventilation environment. *Energy and Buildings,* 41**,** 139-145.

Hansen, A., Bi, P., Nitschke, M., Pisaniello, D., Newbury, J. & Kitson, A. 2011. Perceptions of Heat-Susceptibility in Older Persons: Barriers to Adaptation. *International Journal of Environmental Research and Public Health,* 8**,** 4714-4728.

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D. & Tucker, G. 2008a. The effect of heat waves on mental health in a temperate Australian city. *Environmental Health Perspectives,* 116**,** 1369.

Hansen, A., Bi, P., Ryan, P., Nitschke, M., Pisaniello, D. & Tucker, G. 2008b. The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. *International journal of epidemiology,* 37**,** 1359-1365.

Hansen, A. & Soebarto, V. 2019. The epidemiology of health and mortality at extremes. *Proceedings of the 1st International Conference on Comfort at the Extremes: Energy, Economy and Climate.* Heriot Watt University, Dubai.

Harmsen, N. 2017. Curious Adelaide: Why does SA have the nation's highest electricity prices? *ABC News*, 17 Nov 2017.

Hashiguchi, N., Tochihara, Y., Ohnaka, T., Tsuchida, C. & Otsuki, T. 2004. Physiological and subjective responses in the elderly when using floor heating and air conditioning systems. *Journal of Physiological Anthropology and Applied Human Science,* 23**,** 205-213.

Hashizume, M., Wagatsuma, Y., Hayashi, T., Saha, S. K., Streatfield, K. & Yunus, M. 2009. The effect of temperature on mortality in rural Bangladesh—a population-based time-series study. *International journal of epidemiology,* 38**,** 1689-1697.

Haskell, E. H., Palca, J. W., Walker, J. M., Berger, R. J. & Heller, H. C. 1981. The effects of high and low ambient temperatures on human sleep stages. *Electroencephalography and clinical neurophysiology,* 51**,** 494-501.

Hassenboehler, C. B. & Donoghue, M. J. 1981. Thermal performance improvement of window drape configurations. *Textile Research Journal,* 51**,** 441-448.

Head, K., Clarke, M., Bailey, M., Livinski, A., Ludolph, R. & Singh, A. 2018. Report of the systematic review on the effect of indoor heat on health. *WHO Housing and Health Guidelines.* World Health Organization.

Heijs, W. & Stringer, P. 1988. Research on residential thermal comfort: some contributions from environmental psychology. *Journal of Environmental Psychology,* 8**,** 235-247.

Herzog, A. R. & Rodgers, W. L. 1988. Interviewing older adults: mode comparison using data from a face-to-face survey and a telephone resurvey. *Public Opinion Quarterly,* 52**,** 84-99.

Hillcoat-Nallétamby, S. & Ogg, J. I. M. 2013. Moving beyond 'ageing in place': older people's dislikes about their home and neighbourhood environments as a motive for wishing to move. *Ageing and Society,* 34**,** 1771-1796.

Hitchings, R. & Day, R. 2011. How older people relate to the private winter warmth practices of their peers and why we should be interested. *Environment and Planning A: Economy and Space,* 43**,** 2452-2467.

Hitchings, R., Waitt, G., Roggeveen, K. & Chisholm, C. 2015. Winter cold in a summer place: Perceived norms of seasonal adaptation and cultures of home heating in Australia. *Energy Research & Social Science,* 8**,** 162-172.

Hong, S. H., Gilbertson, J., Oreszczyn, T., Green, G. & Ridley, I. 2009. A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. *Building and Environment,* 44**,** 1228-1236.

Howden-Chapman, P., Crane, J., Matheson, A., Viggers, H., Cunningham, M., Blakely, T., O'Dea, D., Cunningham, C., Woodward, A. & Saville-Smith, K. 2005. Retrofitting houses with insulation to reduce health inequalities: aims and methods of a clustered, randomised community-based trial. *Social science & medicine,* 61**,** 2600-2610.

Howden-Chapman, P., Pierse, N., Nicholls, S., Gillespie-Bennett, J., Viggers, H., Cunningham, M., Phipps, R., Boulic, M., Fjällström, P. & Free, S. 2008. Effects of improved home heating on asthma in community dwelling children: randomised controlled trial. *British Medical Journal,* 337.

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Telfar Barnard, L. & Lloyd, B. 2012. Tackling cold housing and fuel poverty in New Zealand: a review of policies, research, and health impacts. *Energy Policy,* 49**,** 134-142.

Howell, R., Saurer Jr, H. & Coad, W. 1998. *Principles of heating, ventilating and air conditioning,* Atlanta, GA, ASHRAE.

Huang, W., Kan, H. & Kovats, S. 2010. The impact of the 2003 heat wave on mortality in Shanghai, China. *Science of the total environment,* 408**,** 2418-2420.

Humphreys, M. A. & Hancock, M. 2007. Do people like to feel 'neutral'?: Exploring the variation of the desired thermal sensation on the ASHRAE scale. *Energy and Buildings,* 39**,** 867-874.

Humphreys, M. A. & Nicol, J. F. 1998. Understanding the adaptive approach to thermal comfort. *ASHRAE transactions,* 104**,** 991.

Humphreys, M. A. & Nicol, J. F. 2004. Do people like to feel "neutral"? Response to the ASHRAE scale of subjective warmth in relation to thermal preference,indoor and outdoor temperature. *ASHRAE Transactions,* 110.

Huynen, M. M., Martens, P., Schram, D., Weijenberg, M. P. & Kunst, A. E. 2001. The impact of heat waves and cold spells on mortality rates in the Dutch population. *Environmental Health Perspectives,* 109**,** 463-470.

Hwang, R.-L. & Chen, C. P. 2010. Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments. *Indoor Air,* 20**,** 235-245.

Hwang, R.-L., Lin, T.-P. & Kuo, N.-J. 2006. Field experiments on thermal comfort in campus classrooms in Taiwan. *Energy and Buildings,* 38**,** 53-62.

IBM 2017. SPSS Statistics. 25 ed.

Idler, E. L. & Benyamini, Y. 1997. Self-Rated Health and Mortality: A Review of Twenty-Seven Community Studies. *Journal of Health and Social Behavior,* 38**,** 21-37.

Indraganti, M. 2010a. Adaptive use of natural ventilation for thermal comfort in Indian apartments. *Building and Environment,* 45**,** 1490-1507.

Indraganti, M. 2010b. Behavioural adaptation and the use of environmental controls in summer for thermal comfort in apartments in India. *Energy and Buildings,* 42**,** 1019-1025.

Indraganti, M. 2010c. Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India. *Applied Energy,* 87**,** 866-883.

Indraganti, M. 2011. Thermal comfort in apartments in India: Adaptive use of environmental controls and hindrances. *Renewable Energy,* 36**,** 1182-1189.

Indraganti, M. & Rao, K. D. 2010. Effect of age, gender, economic group and tenure on thermal comfort: a field study in residential buildings in hot and dry climate with seasonal variations. *Energy and buildings,* 42**,** 273-281.

Infinite Energy. 2018. How Much Do Solar Panels Cost? *Solar Blog* [Online]. Available from: https://www.infiniteenergy.com.au/how-much-do-solar-panels-cost/ [Accessed 2/11/2018 2018].

Inglis, S. C., Clark, R. A., Shakib, S., Wong, D. T., Molaee, P., Wilkinson, D. & Stewart, S. 2008. Hot summers and heart failure: seasonal variations in morbidity and mortality in Australian heart failure patients (1994–2005). *European journal of heart failure,* 10**,** 540-549.

Inoue, Y., Shibasaki, M., Ueda, H. & Ishizashi, H. 1999. Mechanisms underlying the age-related decrement in the human sweating response. *European journal of applied physiology and occupational physiology,* 79**,** 121-126.

Integrated Environmental Solutions Limited 2017. IES Virtual Environment. Glasgow, UK: Integrated Environmental Solutions.

Jacobsen, S. J., Goldberg, J., Miles, T. P., Brody, J. A., Stiers, W. & Rimm, A. A. 1992. Race and sex differences in mortality following fracture of the hip. *American Journal of Public Health,* 82**,** 1147-1150.

Jamison, R. N., Anderson, K. O. & Slater, M. A. 1995. Weather changes and pain: perceived influence of local climate on pain complaint in chronic pain patients. *Pain,* 61**,** 309-315.

Jiao, Y., Yu, H., Wang, T., An, Y. & Yu, Y. 2017. Thermal comfort and adaptation of the elderly in free-running environments in Shanghai, China. *Building and Environment,* 118**,** 259-272.

Johnston, W. 2018. National survey report of photovoltaic applications in Australia 2017. NSW: Australian PV Institute.

Karjalainen, S. 2007. Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and environment,* 42**,** 1594-1603.

Karjalainen, S. 2009. Thermal comfort and use of thermostats in Finnish homes and offices. *Building and Environment,* 44**,** 1237-1245.

Karjalainen, S. 2012. Thermal comfort and gender: a literature review. *Indoor air,* 22**,** 96-109.

Kawasaki, J. & Raven, M. 1995. Computer-administered Surveys in Extension. *Journal of Extension,* 33.

Kendig, H., Duckett, S. J. & Institute, A. H. P. 2001. Australian directions in aged care : the generation of policies for generations of older people. Sydney: Australian Health Policy Institute at the University of Sydney.

Kendig, H., Gong, C. H., Cannon, L. & Browning, C. 2017. Preferences and predictors of aging in place: Longitudinal evidence from Melbourne, Australia. *Journal of Housing for the Elderly,* 31**,** 259-271.

Kenney, W. L. & Munce, T. A. 2003. Invited review: aging and human temperature regulation. *Journal of applied physiology,* 95**,** 2598-2603.

Kenny, G. P., Sigal, R. J. & McGinn, R. 2016. Body temperature regulation in diabetes. *Temperature,* 3**,** 119-145.

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H. G., Smith, D., Solomon, G., Trent, R. & English, P. 2008. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environmental health perspectives,* 117**,** 61-67.

Kolarik, J. & Olesen, B. W. 2015. Influence of measurement uncertainty on classification of thermal environment in buildings according to European Standard EN 15251. *7PHN Sustainable Cities and Buildings*.

Koskela, H. O. 2007. Cold air-provoked respiratory symptoms: the mechanisms and management. *International journal of circumpolar health,* 66**,** 91-100.

Kravchenko, J., Abernethy, A. P., Fawzy, M. & Lyerly, H. K. 2013. Minimization of Heatwave Morbidity and Mortality. *American Journal of Preventive Medicine,* 44**,** 274-282.

Krieger, J. & Higgins, D. L. 2002. Housing and health: time again for public health action. *American journal of public health,* 92**,** 758-768.

kW Engineering Inc 2011. ¡Get Psyched! 2.08 ed.

Laaidi, K., Zeghnoun, A., Dousset, B., Bretin, P., Vandentorren, S., Giraudet, E. & Beaudeau, P. 2012. The impact of heat islands on mortality in Paris during the August 2003 heat wave. *Environmental health perspectives,* 120**,** 254.

Lan, L., Lian, Z., Liu, W. & Liu, Y. 2008. Investigation of gender difference in thermal comfort for Chinese people. *European Journal of Applied Physiology,* 102**,** 471-480.

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S.-A. & Chinery, R. 2009. Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology***,** 738-746.

Lindemann, U., Oksa, J., Skelton, D. A., Beyer, N., Klenk, J., Zscheile, J. & Becker, C. 2014. Effect of cold indoor environment on physical performance of older women living in the community. *Age and Ageing*.

Lomas, K. J. & Kane, T. 2013. Summertime temperatures and thermal comfort in UK homes. *Building Research & Information,* 41**,** 259-280.

Lomax, P. & Schönbaum, E. 1998. Chapter 12 The effects of drugs on thermoregulation during exposure to hot environments. *Progress in Brain Research,* 115**,** 193-204.

Loughnan, M., Carroll, M. & Tapper, N. J. 2015. The relationship between housing and heat wave resilience in older people. *International journal of biometeorology,* 59**,** 1291-1298.

Loughnan, M., Nicholls, N. & Tapper, N. 2010. Mortality–temperature thresholds for ten major population centres in rural Victoria, Australia. *Health & Place,* 16**,** 1287-1290.

Loughnan, M., Nicholls, N. & Tapper, N. J. 2008. Demographic, seasonal, and spatial differences in acute myocardial infarction admissions to hospital in Melbourne Australia. *International Journal of Health Geographics,* 7**,** 42.

Loughnan, M., Tapper, N., Phan, T., Lynch, K. & McInnes, J. 2013. *A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities,* Gold Coast, National Climate Change Adaptation Research Facility.

Lowen, A. C., Mubareka, S., Steel, J. & Palese, P. 2007. Influenza virus transmission is dependent on relative humidity and temperature. *PLoS Pathogens,* 3**,** 1470-6.

Mäkinen, T. M., Juvonen, R., Jokelainen, J., Harju, T. H., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M. & Hassi, J. 2009. Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. *Respiratory Medicine,* 103**,** 456-462.

Mavrogianni, A., Wilkinson, P., Davies, M., Biddulph, P. & Oikonomou, E. 2012. Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Building and Environment,* 55**,** 117-130.

Mayner, L., Arbon, P. & Usher, K. 2010. Emergency department patient presentations during the 2009 heatwaves in Adelaide. *Collegian,* 17**,** 175-182.

McAlindon, T., Formica, M., Schmid, C. H. & Fletcher, J. 2007. Changes in Barometric Pressure and Ambient Temperature Influence Osteoarthritis Pain. *The American Journal of Medicine,* 120**,** 429-434.

McIntyre, D. 1973. A guide to thermal comfort. *Applied ergonomics,* 4**,** 66-72.

McIntyre, D. A. 1982. Chamber studies—reductio ad absurdum? *Energy and Buildings,* 5**,** 89-96.

Meier, A. 2012. How people actually use thermostats. *ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, Calif.: American Council for an Energy Efficient Economy.*

Microsoft Corporation 2013. Microsoft Excel.

Milne, G., Reardon, C., Ryan, P. & Pavia, M. 2010. *Heating and Cooling* [Online]. Canberra: Deptartment of Climate Change and Energy Efficiency. Available: http://www.yourhome.gov.au/energy/heating-and-cooling.

Milo-Cotter, O., Setter, I., Uriel, N., Kaluski, E., Vered, Z., Golik, A. & Cotter, G. 2006. The Daily Incidence of Acute Heart Failure Is Correlated With Low Minimal Night Temperature: Cold Immersion Pulmonary Edema Revisited? *Journal of Cardiac Failure,* 12**,** 114-119.

Mishra, A. K. & Ramgopal, M. 2013. Field studies on human thermal comfort — An overview. *Building and Environment,* 64**,** 94-106.

Moore, R. 2012. Definitions of fuel poverty: Implications for policy. *Energy Policy,* 49**,** 19-26.

Muzet, A., Ehrhart, J., Candas, V., Libert, J. & Vogt, J. 1983. REM sleep and ambient temperature in man. *International Journal of Neuroscience,* 18**,** 117-125.

Nahlik, M. J., Chester, M. V., Pincetl, S. S., Eisenman, D., Sivaraman, D. & English, P. 2016. Building Thermal Performance, Extreme Heat, and Climate Change. *Journal of Infrastructure Systems,* 23**,** 04016043.

Natsume, K., Ogawa, T., Sugenoya, J., Ohnishi, N. & Imai, K. 1992. Preferred ambient temperature for old and young men in summer and winter. *International Journal of Biometeorology,* 36**,** 1-4.

NCC Online. 2019. *BCA History* [Online]. Available: https://ncc.abcb.gov.au/ncc-online/About/BCA-History [Accessed 10/5/2019.

Ng, J., Scott, D., Taneja, A., Gow, P. & Gosai, A. 2004. Weather changes and pain in rheumatology patients. *APLAR Journal of Rheumatology,* 7**,** 204-206.

Nicholls, N., Skinner, C., Loughnan, M. & Tapper, N. 2008. A simple heat alert system for Melbourne, Australia. *International Journal of Biometeorology,* 52**,** 375-384.

Nicol, F., Humphreys, M. & Roaf, S. 2012. *Adaptive Thermal Comfort: Principles and Practice*, Routledge.

Nicol, J. & Humphreys, M. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and buildings,* 34**,** 563-572.

Nitschke, M., Hansen, A., Bi, P., Pisaniello, D., Newbury, J., Kitson, A., Tucker, G., Avery, J. & Dal Grande, E. 2013. Risk factors, health effects and behaviour in older people during extreme heat: A survey in South Australia. *International journal of environmental research and public health,* 10**,** 6721-6733.

Nitschke, M., Hansen, A., Bi, P., Pisaniello, D., Newbury, J., Kitson, A., Tucker, G., Dal Grande, E. & Avery, J. 2014. Adaptive capabilities in the elderly during extreme heat events in South Australia. Adelaide.

Nitschke, M., Tucker, G. R. & Bi, P. 2007. Morbidity and mortality during heatwaves in metropolitan Adelaide. *Medical Journal of Australia,* 187**,** 662-665.
Nitschke, M., Tucker, G. R., Hansen, A. L., Williams, S., Zhang, Y. & Bi, P. 2011. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environmental Health,* 10**,** 42.
Nunes, A., Lorenzoni, I., Lake, I. & Few, R. 2015. PP26 Growing old: the impact of health inequalities on the vulnerability, resilience and adaptation of older adults to extreme temperatures. BMJ Publishing Group Ltd.
Onset Computer Corporation 2002-2015. HOBOWare Pro. 3.7.2 ed.
Onset Computer Corporation 2015. TMCx-HD Water/Soil Temperature Sensor. Bourne, MA: Onset Computer Corporation.
Onset Computer Corporation 2016. HOBO® U12 Logger Multi-channel energy & environmental monitoring. Bourne, MA: Onset Computer Corporation.
Oreszczyn, T., Hong, S. H., Ridley, I. & Wilkinson, P. 2006. Determinants of winter indoor temperatures in low income households in England. *Energy and Buildings,* 38**,** 245-252.
Ormandy, D. & Ezratty, V. 2012. Health and thermal comfort: From WHO guidance to housing strategies. *Energy Policy,* 49**,** 116-121.
Osman, L. M., Ayres, J. G., Garden, C., Reglitz, K., Lyon, J. & Douglas, J. G. 2008. Home warmth and health status of COPD patients. *European journal of public health,* 18**,** 399-405.
Pacheco, R., Ordóñez, J. & Martínez, G. 2012. Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews,* 16**,** 3559-3573.
Palmer, G. 2012. Does energy efficiency reduce emissions and peak demand? A case study of 50 years of space heating in Melbourne. *Sustainability,* 4**,** 1525-1560.
Parker, L. 1992. Collecting data the e-mail way. *Training & Development,* 46**,** 52-55.
Patberg, W. R. & Rasker, J. J. 2004. Weather effects in rheumatoid arthritis: from controversy to consensus. A review. *The Journal of rheumatology,* 31**,** 1327-1334.
Phillips, P., Bretherton, M., Johnston, C. & Gray, L. 1991. Reduced osmotic thirst in healthy elderly men. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology,* 261**,** R166-R171.
Phillips, S. 2014. Heat is Australia's number one natural killer. *ABC Environment*.
Pitt, A. The languages and semantics of thermal comfort. Comfort and Energy Use in Buildings - Getting them Right, 2006 Cumberland Lodge, Windsor, UK. Network for Comfort and Energy Use in Buildings.
Porritt, S. M., Cropper, P. C., Shao, L. & Goodier, C. I. 2012. Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Buildings,* 55**,** 16-27.
Poruschi, L., Ambrey, C. L. & Smart, J. C. R. 2018. Revisiting feed-in tariffs in Australia: A review. *Renewable and Sustainable Energy Reviews,* 82**,** 260-270.
Preval, N., Chapman, R., Pierse, N. & Howden-Chapman, P. 2010. Evaluating energy, health and carbon co-benefits from improved domestic space heating: A randomised community trial. *Energy Policy,* 38**,** 3965-3972.
Property Council of Australia 2014. National overview of the retirement village sector.
Queensland University of Technology 2010. Impacts and adaptation response of infrastructure and communities to heatwaves: The southern Australian experience of 2009. Gold Coast.
Rajasekar, E. & Ramachandraiah, A. 2010. Adaptive comfort and thermal expectations–a subjective evaluation in hot humid climate. *Proceedings of the adapting to change: new thinking on comfort. Windsor, London, UK***,** 9-11.
Raosoft Inc. 2004. *Sample size calculator* [Online]. Available: http://www.raosoft.com/samplesize.html [Accessed 22/3/2017 2017].
Rawlinsons Group 2018. *Rawlinsons Australian Construction Handbook,* Perth, WA, Rawlinsons.
Robine, J.-M., Cheung, S. L. K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.-P. & Herrmann, F. R. 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes rendus biologies,* 331**,** 171-178.
Rocklöv, J., Ebi, K. & Forsberg, B. 2011. Mortality related to temperature and persistent extreme temperatures: a study of cause-specific and age-stratified mortality. *Occupational and Environmental Medicine,* 68**,** 531-536.
Rohles, F. H. 1971. Psychological aspects of thermal comfort. *ASHRAE Journal,* 13**,** 86-90.
Rohles, F. H. 1980. Temperature or temperament: A psychologist looks at thermal comfort. *ASHRAE Transactions,* 86**,** 541-551.

Royapoor, M. & Roskilly, T. 2015. Building model calibration using energy and environmental data. *Energy and Buildings,* 94**,** 109-120.

SA Government 2016. Summer cooling guide 2016-17. Adelaide: Government of South Australia.

Saman, W., Boland, J., Pullen, S., de Dear, R. J., Soebarto, V., Miller, W. F., Pocock, B., Belusko, M., Bruno, F. & Whaley, D. 2013. *A framework for adaptation of Australian households to heat waves*, National Climate Change Adaptation Research Facility.

Sandyk, R., Iacono, R. P. & Bamford, C. R. 1987. The hypothalamus in Parkinson Disease. *The Italian Journal of Neurological Sciences,* 8**,** 227-234.

Saville-Smith, K., James, B. & Fraser, R. 2008. Older people's house performance and their repair and maintenance practices: Analysis from a 2008 National Survey of Older People and existing datasets. *Centre for Research Evaluation and Social Assessment*.

Schellen, L., Loomans, M. G. L. C., de Wit, M. H., Olesen, B. W. & Lichtenbelt, W. D. V. M. 2012. The influence of local effects on thermal sensation under non-uniform environmental conditions - Gender differences in thermophysiology, thermal comfort and productivity during convective and radiant cooling. *Physiology and Behavior,* 107**,** 252-261.

Schellen, L., van Marken Lichtenbelt, W., Loomans, M., Toftum, J. & De Wit, M. 2010. Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady - state condition. *Indoor Air,* 20**,** 273-283.

Simpson, G. & Clifton, J. 2015. The emperor and the cowboys: The role of government policy and industry in the adoption of domestic solar microgeneration systems. *Energy Policy,* 81**,** 141-151.

Simshauser, P., Nelson, T. & Doan, T. 2011. The boomerang paradox, part II: policy prescriptions for reducing fuel poverty in Australia. *The Electricity Journal,* 24**,** 63-75.

Sivaraman, D. & Horne, R. E. 2011. Regulatory potential for increasing small scale grid connected photovoltaic (PV) deployment in Australia. *Energy Policy,* 39**,** 586-595.

Skelton, D. A., Kennedy, J. & Rutherford, O. M. 2002. Explosive power and asymmetry in leg muscle function in frequent fallers and non - fallers aged over 65. *Age and ageing,* 31**,** 119-125.

Soebarto, V. & Bennetts, H. 2014. Thermal comfort and occupant responses during summer in a low to middle income housing development in South Australia. *Building and Environment,* 75**,** 19-29.

Soebarto, V., Bennetts, H., Hansen, A., Zuo, J., Williamson, T., Pisaniello, D., van Hoof, J. & Visvanathan, R. 2019. Living environment, heating-cooling behaviours and well-being: Survey of older South Australians. *Building and Environment,* 157**,** 215-226.

Soebarto, V., Zhang, H. & Schiavon, S. 2019. A thermal comfort environmental chamber study of older and younger people. *Building and Environment,* 155**,** 1-14.

Son, J.-Y., Lee, J.-T., Anderson, G. B. & Bell, M. L. 2012. The impact of heat waves on mortality in seven major cities in Korea. *Environmental health perspectives,* 120**,** 566.

Sovacool, B. K. 2015. Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. *Energy,* 93**,** 361-371.

Straka, V. & Aleksic, M. Post-occupancy evaluation. PLEA2009-26th Conference on Passive and Low Energy Architecture, 2009 Quebec City, Canada. 22-24.

Suppiah, R., Hennessy, K., Whetton, P., McInnes, K., Macadam, I., Bathols, J., Ricketts, J. & Page, C. 2007. Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine,* 56**,** 131-152.

SurveyMonkey. 2017. Available: https://www.surveymonkey.net/.

Thompson, W. W., Shay, D. K., Weintraub, E., Brammer, L., Cox, N., Anderson, L. J. & Fukuda, K. 2003. Mortality associated with influenza and respiratory syncytial virus in the United States. *Journal of the American Medical Association,* 289**,** 179-186.

Thomson, H., Petticrew, M. & Morrison, D. 2001. Health effects of housing improvement: systematic review of intervention studies. *British Medical Journal,* 323**,** 187-190.

Thomson, H., Thomas, S., Sellstrom, E. & Petticrew, M. 2009. The health impacts of housing improvement: a systematic review of intervention studies from 1887 to 2007. *American Journal of Public Health,* 99.

Timmermans, E. J., Van Der Pas, S., Schaap, L. A., Sánchez-Martínez, M., Zambon, S., Peter, R., Pedersen, N. L., Dennison, E. M., Denkinger, M. & Castell, M. V. 2014. Self-perceived weather sensitivity and joint pain in older people with osteoarthritis in six European countries: results from the European Project on OSteoArthritis (EPOSA). *BMC musculoskeletal disorders,* 15**,** 66.

Tod, A. M., Lusambili, A., Homer, C., Abbott, J., Cooke, J. M., Stocks, A. J. & McDaid, K. A. 2012. Understanding factors influencing vulnerable older people keeping warm and well in winter: a qualitative study using social marketing techniques. *BMJ Open,* 2**,** e000922.

Toloo, G., Yu, W., Aitken, P., FitzGerald, G. & Tong, S. 2014. The impact of heatwaves on emergency department visits in Brisbane, Australia: a time series study. *Critical Care,* 18**,** 1-9.

Tong, S., Ren, C. & Becker, N. 2010. Excess deaths during the 2004 heatwave in Brisbane, Australia. *International journal of biometeorology,* 54**,** 393-400.

Tong, S., Wang, X. Y., Yu, W., Chen, D. & Wang, X. 2014. The impact of heatwaves on mortality in Australia: a multicity study. *BMJ Open,* 4.

Torzillo, P. J., Pholeros, P., Rainow, S., Barker, G., Sowerbutts, T., Short, T. & Irvine, A. 2008. The state of health hardware in Aboriginal communities in rural and remote Australia. *Australian and New Zealand Journal of Public Health,* 32**,** 7-11.

Truell, A. D., Bartlett, J. E. & Alexander, M. W. 2002. Response rate, speed, and completeness: A comparison of Internet-based and mail surveys. *Behavior Research Methods, Instruments, & Computers,* 34**,** 46-49.

Turnquist, R. & Volmer, R. 1980. Assessing environmental conditions in apartments of the elderly. *ASHRAE Transactions,* 86**,** 536-540.

U3A South Australia. 2017. Available: http://u3asouthaustralia.org.au/about-us/ [Accessed 3/3/2017.

US Department of Energy 2002. International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings, Volume I. Energy Efficiency and Renewable Energy Clearinghouse: National Renewable Energy Lab., Golden, CO (US).

Van Hoof, J. 2008. Forty years of Fanger's model of thermal comfort: comfort for all? *Indoor air,* 18**,** 182-201.

van Hoof, J. & Hensen, J. L. 2006. Thermal comfort and older adults. *Gerontechnology,* 4**,** 223-228.

Van Hoof, J., Mazej, M. & Hensen, J. L. 2010. Thermal comfort: research and practice. *Frontiers in Bioscience,* 15**,** 765-788.

Vardoulakis, S., Dear, K., Hajat, S., Heaviside, C., Eggen, B. & McMichael, A. J. 2014. Comparative assessment of the effects of climate change on heat-and cold-related mortality in the United Kingdom and Australia. *Environmental Health Perspectives,* 122**,** 1285.

Voermans, N., Snijders, A., Schoon, Y. & Bloem, B. 2007. Why old people fall (and how to stop them). *Practical Neurology,* 7**,** 158-171.

von Mackensen, S., Hoeppe, P., Maarouf, A., Tourigny, P. & Nowak, D. 2005. Prevalence of weather sensitivity in Germany and Canada. *International Journal of Biometeorology,* 49**,** 156-166.

Wagner, A., Gossauer, E., Moosmann, C., Gropp, T. & Leonhart, R. 2007. Thermal comfort and workplace occupant satisfaction—Results of field studies in German low energy office buildings. *Energy and Buildings,* 39**,** 758-769.

Waitt, G., Roggeveen, K., Gordon, R., Butler, K. & Cooper, P. 2016. Tyrannies of thrift: Governmentality and older, low-income people's energy efficiency narratives in the Illawarra, Australia. *Energy Policy,* 90**,** 37-45.

Watt, M. 2001. Added values of photovoltaic power systems. Sydney, NSW: International Energy Agency.

Weerasinghe, D. P., MacIntyre, C. R. & Rubin, G. L. 2002. Seasonality of coronary artery deaths in New South Wales, Australia. *Heart,* 88**,** 30-34.

WHO 2007. Large Analysis and Review of European housing and health Status (LARES). *Copenhagen: WHO Regional Office for Europe*.

WHO Working Group 1982. The effects of the indoor housing climate on the health of the elderly. Graz, Austria: World Health Organisation.

Willand, N. & Horne, R. 2018. "They are grinding us into the ground" – The lived experience of (in)energy justice amongst low-income older households. *Applied Energy,* 226**,** 61-70.

Willand, N., Maller, C. & Ridley, I. 2017a. "It's not too bad" - The Lived Experience of Energy Saving Practices of Low-Income Older and Frail People. *Energy Procedia,* 121**,** 166-173.

Willand, N., Maller, C. & Ridley, I. 2017b. Understanding the contextual influences of the health outcomes of residential energy efficiency interventions: realist review. *Housing Studies***,** 1-28.

Williamson, T., Coldicutt, S. & Penny, R. 1991. Aspects of thermal preferences in housing in a hot humid climate, with particular reference to Darwin, Australia. *International Journal of Biometeorology,* 34**,** 251-258.

Williamson, T. & Daniel, L. Changing thermal comfort expectations: Studies in Darwin, Australia. Proceedings of 10th Windsor Conference: Rethinking Comfort, 2018 Windsor, UK. Network for Comfort and Energy Use in Buildings.

Williamson, T., Grant, E., Hansen, A., Pisaniello, D. & Andamon, M. 2009. An investigation of potential health benefits from increasing energy efficiency stringency requirements: Building Code of Australia volumes one & two. University of Adelaide.

Wolff, L. & White, P. D. 1926. Acute coronary occlusion. *The Boston Medical and Surgical Journal,* 195**,** 13-25.

Wood, T., Blowers, D. & Percival, L. 2018. Mostly working: Australia's wholesale electricity market. VIC: Grattan Institute.

Wright, F. 2004. Old and cold: older people and policies failing to address fuel poverty. *Social Policy & Administration,* 38**,** 488-503.

Yochihara, Y., Ohnaka, T., Nagai, Y., Tokuda, T. & Kawashima, Y. 1993. Physiological responses and thermal sensations of the elderly in cold and hot environments. *Journal of Thermal Biology,* 18**,** 355-361.

Young, M. 1924. The Influence of Weather Conditions on the Mortality from Bronchitis and Pneumonia in Children. *Journal of Hygiene,* 23**,** 151-175.

Zimring, C. M. & Reizenstein, J. E. 1980. Post-occupancy evaluation an overview. *Environment and Behavior,* 12**,** 429-450.

Legislation

National Health Act 1953 (Australia)

Warm homes and energy conservation act 2000 (UK)

Appendices

Appendix A

Participant Information Sheet

THE UNIVERSITY of ADELAIDE

Mrs Rachel Bills
School of Architecture and Built Environment
University of Adelaide
North Terrace, Adelaide SA 5005

To whom it may concern,

You are invited to participate in a research project conducted by a PhD candidate from the University of Adelaide. This research is about thermal comfort in housing for people over 65, and how this might affect their health.

Participation is voluntary. If you agree to participate please fill out the attached survey, which will ask questions about your housing situation, how you respond to extremes in hot and cold weather, and some general health questions.

There is also an opportunity to volunteer to participate in a year-long study of the thermal environment of your home. This will involve the installation of an unobtrusive measuring device in your home as well as frequent but short questionnaires about your comfort and health. If you are interested in being part of this year-long research project the final page of the attached survey has a space for you to provide your details so we can contact you with more information.

Please read the attached participant information sheet before you begin the survey. It details my qualifications and provides more information about the research. Once you have completed the survey please return it to us in the self-addressed reply paid envelope provided. No stamp is required.

Thankyou in advance for any time you are able to spare for this project

Sincerely,

Rachel Bills

rachel.bills@adelaide.edu.au

0439 287 895

PLEASE RETAIN THIS LETTER AND THE ATTACHED INFORMATION SHEET FOR YOUR FUTURE REFERENCE

PARTICIPANT INFORMATION SHEET

PROJECT TITLE: Cool or Cook: Thermal Comfort, Affordability and Health in Housing for Ageing Australians
PRINCIPAL INVESTIGATOR: Assoc/Prof Veronica Soebarto
STUDENT RESEARCHER: Rachel Bills
STUDENT'S DEGREE: Doctor of Philosophy

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

This project will examine the thermal conditions of houses of people over 65 who live in Adelaide. It seeks to discover whether the houses provide a good thermal environment for people to live in a healthy manner as they get older, what the barriers to achieving a good thermal environment are, and whether these barriers can be overcome with design and behavioural interventions

Aims

To investigate ways to better enable older Australians to live in their own thermally comfortable and low energy homes; allowing them to stay healthier for longer.

To show that this has the double pronged benefit of improving the quality of life for older Australians and reducing strain on the hospital and residential aged care systems.

Objectives

To investigate the thermal conditions of a sample of houses occupied by older people in Adelaide, and what impact these conditions have on the health and wellbeing of the occupants.

To investigate any barriers that older people face in achieving thermal comfort, and whether various building design interventions can assist with mitigating these barriers

To investigate the cost/benefit of having people remain healthy in their own homes compared with incurring costs to the health care system and/or aged care sector

Who is undertaking the project?
This project is being conducted by Rachel Bills.
This research will form the basis for the degree of Doctor of Philosophy at the University of Adelaide under the supervision of Drs Veronica Soebarto and Alana Hansen. This research is being supported with scholarships from the Australian Federal Government via an Australian Postgraduate Award and the Australian Housing and Urban Research Institute (AHURI).

Why am I being invited to participate?

This study is aimed at South Australian residents aged 65 or over who live in houses, units or apartments which they own or rent. It does not include those living in residential aged care facilities.

What will I be asked to do?

The initial phase of this research involves a simple survey about your housing. It includes questions relating to what kind of house you live in, its heating and cooling, and how comfortable you find it in summer and winter. It also includes some general questions about you, your household and your health.

There is an option to volunteer for a second phase of research, which will involve a small measuring device being installed in your home which will track the climate conditions of your house for a period up to 12 months. You will be asked to fill out a short survey several times a week which will ask about your comfort and health. There will be no need to change your regular activities or behaviour during this period of climate logging. You will be visited by the researchers at regular intervals to review the data and possibly answer some further questions through an interview format.

How much time will the project take?

The initial survey should only take 20-30 minutes to complete at the most.

If you agree to participate in the longer term study, the small measuring device will be in your home for up to 12 months. The survey you will need to till out several times a week should only take you a maximum of 2-3 minutes each time. You will be visited by researchers approximately every three months, and these visits will last between 30 and 45 minutes.

Are there any risks associated with participating in this project?

There are no foreseeable risks with participation in this research.

What are the benefits of the research project?

The main benefit of this research is a greater understanding of the environmental conditions of the housing of people over 65 who are still living at home, and whether these conditions affect their health. This information can help designers to create housing which will keep future people more comfortable and hopefully healthy for longer.

You will be provided with a short report detailing possible improvements to your house which may reduce your electricity use and make your house more comfortable, but there will be no changes made to your residence by the researchers.

Can I withdraw from the project?

Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the study at any time.

What will happen to my information?

If you opt in to be involved in the longer term study, we will need identifying information such as your name and contact details. These details will be kept in a locked filing cabinet accessible only to staff involved in this research. These details will be kept for five years as required by the University then destroyed. Your contact details will also be kept separate from your initial survey responses to avoid bias in the data.

Any data used for publication will be anonymous and will not identify you or your address. If there are quotes or comments from you, your name will be changed for anonymity purposes and this information will not be used without your permission.

At the completion of the project, you will be sent a short summary of the findings, of both the entirety of the research and any findings specific to your property.

Who do I contact if I have questions about the project?

This research is being conducted by Rachel Bills. She can be contacted by telephone during business hours on 0439 287 895 and by email at rachel.bills@adelaide.edu.au

You can also contact Rachel's primary supervisor Associate Professor Veronica Soebarto on 8313 5695 or by email at veronica.soebarto@adelaide.edu.au

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2014-199). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. Contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to hrec@adelaide.edu.au. if you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant. Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?

Initially, we only ask you to complete the attached survey. By doing so, you are giving your consent to be part of the first phase of this study. Please answer all the questions and return it in the addressed reply-paid envelope provided.

If you wish to be involved in the second phase of the study, the final page contains space for you to provide us with your contact details. We will then send you a consent form. You will need to complete and sign this consent form and return it to us before we can contact you to make a time for the initial interviews and the installation of the environmental logger.

Yours sincerely,

Mss Rachel Bills,

PhD Candidate, University of Adelaide

Dr Veronica Soebarto

Associate Professor, School of Architecture and Built Environment University of Adelaide

Appendix B

Housing and Health Survey

THE UNIVERSITY of ADELAIDE

This survey is about the temperatures in the houses of people over the age of 65, and what effects, if any, this may have on their health. The survey will ask a number of questions about your house, your use of heating and cooling appliances, and your health.

This research is being conducted as part of a PhD research project in the School of Architecture and Built Environment at the University of Adelaide. Your participation in this research is voluntary.

Please answer the questions below, which should take around 20-30 minutes to complete, depending on which questions are relevant to you. Many of the questions include a space for you to make comments; this is not required but feel free to use this space to explain any additional details you think we should know. Only one person in your household needs to fill out the survey.

Completion and return of this survey implies consent for this information to be used by researchers at the University of Adelaide for research purposes only. The information your provide will remain confidential and the answers from all participants will be gathered together and presented in a report. No personal information identifying you will be published.

Should you or your family have any questions or concerns about this research, please contact Mrs Rachel Bills on 0439 287 895. Thank you for participating in this research survey.

Section A

This section asks about your type of housing and how much you spend on energy bills

A1. What kind of home do you live in? (tick one)

☐Single house on a block ☐Semi/duplex house

☐Unit on a single storey in a group of units

☐Unit in a group of multi-storey units (2 or more storeys)

☐Other (please specify) ………………………………………………………………………………

PLEASE RETURN THIS SURVEY IN THE REPLY PAID ENVELOPE

A2. Approximately how long ago was your home originally built (tick one)

☐ 0 - 10 years ☐ 11 - 30 years ☐ 31 - 50 years

☐ 51 - 70 years ☐ 71 - 90 years ☐ 91+ years ☐ Don't know

A3. How long have you lived in your current home?

……………. Years……………….Months

A4. What materials is your home built from? (tick all that apply)

☐Double brick ☐Brick veneer ☐Stone ☐Fibro/Timber/Corrugated iron

☐Concrete block ☐Don't know

☐Other (please specify): ……………………………

A5. Is your home insulated? (tick one)

☐Yes – ceiling/roof and walls ☐Yes – ceiling/roof only ☐Yes, walls only

☐No ☐Don't know

A6. How much do you spend on average on your gas bills in a year? *This is the combined total of all monthly or quarterly gas bills*

$...

☐don't know

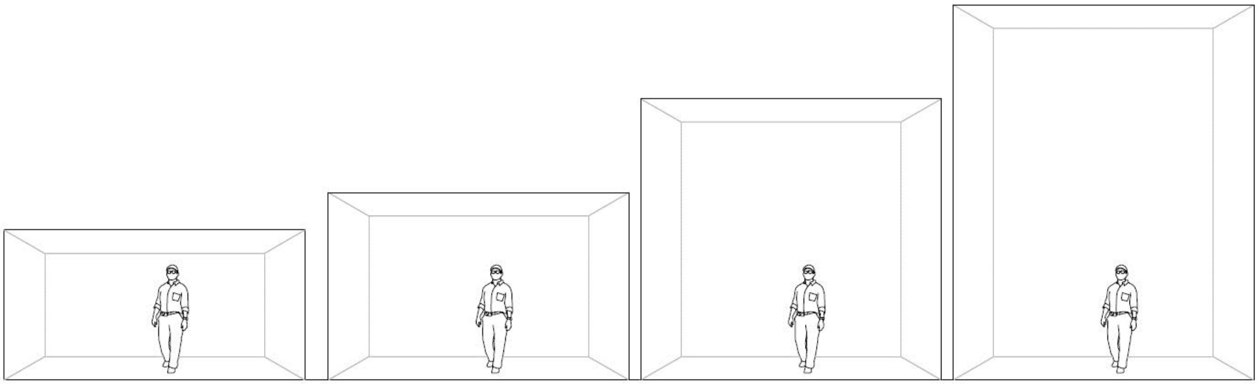
☐don't have gas connected

A7. How much do you spend on average on your electricity bills in a year? ***This is the combined total of all monthly or quarterly electricity bills***

$...

☐don't know

A8. How high is the ceiling in the main living area in your home? (tick one)



☐**Low**	☐**Medium**	☐**High**	☐**Very high**
(2.2-2.4 metres)	(2.5-3.5 metres)	(4-4.5 metres)	(more than 5 metres)

Comments…………………………………………………………………………………………………

………

SECTION B

This section asks questions about the conditions in your home during summer and your use of air-conditioning and other cooling devices

B1. In general, would you say your home is comfortable in summer? (tick one)

☐Always ☐Mostly ☐Sometimes ☐Occasionally ☐Never

Comments…………………………………………………………………………………………………

………

B2. In general in summer, would you say your home is ………..? (tick one)

☐Hot ☐Warm ☐A bit warm ☐Just right

☐A bit cool ☐ Cool ☐Cold

Comments………………………………………………………………………………………………

……

B3. Do your windows have…?

☐Blinds or curtains on some windows ☐Blinds or curtains on all windows

☐Double glazing ☐Other window treatment (tinting etc)

☐No window treatments or internal coverings

Comments………………………………………………………………………………………………

……

B4. If your home has curtains or indoor blinds, do you close these during the day in summer?

☐Yes ☐No ☐Not Applicable

Comments………………………………………………………………………………………………

……

B5. Does your home have awnings or external shade window blinds?

☐ Yes – All windows ☐ Yes – Some windows ☐ No - none

Comments………………………………………………………………………………………………

……

B6. If yes, do you use these awnings or external shades during the day in summer?

☐Yes ☐No ☐Not Applicable

Comments…………………………………………………………………………………………………

………

B7. Is there anything that prevents you from using blinds/curtains/awnings/shades if they are fitted to your home? Please describe below.

☐Not Applicable

………

………

………

………

B8. What kind of cooling is installed in your home? (tick all that apply)

☐None *(go to question B16)*

☐Wall or window unit(s) ☐Split System/Reverse Cycle Unit(s)

☐Ducted evaporative ☐Ducted air-conditioning

☐Portable ☐Don't know the type

☐Other (please specify) …………………………………………………

B9. Which of these is your main source of cooling? …………………………………………

B10. Does your cooler have a thermostat control?

☐Yes ☐No ☐Don't know

B11. Do you know how to change the thermostat settings?

☐Yes ☐No ☐Don't know

B12. If yes, what setting or temperature do you use during the <u>summer</u>?

…………………………

Comments……………………………………………………………………………………………

……………………………………………………………………………………………………

B13. When do you use your cooler in summer (December - February)

☐All day and all night ☐Only during the day ☐Only overnight

☐In the mornings ☐In the afternoon ☐Only when I feel too hot

☐When I have visitors ☐In the evenings before bedtime

☐Only when it gets hot inside

☐Other (please specify): ………………………………………………………………………

……………………………………………………………………………………………………

B14. Do you ever avoid using your cooler in summer even if you feel uncomfortably hot?

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

Comments……………………………………………………………………………………………

……………………………………………………………………………………………………

B15. If you do avoid using cooling, what are your reasons for doing so? (tick all that apply)

☐Can't afford it ☐Don't want to spend money on electricity

☐Don't like the air blowing on me ☐Health reasons ☐They don't work

☐I don't know how to use them ☐I want to save the environment

☐Not Applicable

☐Other (please specify) ……………………………………………………………………………

………………………………………………………………………………………………………..

……

B16. Do the windows in your home open?

☐No ☐Some of them ☐All of them

B17. Is there anything that prevents you from opening these windows?

☐Yes ☐No

Comments…………………………………………………………………………………………

……

B18. Do you have ceiling or pedestal fans in your home? (tick all that apply)

☐No ☐ Main bedroom ☐ Living areas ☐ Kitchen ☐ Other bedrooms

☐Other areas (please specify)……………………………………………………………………

B19. Do you use ceiling or pedestal fans in the bedrooms and living areas? (tick all that apply)

Bedrooms:

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

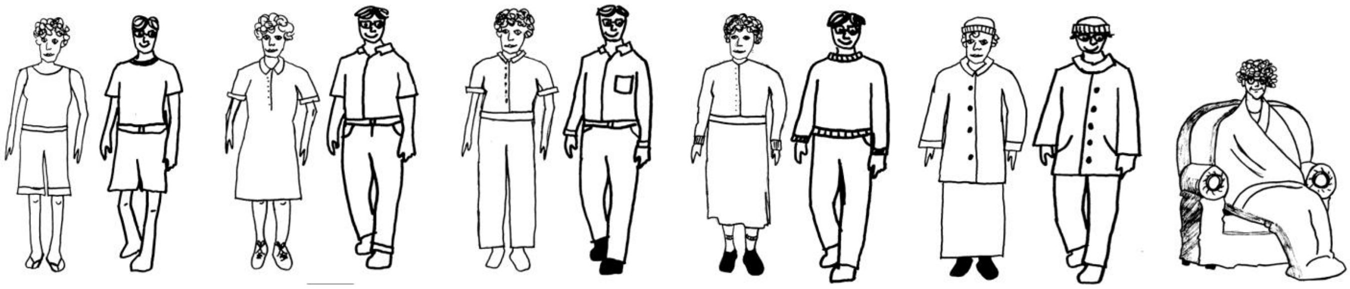
Living Areas:

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

Comments……………………………………………………………………………………………

………

B20. What sort of clothing do you typically wear inside your home during the summer?



☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Comments……………………………………………………………………………………………

………

SECTION C

This section asks questions about the conditions in your home during winter and your use of heating devices

C1. In general, would you say your home is comfortable in winter? (tick one)

☐Always ☐Mostly ☐Sometimes ☐Occasionally ☐Never

Comments…………………………………………………………………………………………

……

C2. In general in winter, would you say your home is …………? (tick one)

☐Hot ☐Warm ☐A bit warm ☐Just right

☐A bit cool ☐ Cool ☐Cold

Comments…………………………………………………………………………………………

……

C3. What kind of heating do you have in your home? (tick all that apply)

☐None *(Go to question C11)* ☐Ducted (any kind) ☐ Gas fire/wall heater

☐Reverse cycle ☐Wood fire ☐Column/oil heater

☐Bar radiator ☐Fan heater ☐Slow combustion/pot belly stove

☐Don't know the type ☐Other (please specify): ……………………………

C4. Which of the above is your main source of heating?

…………………………………………………

C5. Does this heater have a thermostat control?

☐Yes ☐No ☐Don't know

C6. If your heater has a thermostat, do you know how to change the thermostat settings?

☐Yes ☐No ☐Don't know

C7. If yes, what temperature or setting do you use during the winter?

…………………………

Comments………………………………………………………………………………………………

……

C8. When do you use your heater in winter (tick all that apply)

☐All day and all night ☐Only during the day ☐Only overnight

☐In the mornings ☐In the afternoon

☐In the evenings before bedtime ☐Only when I feel too cold ☐When I have visitors

☐Only when it gets cold inside

☐Other (please specify)……………………………………………………………………………

……

C9. Do you ever avoid using your heater in winter even if you feel uncomfortably cold?

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

Comments………………………………………………………………………………………………

………………………………………………………………………………………………………

C10. If you do avoid using your heater, what are your reasons for doing so? (tick all that apply)

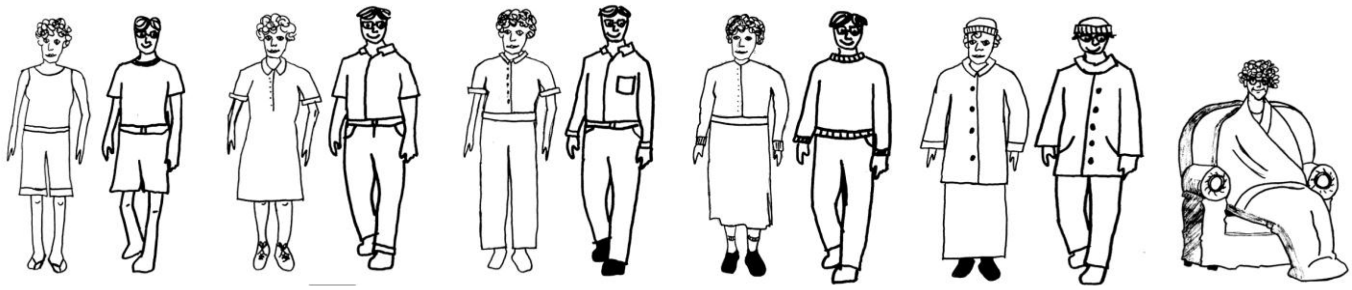
☐ Can't afford it ☐ Don't want to spend money on electricity/gas

☐ Air becomes too dry ☐ Health reasons ☐ They don't work

☐ I don't know how to use them ☐ I want to save the environment

☐ Other (please specify) ……………………………………………………………………………

C11. What sort of clothing do you typically wear inside your home during the winter?



☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Comments………………………………………………………………………………………………

………

SECTION D

This section asks questions about your general health

D1. In general, how would say your health is?

☐Excellent ☐Very good ☐Good ☐Fair ☐Poor

D2. Do you regularly take medication for any of the following medical conditions? (tick all that apply)

☐Diabetes ☐High blood pressure ☐Heart problems ☐Kidney problems

☐Respiratory problems ☐Parkinson's disease

☐Depression or other mental illness ☐Multiple Sclerosis

☐None of the above

Comments……………………………………………………………………………………………

………

D3. During <u>hot</u> weather, do you experience any of the following symptoms/illnesses when you are inside at home? (tick all that apply)

☐Anxiety ☐Dizziness ☐A fall ☐Headache

☐Shortness of breath ☐Heat stress/stroke ☐Heart condition

☐Kidney problems ☐Asthma ☐Joint pain/arthritis

☐High blood pressure ☐Low blood pressure ☐Coughing

☐None of the above

☐Other ………………………………………………………………………………………………

Comments……………………………………………………………………………………………

………

D4. During <u>cold</u> weather, do you experience any of the following symptoms/illnesses when you are inside at home? (tick all that apply)

☐Anxiety ☐Dizziness ☐A fall ☐Headache

☐Shortness of breath ☐Asthma ☐Heart condition

☐Kidney problems ☐Other respiratory disease ☐Joint pain/arthritis

☐High blood pressure ☐Low blood pressure ☐Coughing

☐None of the above

☐Other ……………………………………………………………………………………………

Comments……………………………………………………………………………………………

……………………………………………………………………………………………………

D5. Do you worry more than usual more about your health when there is a heatwave?

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

Please give details if you wish

……………………………………………………………………………………………………

……………………………………………………………………………………………………

D6. Does someone check on your wellbeing during very hot weather?

☐No-one ☐Family member ☐Neighbour ☐Carer ☐Friend

☐Other (please specify)……………………………………………………………

Comments……………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

D7. Do you worry more than usual about your health during cold weather?

☐Never ☐Occasionally ☐Sometimes ☐Frequently ☐Always

Please give details if you wish

……

……

……

……

D8. Does someone check on your wellbeing during very cold weather?

☐No-one ☐Family member ☐Neighbour ☐Carer ☐Friend

☐Other (please specify)……………………………………………………………

Comments……………………………………………………………………………………………

……

……

……

……

SECTION E

This section asks some general questions about you and your household

E1. What is your age range:

☐ 65 – 70 ☐ 71 – 75 ☐ 76 – 80 ☐ 81 – 85

☐ 86 – 90 ☐ 91+

E2. Are you:

☐Male ☐Female

E3. What country were you born in?………………………………………………………………

E4. If you were <u>not</u> born in Australia, how long have you lived here?

……………………………………………………………

E5. <u>Including yourself</u>, how many people live in this home?

……………………………………………………………………………………………

E6. How many people in the following age ranges live in your household (if any)?

☐18 or younger ☐19 – 30 ☐31 – 44 ☐45 – 54 ☐55 – 64

☐65 – 70 ☐ 71 – 75 ☐ 76 – 80 ☐ 81 – 85 ☐ 86 – 90

☐ 91+

Please give extra details about your household if you wish.

………

………

………

………

………

E7. What is the gross (before tax) annual income of all the members of your household combined:

☐$20,000 or less ☐ $20,001 - $40,000 ☐ $40,001 - $60,000

☐ $60,001 - $80,000 ☐ $80,001 - $100,000 ☐ $100,001 + ☐Don't know

E8. **Income type**: (tick one)

☐Self-funded retiree ☐Working full time ☐Working part time

☐Government pension ☐Department of Veteran's Affairs pension

☐other (please specify): ……………………………………………………………

Comments…………………………………………………………………………………………

……

E9. Which of the following best describes your housing situation? (tick one)

☐Outright owner ☐Owner with mortgage ☐Renting

☐Public housing/Housing Trust

☐Other (please specify): ………………………………………………………………………

E10 What is your postcode?..

E11. Is there anything else you think we should know about your housing or your health?

………………………………………………………………………………………………………..

……

……

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……

……

……

……

Are you interested in being part of a longer term study regarding temperatures in houses of older people? This study will involve monitoring the indoor environment of your home using small unobtrusive temperature recording devices. It will also include regular short (2-3 minute) surveys about your personal comfort. These devices will be in your home for a period of 12 months to record the full range of seasonal changes in your home. The devices are free standing and will be removed by the researchers at the end of the study period.

☐Yes ☐No

If so, please provide your name and contact details below. These will be kept separate from your survey answers to maintain anonymity in the questionnaire.

Name ____________________

Address ____________________

____

____

Phone number ____________________

Email ____________________

I understand that by giving my personal details I consent to further contact by researchers regarding participation in further studies

Signed ____________________

Thankyou for participating in this research survey. Please place the complete survey in the reply paid envelope provided and post it to us. No stamp is required.

Appendix C

Comfort Vote Survey

Occupant Identification

A B

Date……………………………………………Time……………………………………………

Which room are you in?……………………………………………………………………

How do you feel?

☐cold ☐cool ☐slightly cool ☐just right ☐slightly warm ☐ warm ☐hot

Are the current conditions thermally acceptable?

☐Yes ☐No

How would you like to feel?

☐Cooler ☐No change ☐Warmer

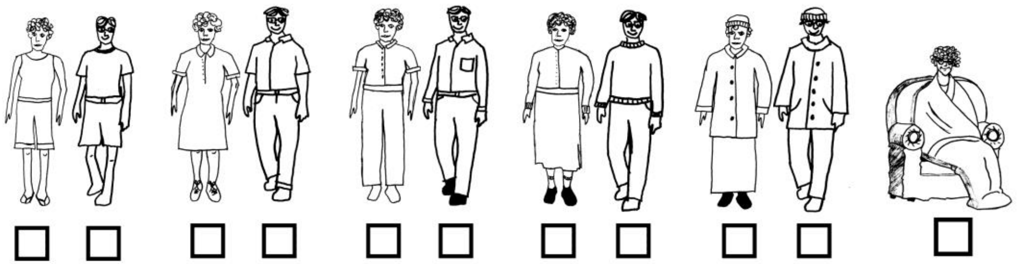
Are there any factors apart from temperature that would change your level of comfort?

Please provide brief explanation……………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

What best describes the clothing you're wearing?



D1

Do you have any windows or doors open for ventilation?

☐Yes ☐No

Do you have any fans operating?

☐Yes ☐No

Do you have heating or cooling operating?

☐Yes ☐No

Are your curtains/blinds/shades

☐Closed ☐Partly Open ☐Fully Opened

Are you experiencing or have you experienced in the last 24 hours any of these?

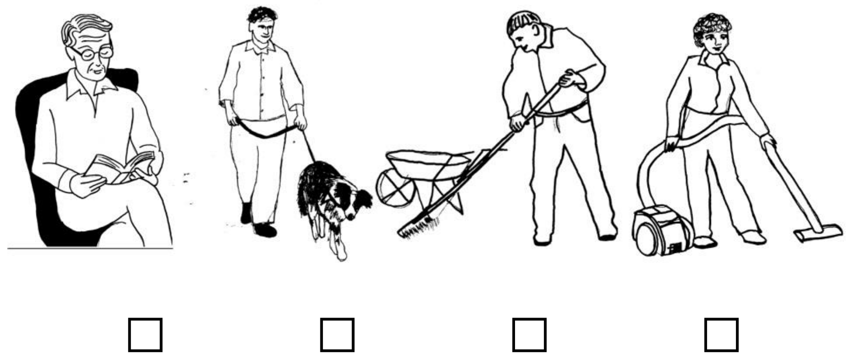
☐Headache ☐dizziness ☐racing heart ☐unexplained tiredness

☐Coughing ☐Joint pain ☐shortness of breath ☐a fall

☐sleeplessness ☐fever

other……………………………………………………………………………………………

What best describes the activity you have been doing for the last 15 minutes?



Appendix D

Table of climate measures during study period

Monthly climate averages during the study period

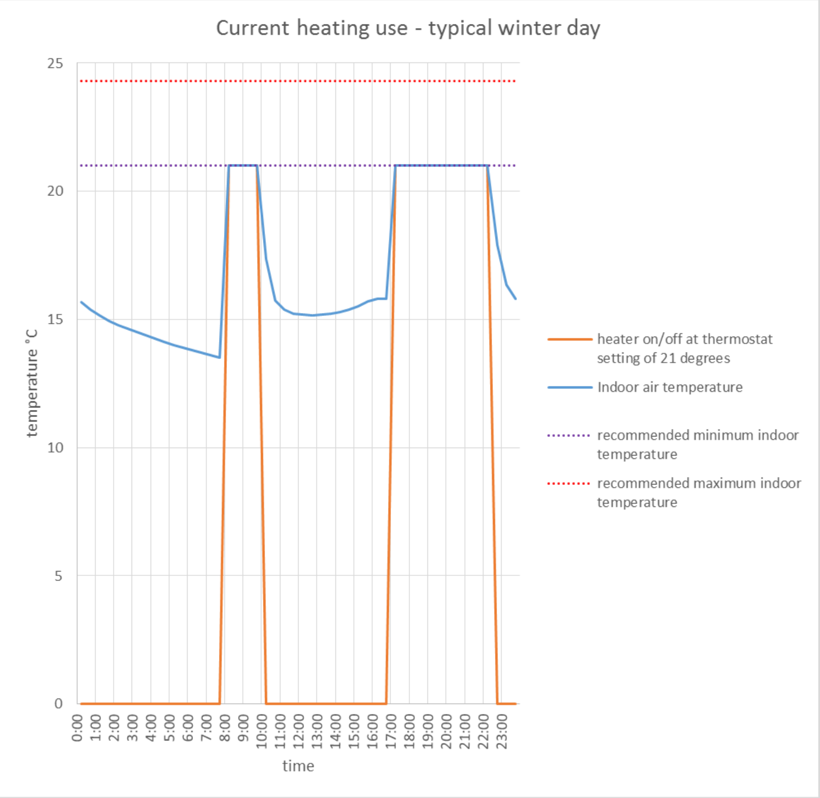
Month	Station	Average Max.	Average Min.	Peak Max.	Peak Min.	Low Max.	Low Min.
Jan	Airport	29.1	17.6	36.0	23.5	19.8	13.2
	Kent Town	31.2	18.3	39.8	24.3	19.5	12.6
	Mt Lofty	25.5	14.0	33.3	25.1	12.4	6.9
Feb	Airport	29.2	17.1	40.9	28.1	22.9	11.6
	Kent Town	31.1	17.5	41.6	28.8	22.9	12.8
	Mt Lofty	25.5	13.3	35.3	25.4	16.4	7.0
Mar	Airport	25.6	15.3	36.9	22.6	19.2	8.5
	Kent Town	27.1	15.7	38.7	23.2	19.3	9.2
	Mt Lofty	21.5	11.2	33.4	19.1	12.2	6.3
Apr	Airport	21.9	11.8	29.3	19.8	16.3	6.6
	Kent Town	22.7	11.8	30.4	19.9	16.2	6.0
	Mt Lofty	16.8	9.2	25.0	18.6	9.9	2.5
May	Airport	18.8	11.3	26.7	17.3	15.3	3.7
	Kent Town	19.1	11.2	27.6	17.7	14.4	4.6
	Mt Lofty	12.9	8.0	20.9	12.8	8.4	2.2
Jun	Airport	16.1	8.6	20.2	13.7	12.7	2.5
	Kent Town	16.1	8.5	20.9	13.6	12.6	2.9
	Mt Lofty	10.4	5.7	16.4	11.9	7.0	1.8
Jul	Airport	14.8	7.6	22.8	14.0	11.7	1.4
	Kent Town	15.0	7.4	22.7	14.0	11.0	1.8
	Mt Lofty	8.9	4.5	16.9	9.8	4.6	0.1
Aug	Airport	16.2	8.0	25.4	13.4	11.8	2.3
	Kent Town	16.7	8.0	24.7	13.2	11.4	3.3
	Mt Lofty	10.5	5.2	18.6	9.8	6.5	1.7
Sep	Airport	18.5	8.8	30.0	15.8	13.5	3.5
	Kent Town	19.2	9.0	29.1	17.1	14.0	4.3
	Mt Lofty	13.3	6.1	22.6	15.2	7.8	1.2
Oct	Airport	25.4	13.0	36.2	20.0	18.4	7.3
	Kent Town	27.1	14.0	36.1	22.1	19.4	7.8
	Mt Lofty	21.4	10.6	29.8	18.2	13.3	3.1
Nov	Airport	25.7	14.1	39.3	20.9	19.2	8.3
	Kent Town	27.5	14.5	40.1	22.4	19.5	8.4
	Mt Lofty	21.2	10.4	33.4	21.1	13.4	5.1
Dec	Airport	30.3	17.2	41.4	31.2	19.3	7.2
	Kent Town	32.5	18.1	43.2	30.7	19.7	7.9
	Mt Lofty	26.4	13.9	36.3	24.7	11.7	5.1

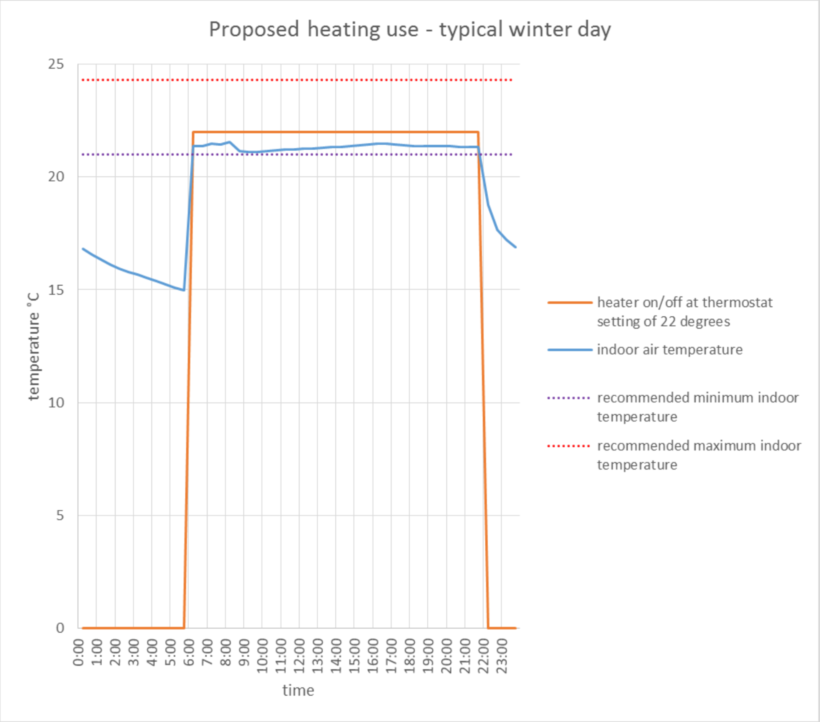
Appendix E

Usage profiles in the building simulation models

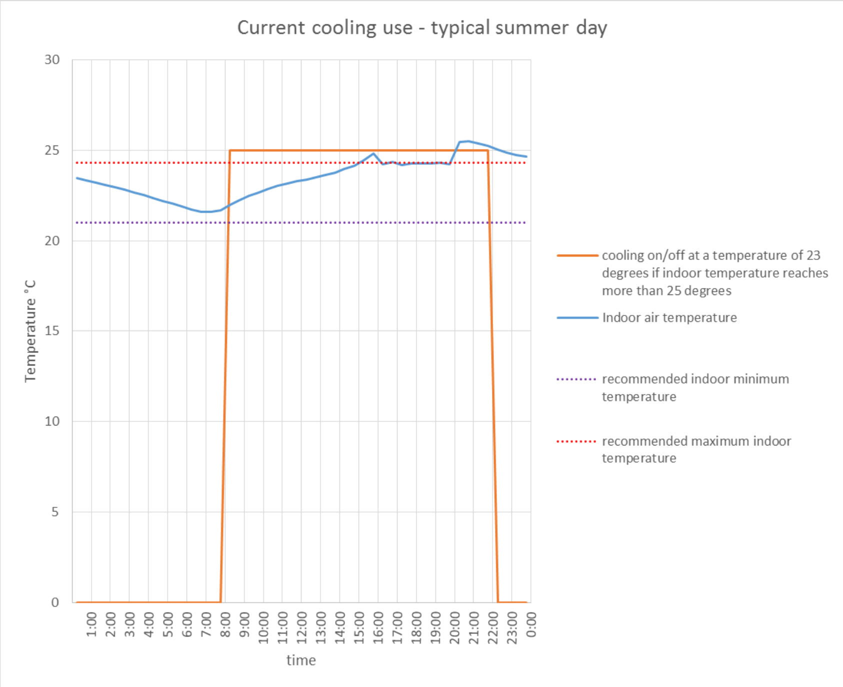
Appendix E – IES Profile Data
House 4

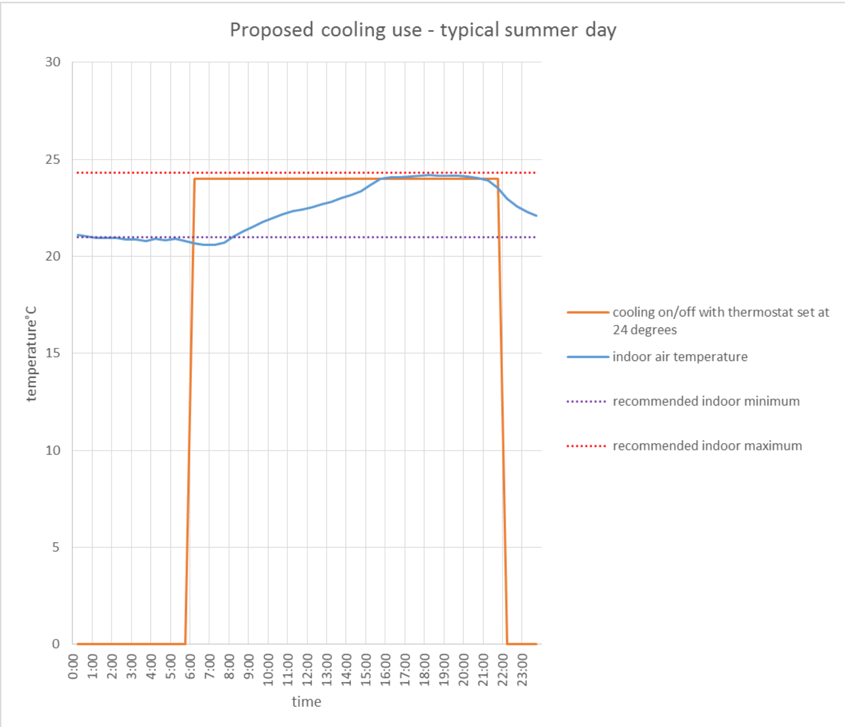
Heating and cooling profiles from IES-VE





Appendix E – IES Profile Data





Ventilation Profile (windows and doors open)

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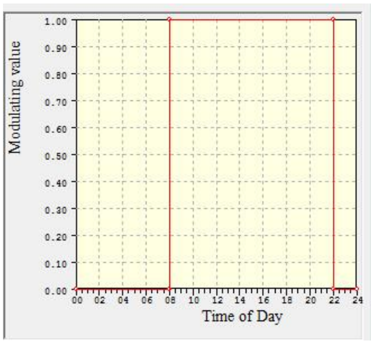
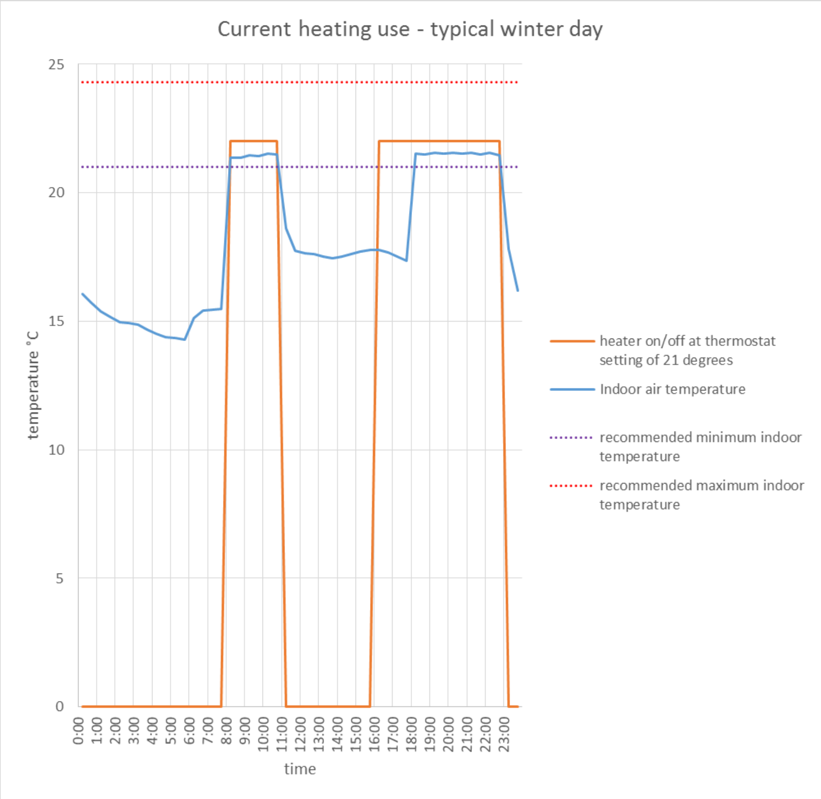
2	07:00	0.000
3	07:00	(to>21) & (to<30)
4	20:00	(to>21) & (to<30)
5	20:00	0.000
6	24:00	0.000

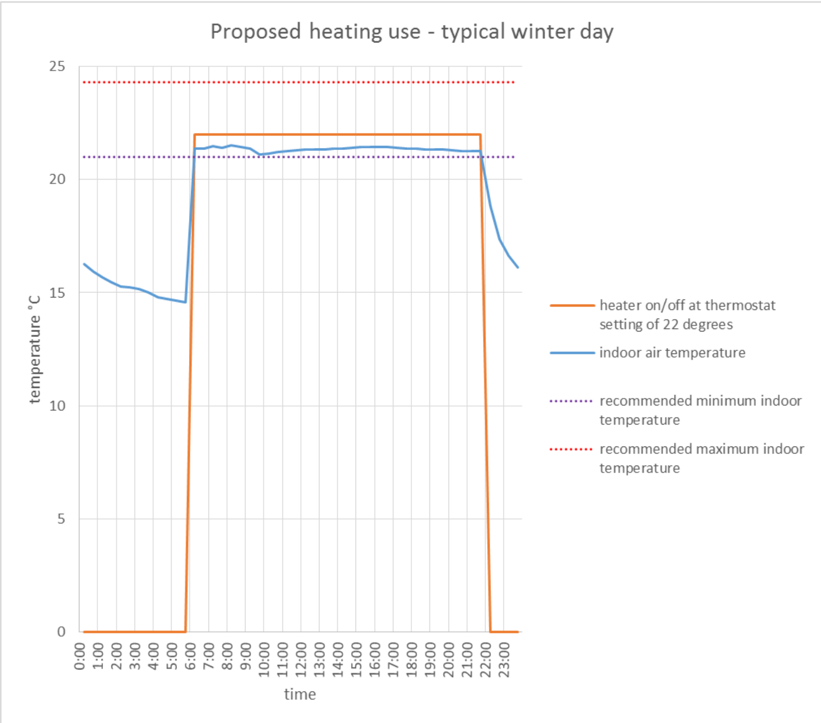
Occupancy Profile



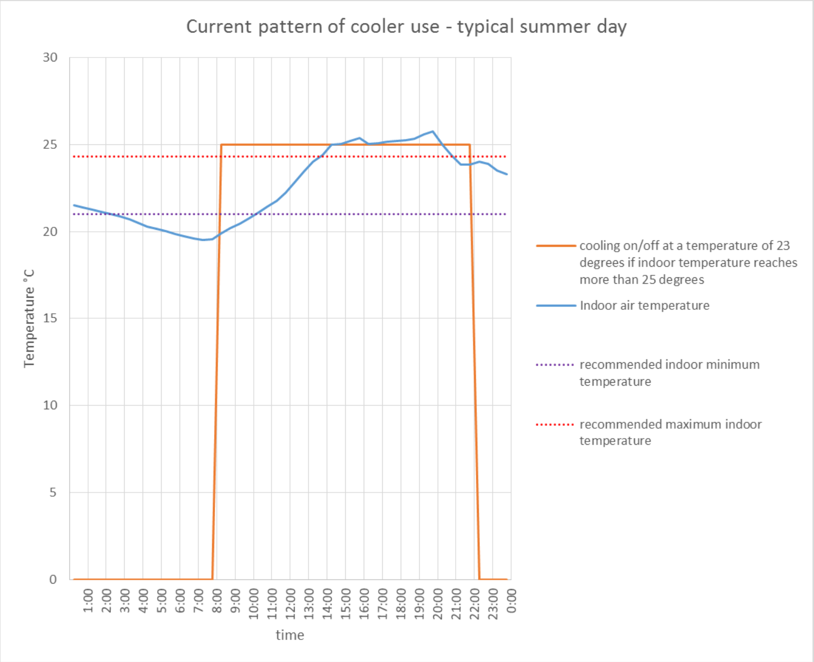
Appendix E – IES Profile Data
House 10

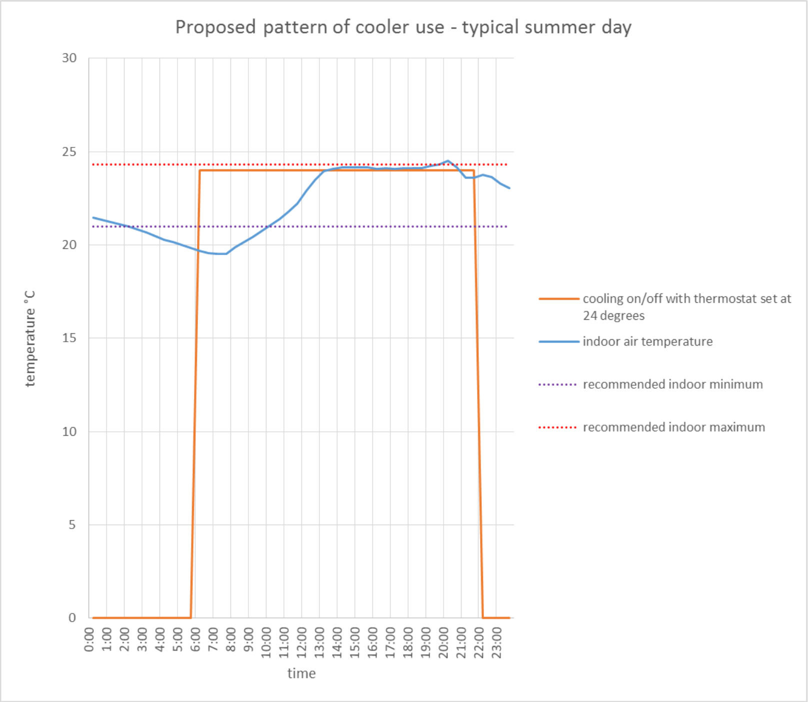
Heating and cooling profiles from IES-VE





Appendix E – IES Profile Data





Ventilation Profile (windows and doors open)

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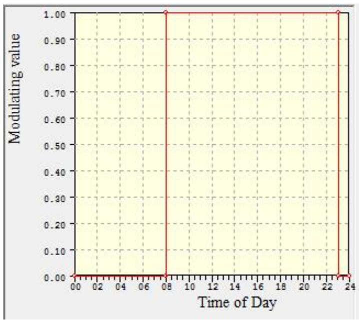
6	24:00	0.000

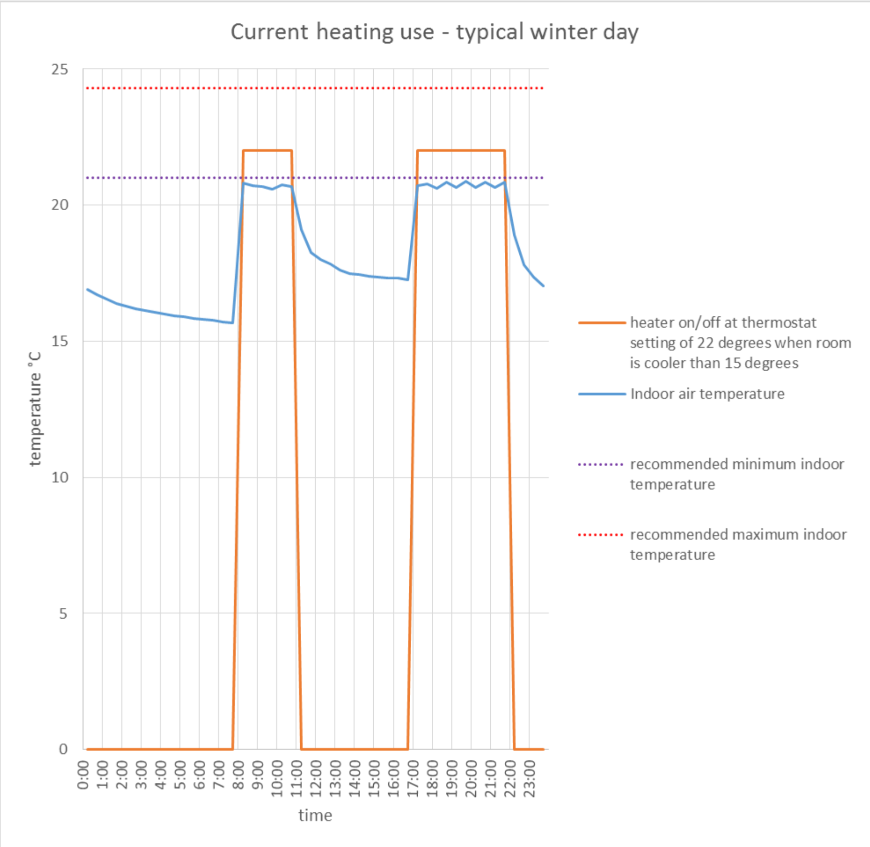
Occupancy Profile

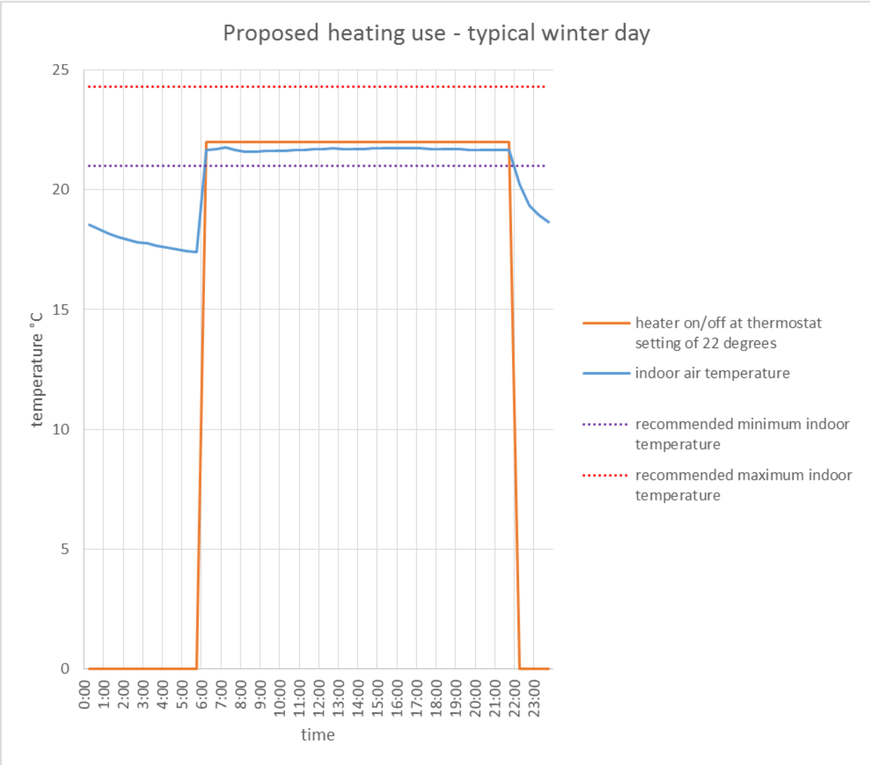


Appendix E – IES Profile Data

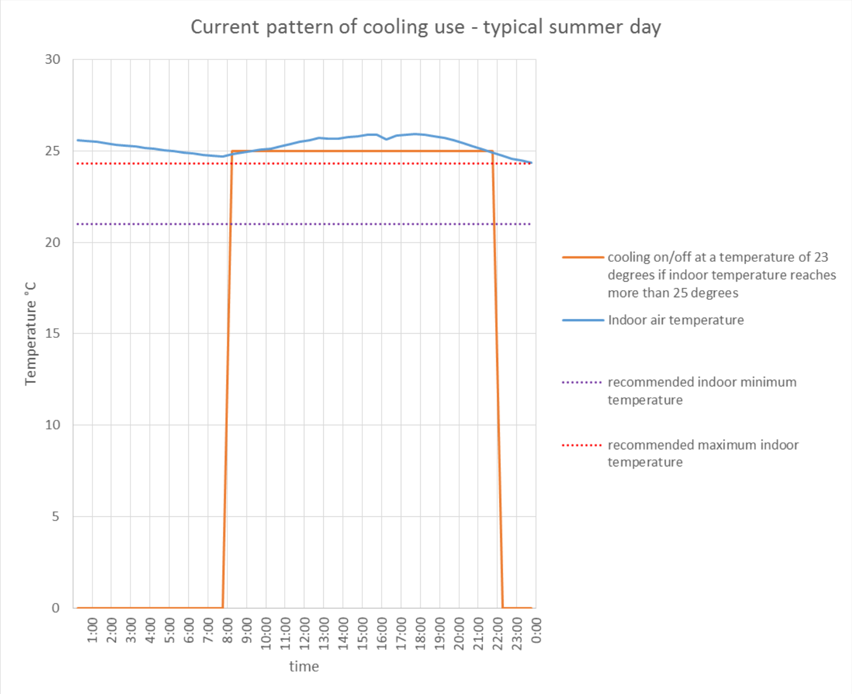
House 12

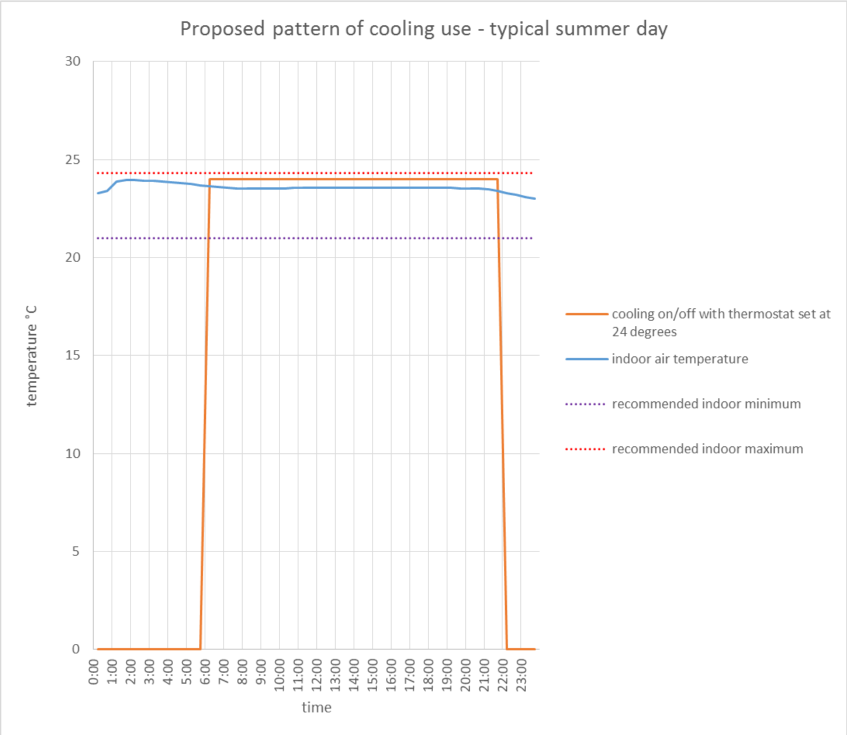
Heating and cooling profiles from IES-VE



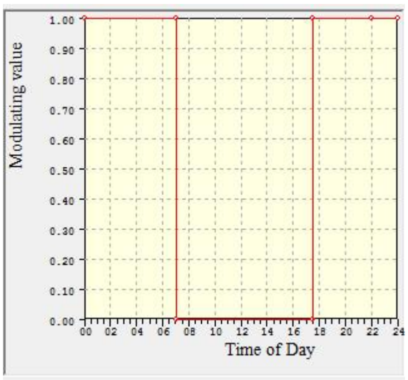


Appendix E – IES Profile Data

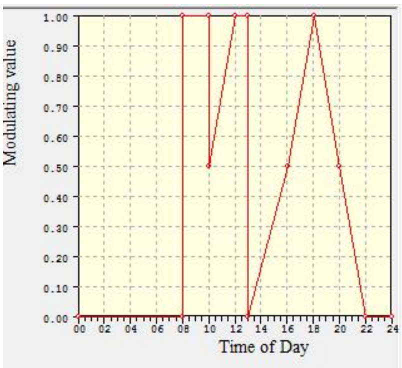




Ventilation Profile (windows and doors open, summer)

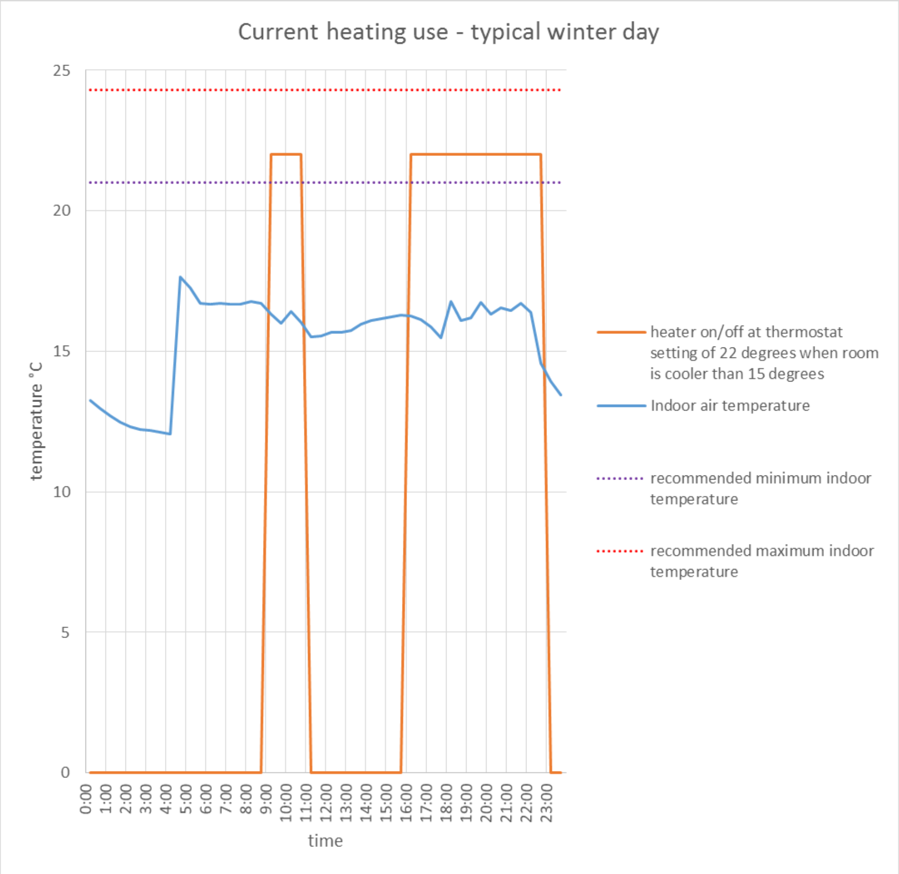


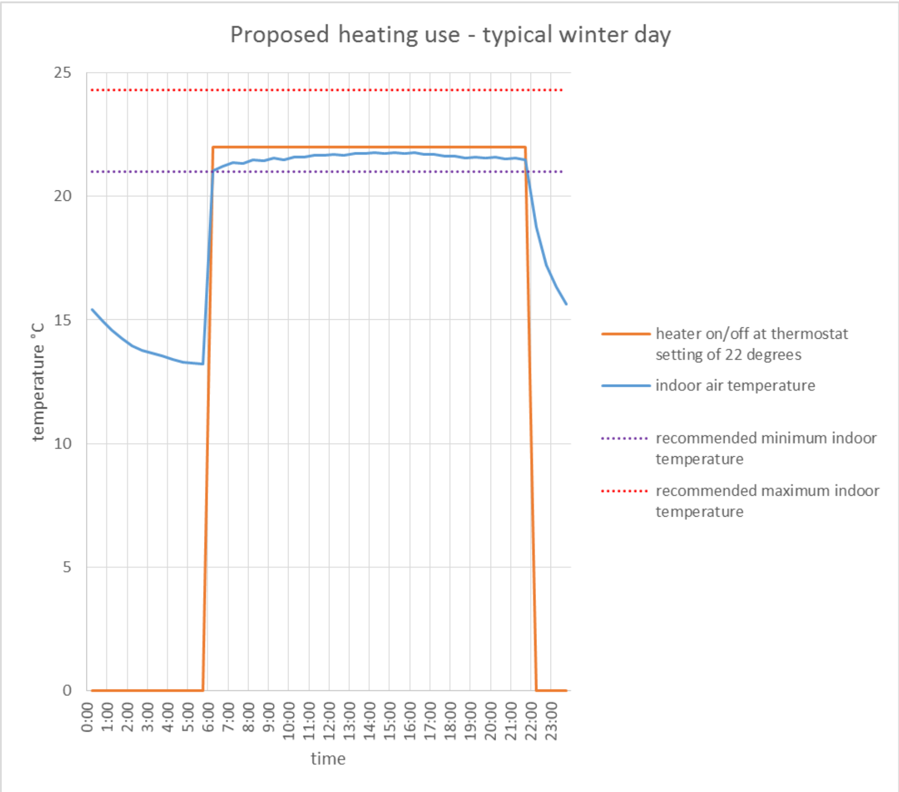
Occupancy Profile



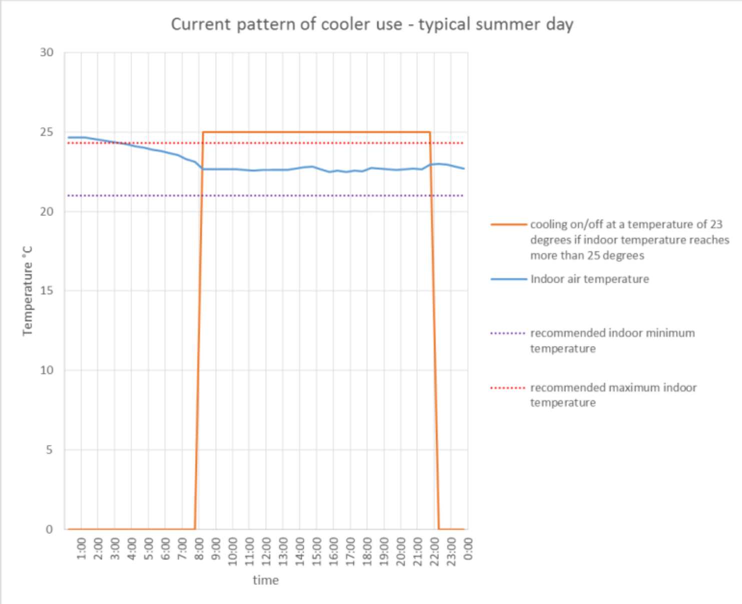
Appendix E – IES Profile Data
House 16

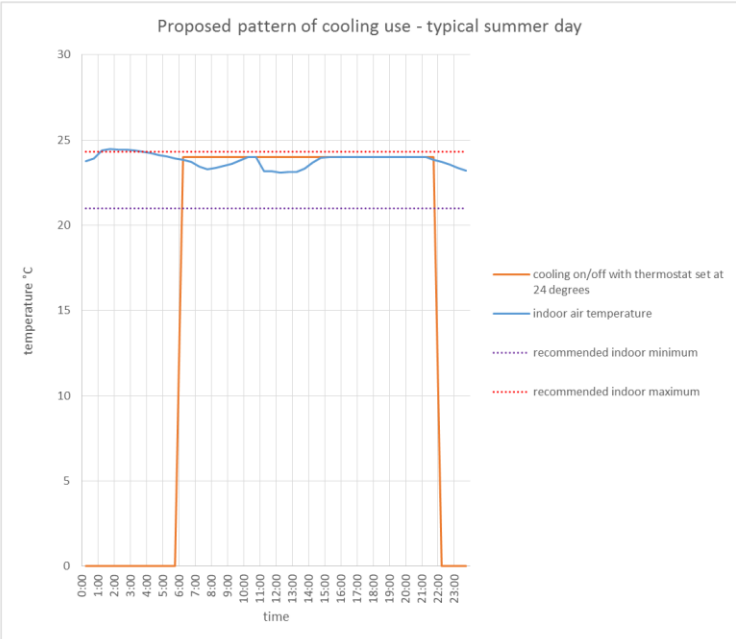
Heating and cooling profiles from IES-VE





Appendix E – IES Profile Data





Ventilation Profile (windows and doors open)

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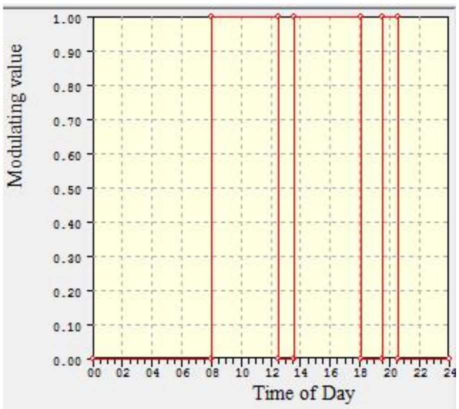
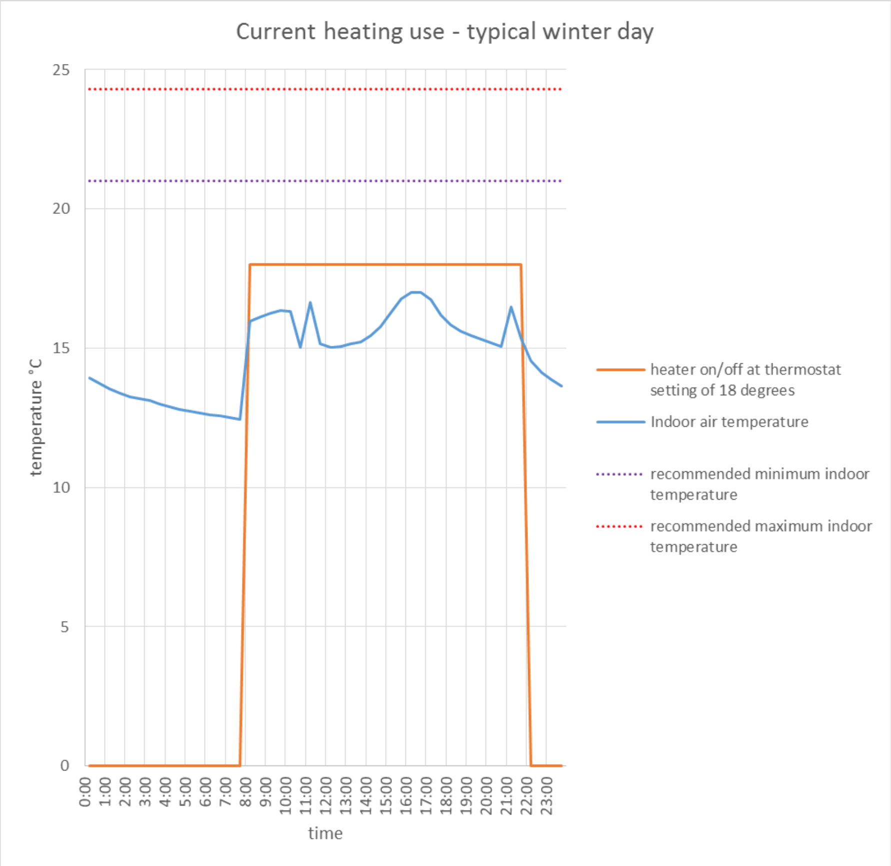
4	18:00	(ta>23) & (to<34) & (to<ta)
5	18:00	0.000
6	18:00	0.000
7	24:00	0.000

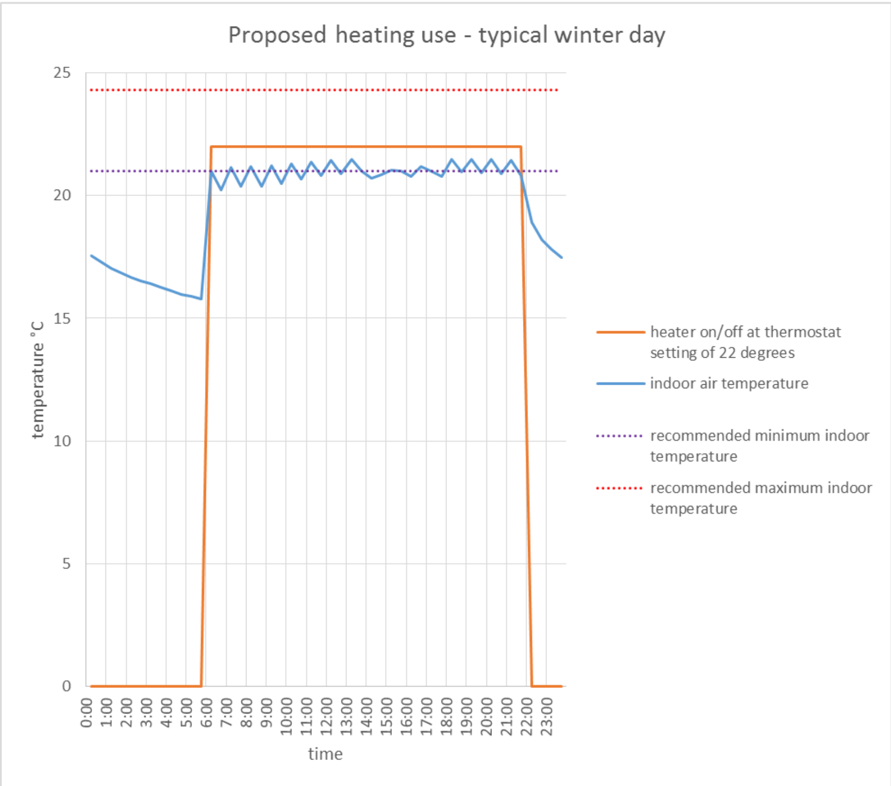
Occupancy Profile



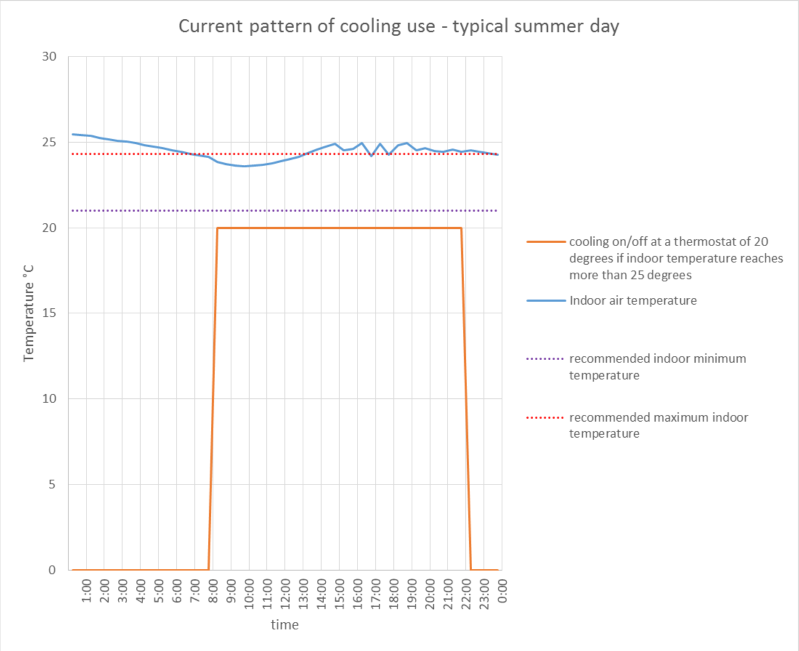
Appendix E – IES Profile Data
House 18

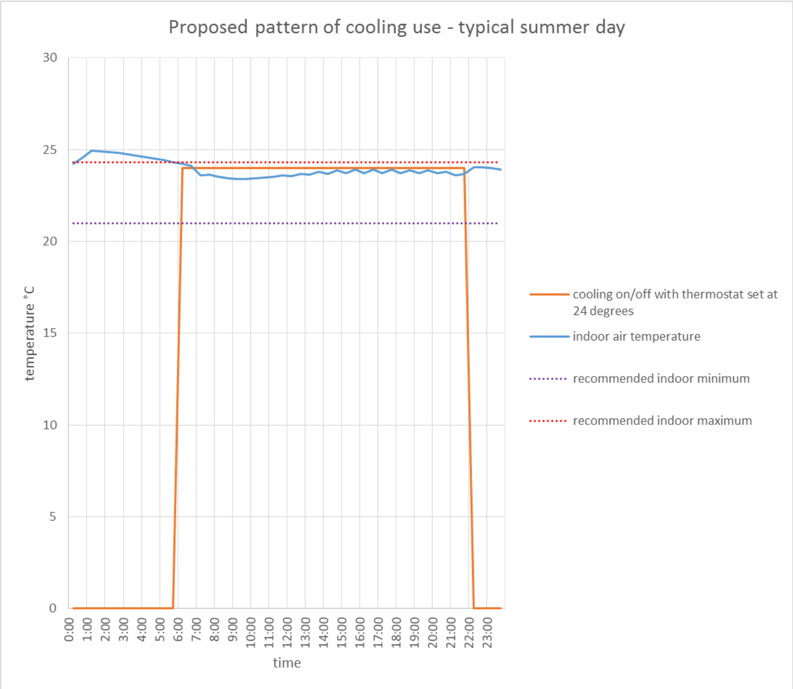
Heating and cooling profiles from IES-VE



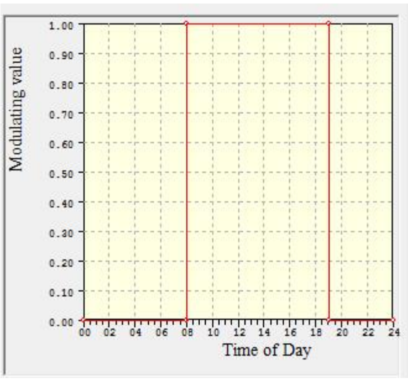


Appendix E – IES Profile Data

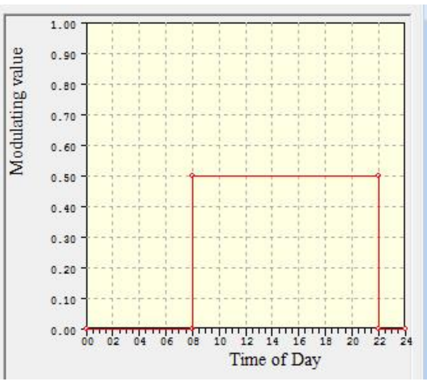




Ventilation Profile (windows and doors open, summer)



Occupancy Profile

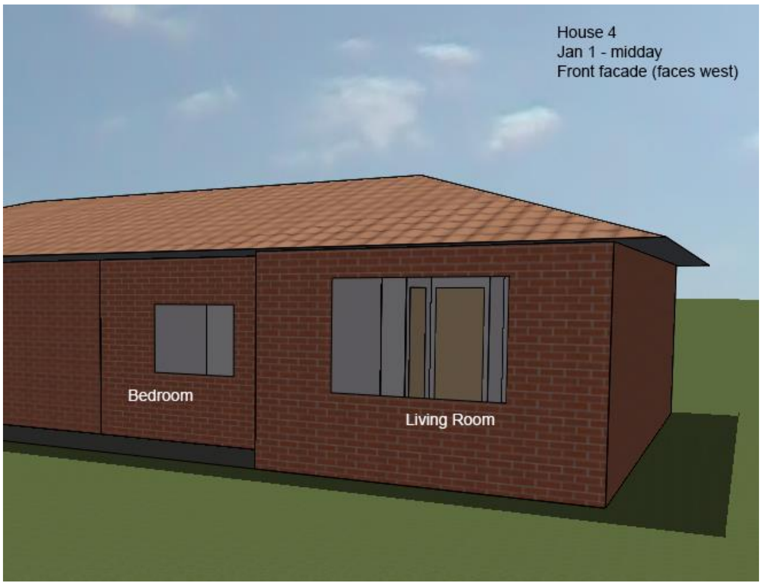


Appendix F

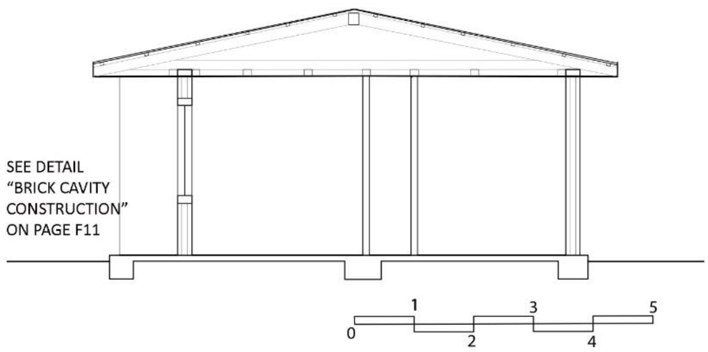
Additional building geometry and simulation parameters

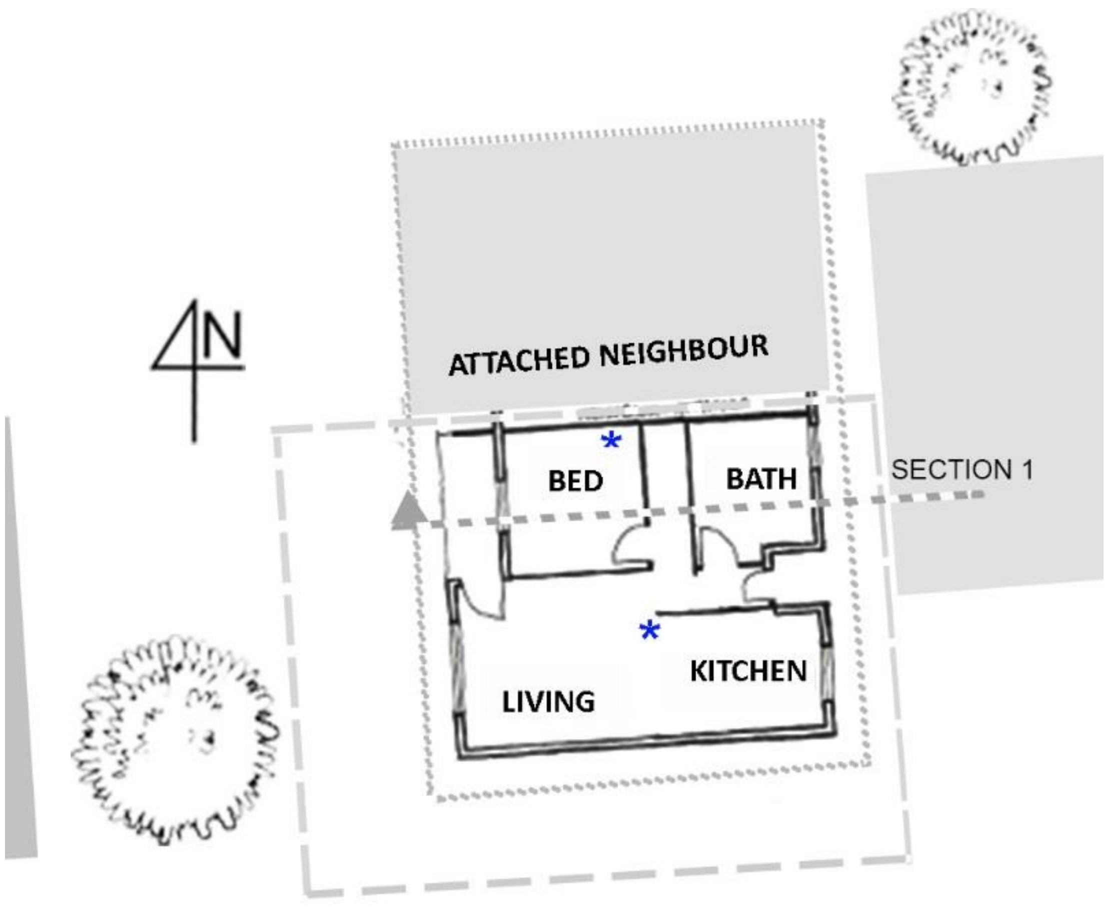
House 4 – Additional construction details

Construction type	Materials (outside to inside)	Thickness (mm)	Total thickness (mm)	Total area (m^2)	U-value (W/m²·K)	R-value (m²K/W)
external wall - double brick cavity	brick	90	240	48.6	1.6351	0.4619
	air gap	50				
	brick	90				
	Plaster	10				
internal wall - single brick	plaster	10	110	20.7	2.3548	0.1852
	brick	90				
	plaster	10				
floor - concrete slab on ground	(U-Correction layer)	(53)	112	45.6	0.6682	0.1457
	reinforced concrete	100				
	Ceramic tile	12				
roof - clay tile	clay tile	12	approx 3100	59.9	0.3058	3.1159
	air gap	200				
	insulation - rockwool	100				
	plasterboard	12				
window – aluminium and timber framed, single glazed	glass	4	4	5.4	0.5811	0.1554



Appendix F – Additional Construction Details





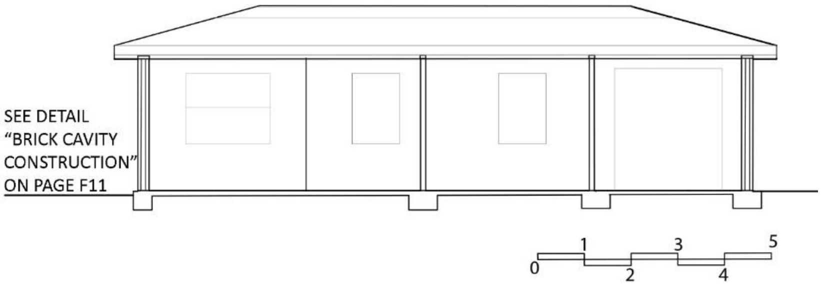
Double brick cavity wall construction
Slab on ground floor
Concrete tile roof

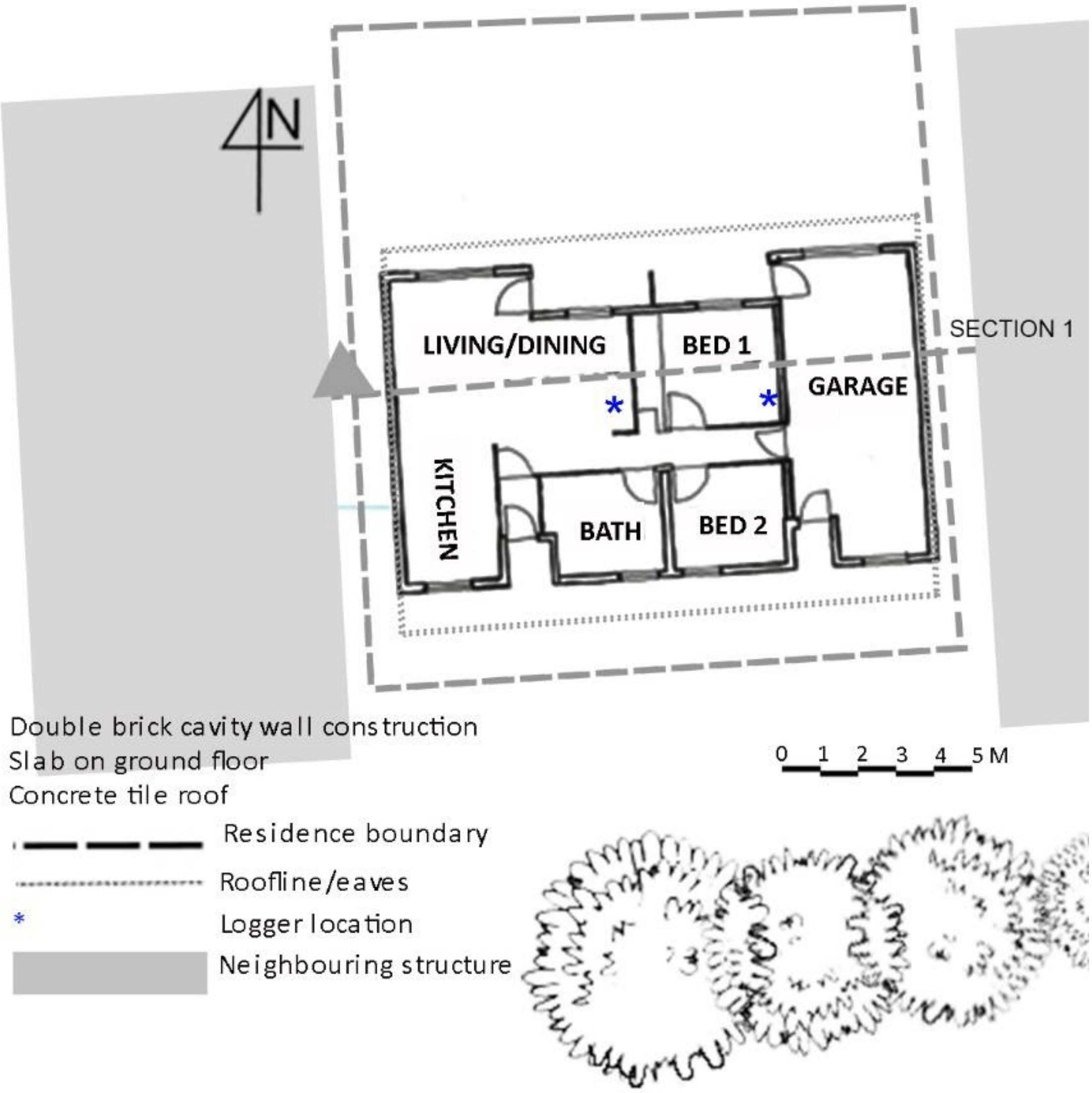
Residence boundary
Roofline/eaves
* Logger location
Neighbouring structure

House 10 – Additional construction details

Construction type	Materials (outside to inside)	Thickness (mm)	Total thickness (mm)	Total area (m²)	U-value (W/m²·K)	R-value (m²K/W)
external wall - double brick cavity	brick	90	240	187.4	1.6351	0.4619
	air gap	50				
	brick	90				
	Plaster	10				
internal wall - single brick	plaster	10	110	34.3	2.3548	0.1852
	brick	90				
	plaster	10				
floor - concrete slab on ground	(U-Correction layer)	(53)	112	45.6	0.6682	0.1457
	reinforced concrete	100				
	Ceramic tile	12				
roof - clay tile	clay tile	12	approx 3100	223.1	0.3058	3.1159
	air gap	200				
	insulation - rockwool	100				
	plasterboard	12				
window – aluminium and timber framed, single glazed	glass	4	4	7.8	0.5811	0.1554

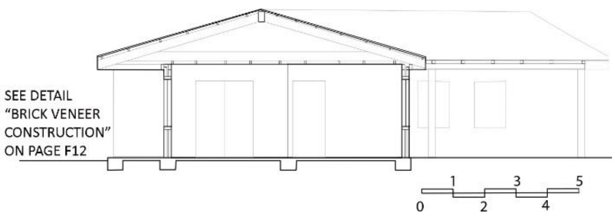
Appendix F – Additional Construction Details

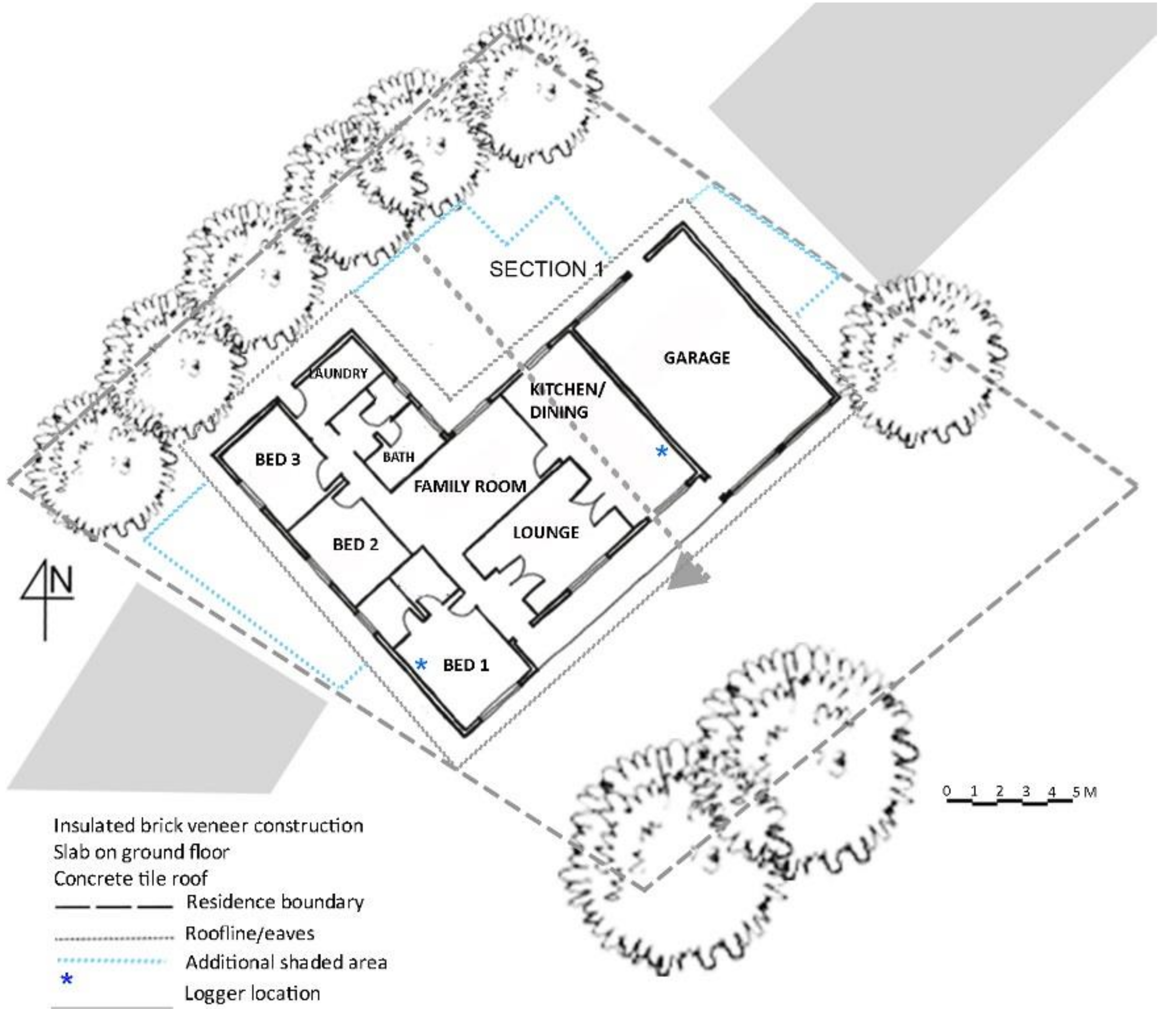




House 12 - Additional construction details

Construction type	materials (outside to inside)	Thickness (mm)	Total thickness (mm)	total area (m²)	U-value (W/m²·K)	R-value (m²K/W)
external wall - brick veneer	brick	110	232.5	190.48	1.6351	0.4619
	air gap	20				
	insulation - rockwool	90				
	Plasterboard	12.5				
internal wall - timber stud	plasterboard	12.5	115	120.8	2.3548	0.1852
	rockwool insulation	90				
	plasterboard	12.5				
floor - concrete slab on ground	(U-Correction layer)	(53)	112	219.78	0.6682	0.1457
	reinforced concrete	100				
	Ceramic tile	12				
roof - clay tile	clay tile	12	approx 3100	308.06	0.3058	3.1159
	air gap	200				
	insulation - rockwool	100				
	plasterboard	12				
window - aluminium framed, single glazed	glass	4	4	14.4	0.5811	0.1554

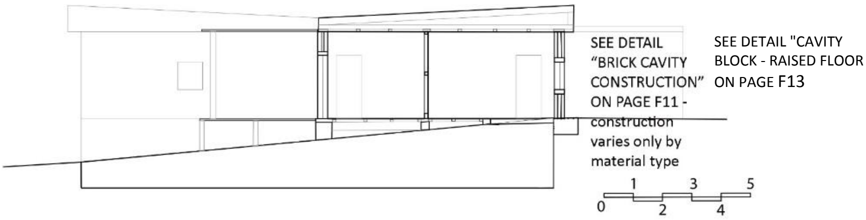


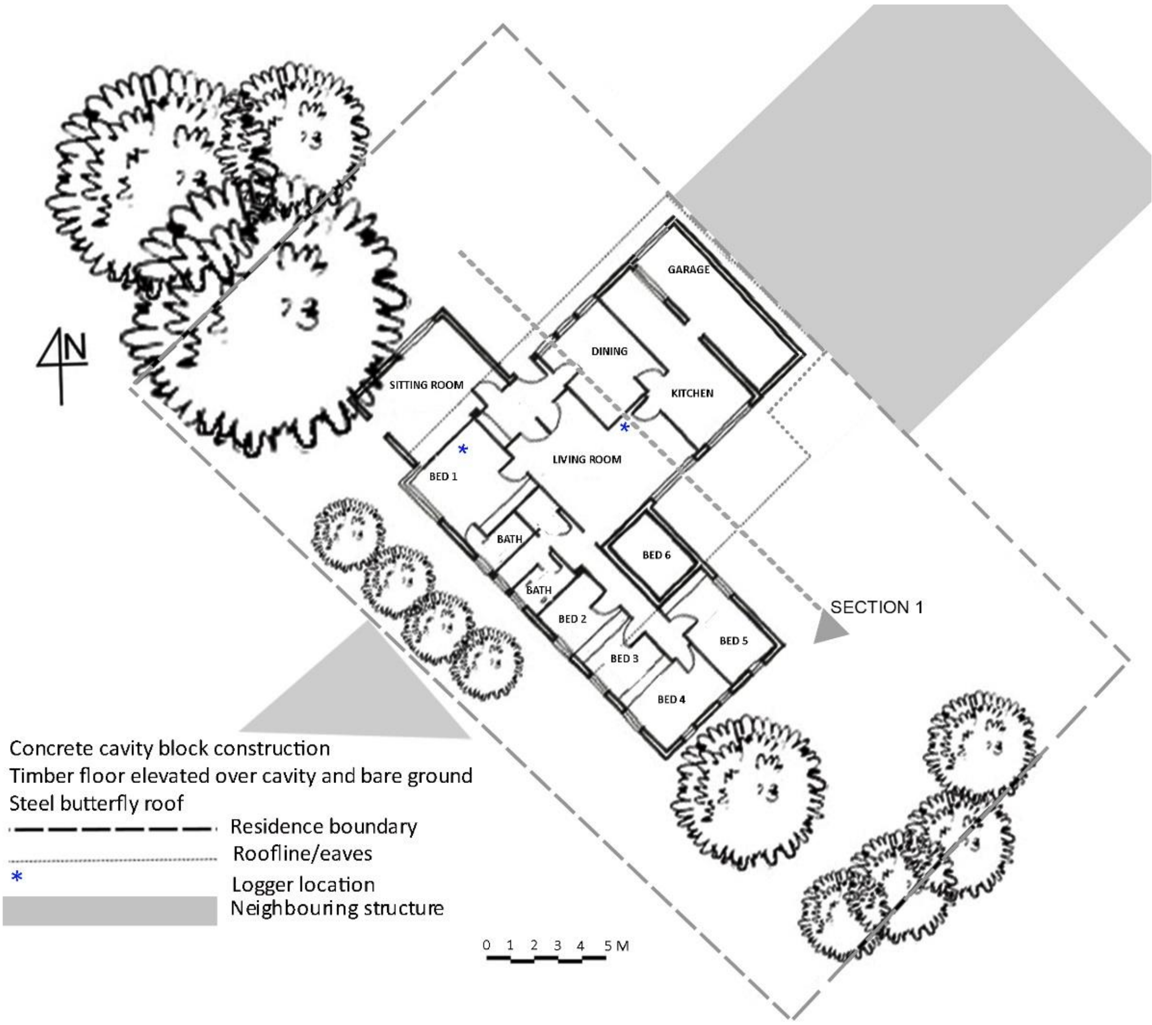


Insulated brick veneer construction
Slab on ground floor
Concrete tile roof
Residence boundary
Roofline/eaves
Additional shaded area
* Logger location
Neighbouring structure

House 16 – Additional construction details

Construction type	Materials (outside to inside)	Thickness (mm)	Total thickness (mm)	Total area (m²)	U-value (W/m²·K)	R-value (m²K/W)
external wall – concrete block	Concrete block	150	345	188.8	1.7089	0.4355
	air gap	30				
	Concrete block	150				
	plasterboard	15				
internal wall - timber stud	plasterboard	15	120	145.75	1.8568	0.299
	air gap	90				
	plasterboard	15				
floor - concrete slab on ground	(U-Correction layer)	-53	112	73.4	0.5517	0.0652
	reinforced concrete	100				
	Ceramic tile	12				
floor - raised timber	U-correction layer	(72.6)	approx 260	154	0.4325	1.5656
	earth	(750)				
	air gap	250				
	Timber sheet	20				
Roof	steel sheet	3	approx 300	227.92	0.3077	3.1122
	air gap	200				
	insulation - rockwool	100				
	plasterboard	12				
window - aluminium framed, single glazed	Glass	4	4	14.4	0.5811	0.1554

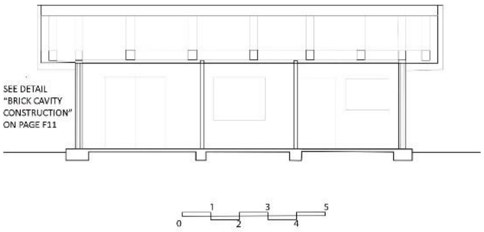

SEE DETAIL
"BRICK CAVITY
CONSTRUCTION"
ON PAGE F11 -
construction
varies only by
material type
SEE DETAIL "CAVITY
BLOCK - RAISED FLOOR
ON PAGE F13
0 1 2 3 4 5

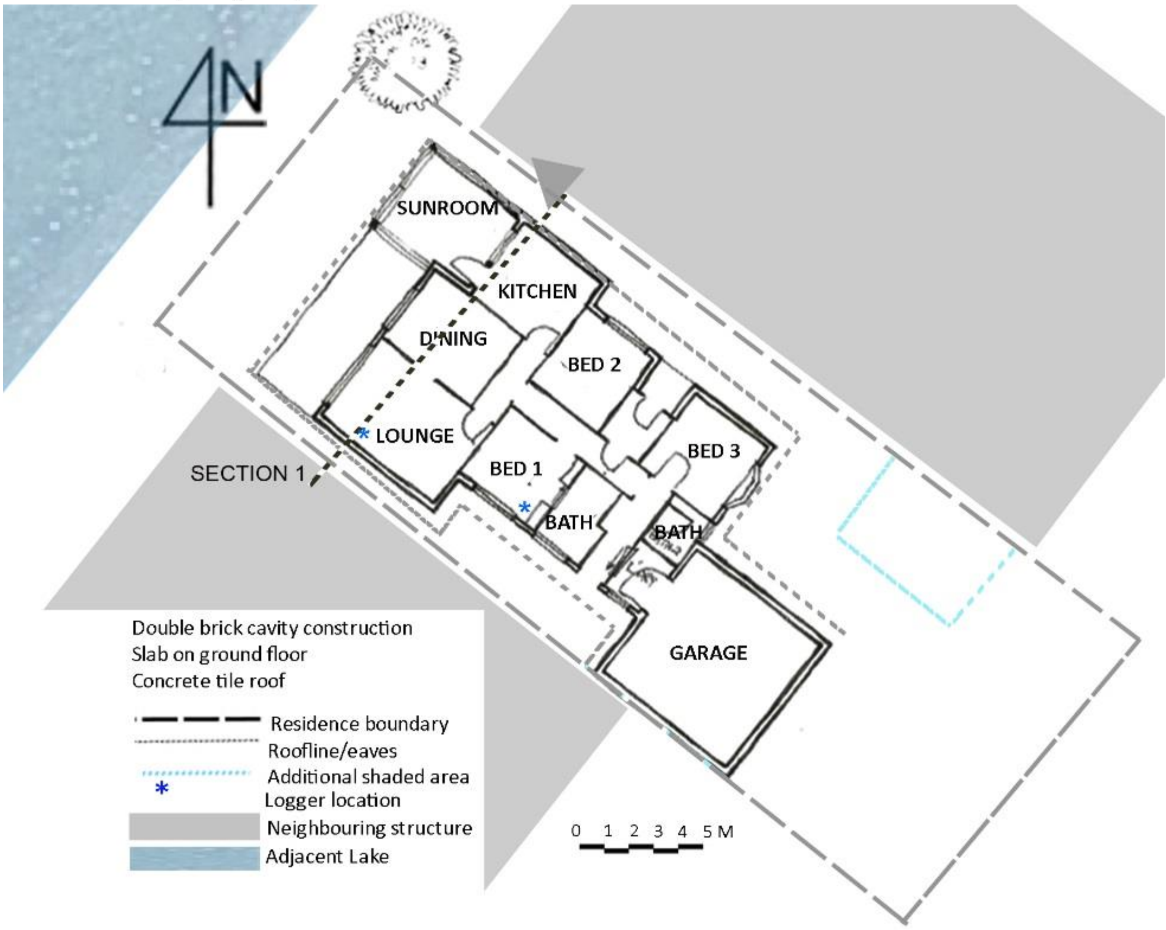

N
GARAGE
DINING
KITCHEN
SITTING ROOM
LIVING ROOM
BED 1
BATH
BATH
BED 2
BED 3
BED 4
BED 5
BED 6
SECTION 1
Concrete cavity block construction
Timber floor elevated over cavity and bare ground
Steel butterfly roof
Residence boundary
Roofline/eaves
* Logger location
Neighbouring structure
0 1 2 3 4 5M

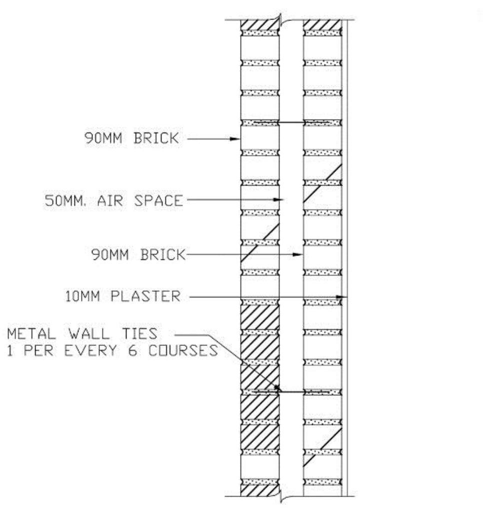
House 18 – Additional construction details

Construction type	materials (outside to inside)	Thickness (mm)	Total thickness (mm)	total area (m^2)	U-value ($W/m^2·K$)	R-value (m^2K/W)
external wall - double brick cavity	brick	90	240	156	1.6351	0.4619
	air gap	50				
	brick	90				
	Plaster	10				
internal wall - single brick	plaster	10	110	122	2.3548	0.1852
	brick	90				
	plaster	10				
floor - concrete slab on ground	(U-Correction layer)	(53)	112	165.48	0.6682	0.1457
	reinforced concrete	100				
	Ceramic tile	12				
roof - steel	steel sheet	3	approx 300	259.4	0.3071	3.1123
	air gap	200				
	insulation - rockwool	100				
	plasterboard	12				
window - aluminium framed, single glazed	glass	4	4	39.4	0.5811	0.1554

Appendix F – Additional Construction Details

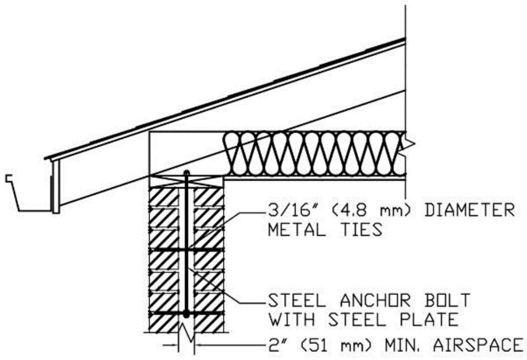






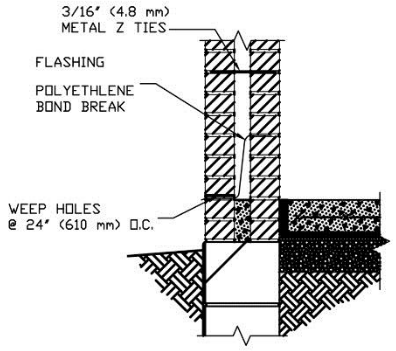
CAVITY WALL CONSTRUCTION DETAIL

same details apply for concrete block cavity construction, however 'brick' is replaced with 150mm concrete block



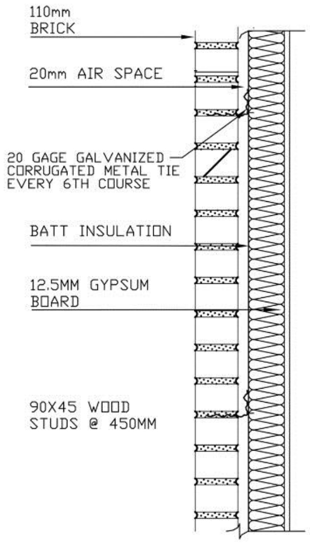
CAVITY WALL CONSTRUCTION DETAIL - ROOF JUNCTION

same details apply for concrete block cavity construction, however 'brick' is replaced with 150mm concrete block

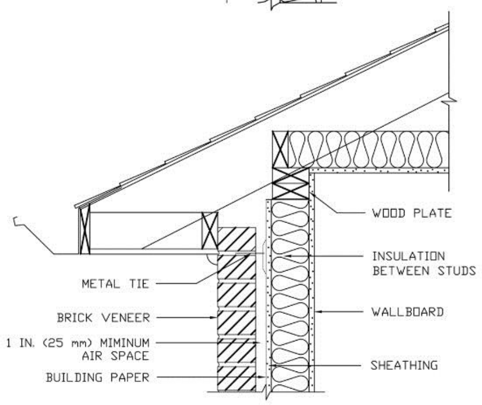


CAVITY WALL CONSTRUCTION DETAIL - SLAB AND GROUND JUNCTION

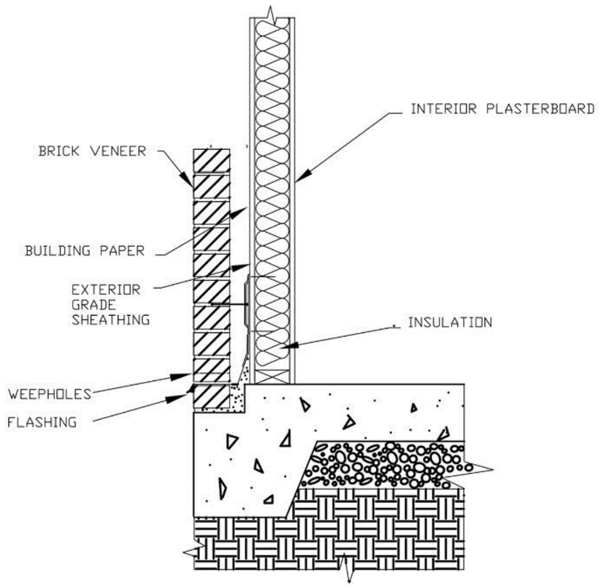
details for the raised floor of House 16 can be found on page F13



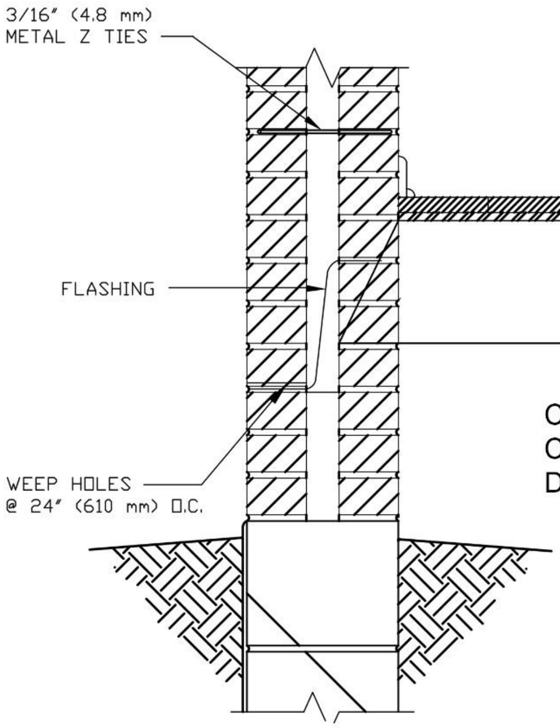
BRICK VENEER WALL CONSTRUCTION DETAIL



BRICK VENEER CONSTRUCTION DETAIL - ROOF JUNCTION



BRICK VENEER CONSTRUCTION DETAIL - SLAB AND GROUND JUNCTION



CAVITY WALL
CONSTRUCTION
DETAIL - RAISED FLOOR

Appendix G

Associated Publications

PUBLISHED VERSION

Rachel Bills

Cold comfort: thermal sensation in people over 65 and the consequences for an ageing population

Proceedings 9th International Windor Conference 2016: Making Comfort Relevant, 2016 / Brotas, L., Roaf, S., Nicol, F., Humphreys, M. (ed./s), pp.156-167

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We have an open papers policy - they can publish where they like. Let me know if you need further clarifications - it is stated eg. on our next proceedings - draft online now at: www.windsorconference.com
The final proceedings will be out next week.

Sue Roaf
Co-Chair of Windsor 2018

1 May 2018

http://hdl.handle.net/2440/111635

Proceedings of 9th Windsor Conference: **Making Comfort Relevant**
Cumberland Lodge, Windsor, UK, 7-10 April 2016.
Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Cold Comfort: Thermal sensation in people over 65 and the consequences for an ageing population

Rachel Bills
School of Architecture and Built Environment, University of Adelaide

Abstract
In Australia the preference of most of the ageing population is to age in place. It is therefore necessary that the thermal environment in homes provides comfort for its occupants to promote healthy ageing. Houses that are too hot or too cold are not only unpleasant to live in but may pose a health risk, especially amongst a vulnerable population.

The study reported in this paper is part of larger research into the thermal practices of people over 65 in Adelaide, South Australia. The aim of this study was to examine the thermal comfort of people over the age of 65 during the coldest winter month as well as during a record breaking hot summer month in 2015. A longitudinal comfort study of both living areas and bedrooms was conducted in 10 South Australian households during these periods. The comfort vote survey included the ASHRAE 7-point sensation scale and the Mcintyre 3-point preference scale.

Preliminary data indicate these occupants find thermal conditions comfortable at cooler temperatures than predicted by the ASHRAE thermal comfort standard, with significant numbers of neutral votes occurring at lower temperatures than expected. During the warmer conditions however, the majority of neutral votes were in the region predicted by-the model.

This research presents a unique perspective of household thermal comfort in older people during two extremes in temperature conditions in Adelaide. This may have implications for healthy housing design for an ageing population.

Keywords: ageing, health, thermal comfort, heat wave, Australia

1 Introduction

Like much of the world, Australia has a rapidly ageing population. By the year 2061, over 20% of the nation's population will be aged 65 or over (Australian Bureau of Statistics 2013). Currently the preference for older Australians is to 'age in place', to remain living independently in either their existing family home or in a smaller private residence. Aged care and other government agencies are then able to provide various levels of care through Home Care Packages (Department of Social Services, 2015).

Ideally the home is a place that is comfortable and healthy. Many housing factors can contribute to the heath of the occupants; temperature, drafts, air quality, damp and associated mould have all been shown to negatively affect occupant health (Howden-Chapman 2004; Martin et al. 1987; Williamson et al. 1997). Conversely, programs which improve insulation and heating in cold climates have shown positive influences on health (Critchley et al. 2007; Howden-Chapman et al. 2008). In this study, the focus is on the thermal environment, and the thermal comfort of older people. Research indicates a higher degree of health problems and deaths during extremes in both heat and cold, especially amongst older people (Nitschke et al. 2007; Wilkinson et al. 2004). These health problems include respiratory and cardiovascular illnesses in the colder temperatures (Analitis et al. 2008) and kidney diseases in extreme heat (Bi et al. 2011).

When examining thermal comfort, it is important to examine not only the environmental conditions themselves, but more importantly the occupant's sensations in those conditions. This is especially true of the older population. Research has shown that as the human body ages, the body's thermoregulatory response is altered and it loses some of its ability to sense heat and cold. Measurements of patterns of sweating, shivering and vasoconstriction in older people have shown quantifiable differences than in younger people (Anderson et al. 1996; Drinkwater et al. 1978; Wagner et al. 1972), with these reactions being slower and/or decreased. A slower response to changes in the external conditions has the potential to cause accidental hypo- or hyperthermia. By studying the self-reported thermal comfort of older people, this study aimed to determine whether older people experience a sensation of comfort in their homes despite the fact the conditions may be considered uncomfortable or indeed unsafe and unhealthy.

2 Context

Adelaide is located at 34.9° South Latitude and 138.6 ° East Longitude, and has a hot Mediterranean climate (Sturman et al. 1996) with hot dry summers and mild winters. Summer extends from December through to February and winter from June to August. The average maximum temperatures in Adelaide during December and February are 27.2° C and 29.5 ° C respectively; however, the city experiences frequent heat waves, during which temperatures often exceed 40° C. These heat waves can occur anywhere from November to March. In July, the average daily minimum and maximum are 7.5° C and 15.3° C respectively (BOM 2016a)

In 2015, conditions in both July and December were markedly different from typical years. July is typically the coldest month of the year; however, whilst the average minimum in July was 6.7 ° C, the temperatures dropped as low as 1.8 ° C, and both maximum and minimum temperatures across the city were close to 1degree colder than average across the city (BOM 2015). Typically February is the hottest month in Adelaide; however, December 2015 recorded averages equal to that of February and was the hottest December on record for the Adelaide region. Maximum temperatures were 5.4 degrees higher than average, and minimum temperatures more than 2.5 degrees above average (BOM 2016b). Heat wave conditions occurred in the third week of December, with six consecutive days over 36 degrees, four of which exceeded 40 degrees. In the month of December there were 7 days with temperatures over 40 degrees, the highest number of days above 40 degrees in a single month on record. For this reason, this study focuses on the experiences of older people during these two months, to compare and contrast their thermal comfort experiences during these extremes in conditions.

Due to the aforesaid hot Mediterranean climate, much of the focus of public health messages is on extreme heat conditions. Indeed, as there are frequent heat waves this seems to be the prudent approach. However, recently attention has turned to the dangers of cold, even in mild winters (Cheng 2015; Gasparrini et al. 2015). Unfortunately houses in Adelaide are typically not designed for colder conditions, with few houses having central heating and many having fixed heating only in the living area, and relying on portable heating appliances for other rooms. Similarly few houses, especially older ones, have whole house cooling, but may have individual reverse cycle appliances (or similar) in living rooms and bedrooms.

3 Methods

3.1 Participants

Participants were recruited from an earlier survey of housing and health in which they could volunteer for the longitudinal study (Bills and Soebarto 2015). For the earlier survey, the participants were recruited through invitations distributed by local councils and church groups. Some participants were also recruited through the University of the Third Age, "a worldwide organisation for 'over 50s' who wish to expand their interest in the world, increase their knowledge by learning and to pass on the experiences of life to others" (University of the Third Age, n.d). In total, 18 households participated in this longitudinal study; however, this paper only focuses on results of the study from 10 households (4 men and 7 women), as the collection of data from the other participants is still ongoing. These 11 participants completed comfort vote surveys during the study period. One participant did not complete the study due to ill health.

3.2 Protocol

Unobtrusive data loggers were installed in the bedrooms and living rooms of the participants' houses. These recorded air temperature, humidity and globe temperature every 15 minutes. Participants were asked to regularly complete short comfort vote surveys which included the ASHRAE 7-point thermal sensation scale (ASHRAE 2013) and the Mcintyre 3-point preference scale (Mcintyre 1973). They were asked to rank their clothing pictorially out of 6 and their activity level pictorially out of 4 (see Figure 1). They were also asked to indicate whether other environmental factors such as ventilation and the operation of any heating, cooling or fans were employed. Times and dates in July and December when surveys were completed were recorded and responses matched with data from the loggers.

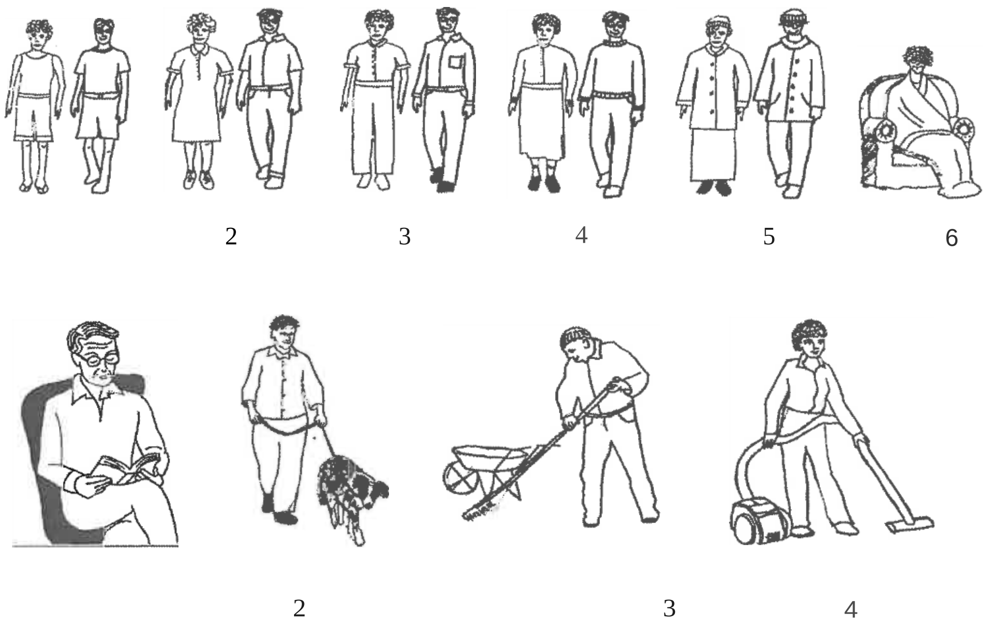


Figure 1- Pictures used to represent clothing and activity levels in the comfort vote survey

The air temperature and humidity data at the times of the neutral sensation votes (3, 4 or 5 on the ASHRAE 7-point sensation scale) were analysed using the Graphic Comfort Zone Method of ASHRAE 55 (ASHRAE 2013). This model was chosen over the Adaptive thermal comfort model due to the high percentage of votes filled out when heating or cooling was in use. The votes were filtered to remove responses made when very high levels of clothing were being worn, or when very high levels of activity had been completed in the last 15 minutes before completing the survey.

4 Results

4.1 Outdoor and Indoor Conditions

Average outdoor maximum and minimum temperatures were sourced from the Australian Bureau of Meteorology and were taken from the weather stations closest to the participating houses. Table 1 shows the comparison between the average outdoor conditions during the study and the average conditions inside the 10 houses studied.

In July, the average, minimum temperatures in the living rooms and bedrooms were close to the outdoor maximum. Maximum temperatures in the living rooms were slightly warmer than in the bedrooms. Many respondents reported not using or not having heating in the bedrooms, which would account for this slightly cooler temperature. All had some form of heating in the main living areas, and movement of this warmer air upward and outward could potentially pull warm air from other areas, like the bedrooms, into these living spaces. However, solar gains from windows and thermal mass from the brick walls, would act to keep the bedrooms warmer than the outside conditions during the day in July.

Table 1: Average outdoor and indoor maximum and minimum temperatures

	Average Outdoor Maximum (OC)	Average Outdoor Minimum (OC)	Average Living Room Maximum (OC)	Average Living Room Minimum (OC)	Average Bedroom Maximum (OC)	Average Bedroom Minimum (OC)
July	14.1	6.7	20.8	14.8	18.0	14.8
December	32.5	18.1	26.7	22.9	26.7	23.0

In December, the average indoor maximum in the living rooms and bedrooms was approximately 6 degrees cooler than the average outdoor maximum. In general the living rooms and bedrooms were very similar in temperature, despite fewer participants reporting using air conditioning in their bedrooms than in their living rooms. The movement of cooler air from the living areas into the bedrooms as well as the effect of shading and insulation may explain these temperatures.

4.2 Thermal sensation votes and preference

In total, 183 thermal comfort votes were completed by participants in July, and 147 in December. Overall, more neutral thermal sensation votes (TSVs) of slightly cool, just right, slightly warm were recorded during December (78.4% neutral votes) than July (47.7% neutral votes). There were subsequently more votes at the extreme ends (cold and hot) during July than December (29.3% vs 6.3%) (Figure 2). This is despite the fact that during the cold July period, participants recorded having heating on 54% of the time in the living area and 41% of the time in the bedrooms. In contrast, participants only recorded using cooling 40% of the time in the living room and 31% of the time in the bedroom in December.

Despite the higher number of 'cold' votes during the winter, participants were less likely to express a desire to be warmer when it was 'cold' (66.7% of the time) than they were to express a desire to be cooler when voting at the 'hot' end of the scale (100% of the time) (see Figure 3). When they reported being 'cool' or 'warm', they were still slightly less likely to report desiring change in July (46% of the time) than in December (58.8 % of the time).

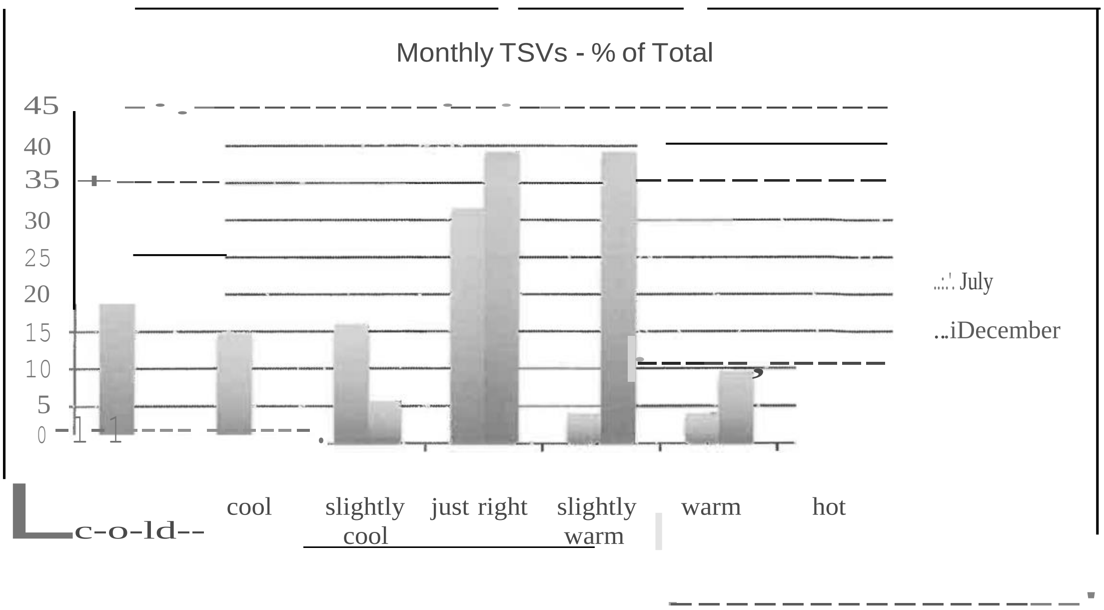


Figure 2: Percentage of total of each TSV separated by month.
Votes in July are in blue. Votes for December are in Red

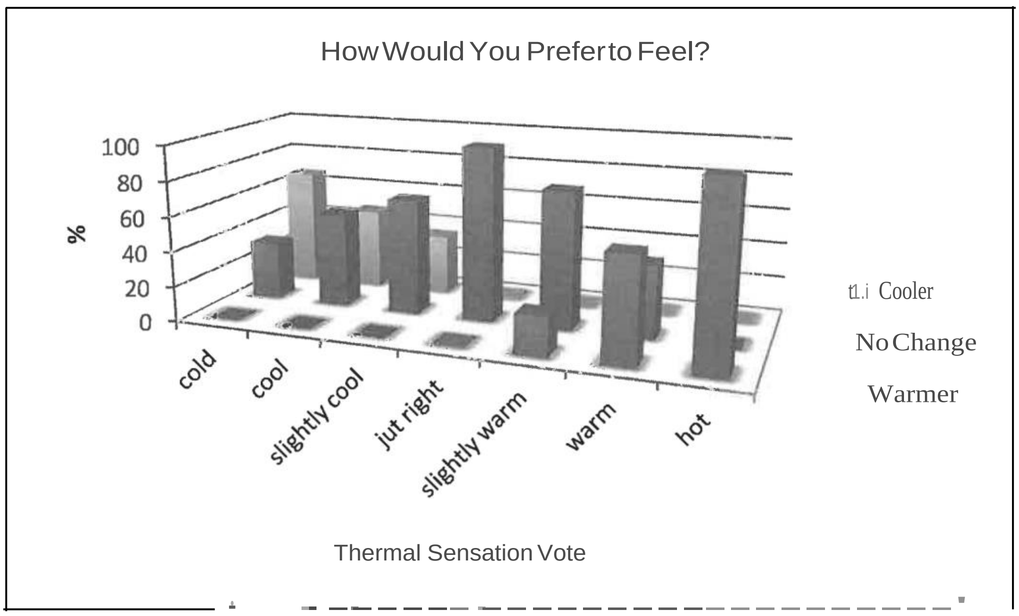
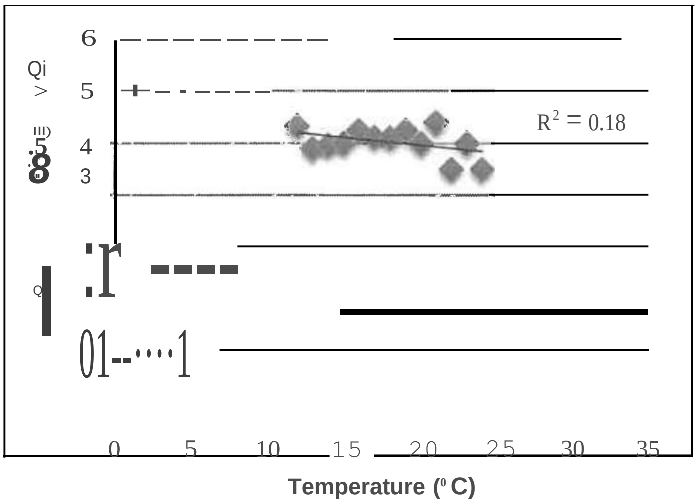


Figure 3: Participants preferences for change by thermal sensation vote

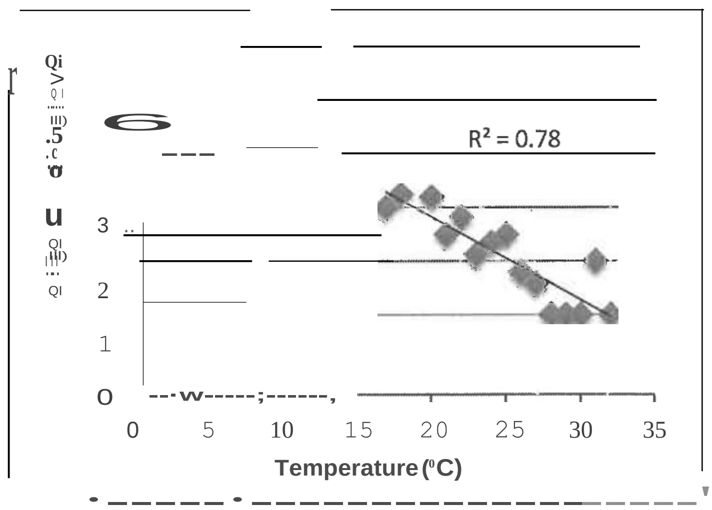
4.3 Clothing

The average clothing level was obtained by binning the clothing scores per degree of indoor operative temperature and calculating the mean.

During July, the results showed that there was no correlation between the clothing worn and the indoor air temperature (Figure 4a). The clothing worn remained very similar regardless of the temperature, around a level 4 (refer to Figure 1). In December there was a clear negative correlation between air temperature and clothing worn. Participants reported much lower levels of clothing as temperatures increased (Figure 4b).



(a)



(b)

Figure 4: Binned average clothing levels for each degree of temperature in (a) July and (b) December.

4.4 Comparison with ASH RAE SS acceptable range of temperature and humidity

When comparing the air temperature and humidity at the times neutral votes were recorded (figure 5) with ASHRAE 55 acceptable range of temperature, there is a difference to experiences of comfort in July when compared to December. In July, participants were more likely to express feelings of comfort at colder temperatures than suggested, whilst in December participants expressed comfort in conditions more aligned with the operative temperature zone outlined in solid lines (see Figure 5). This was observed not only when the neutral votes were considered, but also when participants indicated no preference for a change in thermal conditions, and when participants indicated that conditions were thermally acceptable, as shown earlier in Figure 3. In contrast, most of the neutral votes collected during the December period fell within the comfort zone, with far fewer falling outside.

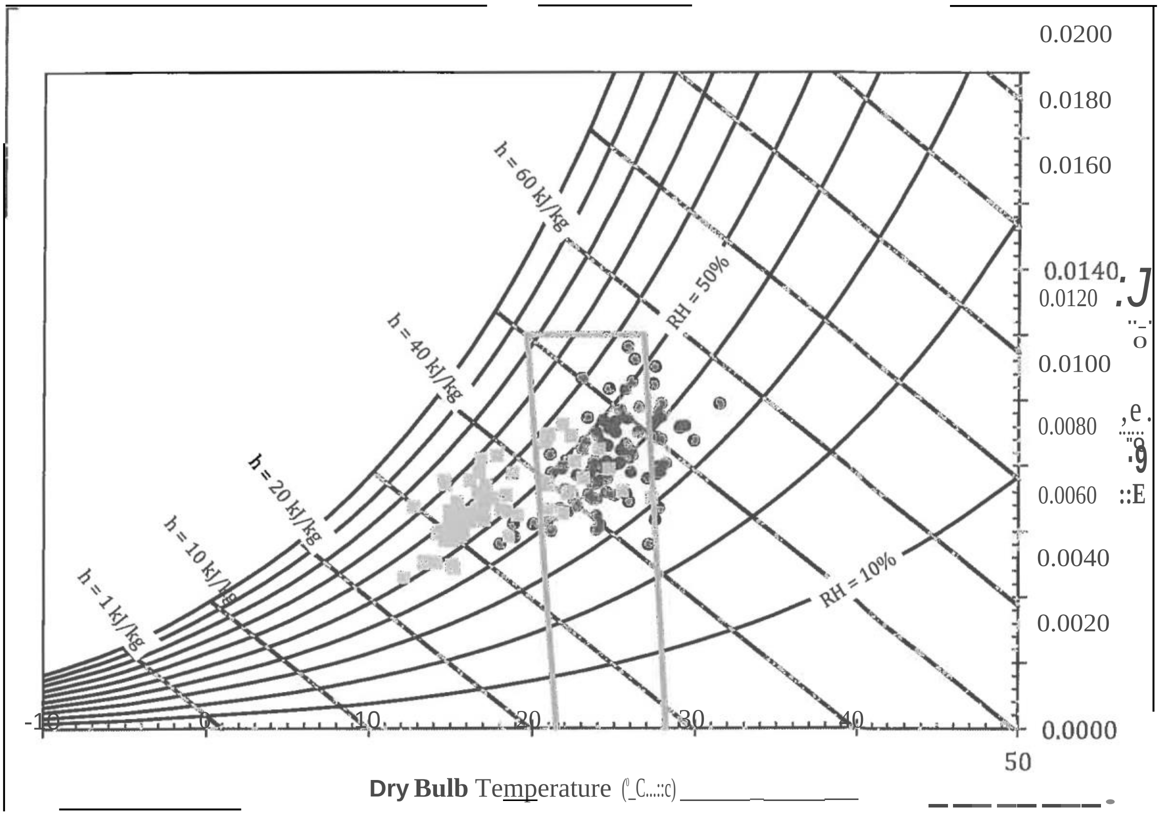


Figure 5 – ASHRAE-55 Acceptable Comfort (1clo Zone) - Temperature and humidity ratio at times when neutral Thermal Sensation Votes (3,4, or 5 on the ASH RAE thermal sensation scale) were recorded by participants. Votes recorded in July are labeled blue whilst those recorded during December are labeled red

Note: The Comfort Zone assumes clothing 0.5 S clo s 1.0 and metabolic rate 1.0 s met s 1.3

Source: Adapted from ASH RAE 55-2013, Figure 5.3.1

5 Discussion

Overall, the older people in this study expressed sensations of thermal comfort at colder temperatures than predicted by the ASH RAE standards most of the time, but rarely reported feelings of comfort at warmer temperatures than predicted. Their neutral thermal sensations during the hot month of December were largely within ASHRAE's acceptable operative temperature and humidity, despite very hot weather throughout the month. In the cold months however they expressed feelings of neutral thermal sensations at temperatures as low as 12 degrees inside, even when only wearing moderate levels of clothing and at times when they were largely at rest.

There are a number of reasons that older people might describe feelings of thermal comfort in conditions that are otherwise considered uncomfortably cold. First, the results indicated that the participants wore heavier clothing in July, with majority wearing long pants, long sleeve jumpers or sweaters, socks and shoes. The results also showed that there was very little correlation in July between the level of clothing and thermal sensation in winter (R^2 = 0.18) compared to those in December (R^2 = 0.78, Figure 4b), indicating that they wore similar clothing throughout July regardless of the indoor temperatures. Wearing heavier clothing seems to be the personal strategy that older people in the study employed to keep themselves comfortable, rather than, for example, turning on the heater. However, it is also worth noting that upon closer examination, the clothing level at lower temperatures (i.e. 13 to 14 degrees) was slightly less than at temperatures above 14 degrees (Figure 4a) even at times when they were largely at rest. Physiological changes associated with age, behavioural factors and adaptations to conditions over the life course are all possibilities as suggested by Hitchings et al. (2011) and Horvath et al. (1955) respectively, but the exact reason for this unexpected clothing value at lower temperatures is still unknown. Also, despite the exclusion of votes where high levels of clothing were reported, and despite of every effort taken to tailor the survey to the clothing typically worn by older people, the actual clothing worn by the respondents in cooler conditions may still be heavier than assumed by the ASHRAE standard for winter (i.e. 1.0 do). Nevertheless, further research is needed to investigate these peculiar results.

Ageing brings with it inevitable physical changes. The metabolism slows, and general frailty increases which can lead to a decrease in physical activity, all of which changes the body's response to thermal conditions. Ageing has also been shown to reduce the body's ability to feel changes in temperature. When examining the data from the cold month of July, any of these could be contributing factors. For instance, a person's activity level can influence their perception of thermal comfort. In general, participants were more active during July than in December, with 50% reporting being at rest at the time of the survey, whereas in December participants reported being at rest 66% of the time. There was a range of frailty in the participants, with some being very sedentary and some being quite active. However, when the data were analysed by participant, respondents were equally represented across the whole range of votes. In contrast, during the warmer weather, participants' votes were largely in the expected range, suggesting that at least in warm conditions they are sensing temperature as expected. Further biomedical testing of metabolic rate and other physiological changes may help in understanding the changing thermal perceptions of older people, and why these changes seem to be limited to colder conditions.

Regardless of the reason for the acceptance and tolerance of colder temperatures, there are concerns about various health conditions that may occur when older people are chronically exposed to cold temperatures. During the study period between the months of May and October, 2 of the female participants reported having fallen, and 2 male participants also reported that their wives (who were not completing comfort vote surveys) had fallen. Falls are of a particular health concern amongst the older population, and their occurrence has been linked to colder temperatures in women(Lindemann et al. 2014) Fractured bones, especially hips are a common result of a fall. Aside from injuries sustained in a fall, other problems can arise. Around half of those who fall are unable to get up unassisted (Tinetti et al. 1993). If left on the floor for a prolonged period, there are risks of hypothermia, pneumonia, pressure sores, dehydration and in some cases death (Tinetti et al. 1993). For those who fall and fracture a hip, there is significantly increased mortality; reports of between 12 and 37% mortality within 12 months exist in the literature (Foster 2015). Half will not be able to continue to live independently following the fracture (Wolinsky et al. 1997). Whilst there are other contributing factors, provision of a healthy thermal environment may thus be important in preventing falls amongst the aged and the subsequent morbidity and mortality.

Along with the changes in sensation amongst older people, there are certain behaviours and attitudes which may also be at play. Older people may have a tendency to be reluctant to identify as an 'old person' and therefore distance themselves from the problems and vulnerabilities of ageing (Day et al. 2011; Hitchings et al. 2011). Some may not regard themselves as being vulnerable due to age and may therefore ignore public health warnings from government and other agencies regarding health and wellbeing during extremes in weather which may be aimed specifically at older people (Day et al. 2011). Having always coped in the past they see no reason to change their behaviours now. This makes a certain amount of sense when potential loss of sensation to cold is taken into consideration. However dissociation from vulnerability could in fact make an older person less likely to take steps to adapt to a cold environment, and therefore increase the risk of health complications from the cold.

Assuming the operative temperature zone assumed by the ASHRAE Standard is appropriate to the Australian context, it would appear that the participants in this study are largely able to keep their houses at an appropriate temperature during hot conditions. In colder temperatures, it seems they keep their houses cooler than would be expected and recommended. Despite this, these participants expressed satisfaction with these cooler conditions. It is possible that this is a cultural acceptance of the cold, due to the fact that the winters in Australia are generally considered to be mild. It is also possible that extensive public health campaigns in recent years have made participants more aware of the dangers of the heat, and therefore more likely to keep their houses cooler during the extreme heat. These public health campaigns are founded in research that has examined mortality during the summer months ((Hansen et al. 2011; Hansen et al. 2008; Nitschke et al. 2011), but as yet few studies of morbidity and mortality during winter have been conducted in Adelaide. Studies during colder weather are complicated by the chronic nature of conditions associated with the cold, such as respiratory infections, as opposed to the more acute nature of health conditions which arise during extreme heat, such as heat stroke and dehydration.

One of the difficulties when conducting residential thermal comfort studies in Australia is the lack of understanding of how the public at large experience thermal comfort to compare possibly outlier groups against. It is reasonable to assume that the climate and culture of Australia means the operative temperature zone used by the ASHRAE standard is not the zone in which Australian people will feel most comfortable, despite the predictions of the thermal comfort model. Such a study has yet to be undertaken in Australia, so any conclusions that may be drawn from residential studies of particular groups are cautious at best. In terms of creating policies and building standards that may improve conditions for older people, the preferences of the general population must also be understood in order to fully understand any changes that are occurring.

6 Conclusion

Some older South Australians appear to experience sensations of acceptable thermal sensations in a wider range of conditions that would otherwise be predicted by the ASH RAE Standard. This study of thermal comfort during the winter months shows experiences of neutral thermal sensation at colder temperatures than expected. It is still unclear what is causing this, and a number of factors including physical and physiological changes, behavioural changes and adaptations over time may be at play. Further research into the reasons for these observed results is required to make definitive statements about the cause. It is important to understand the mechanisms and any health consequences so that interventions can be recommended to ensure older people can remain healthy and comfortable in their own homes.

References

Analitis, A, Katsouyanni, K, Biggeri, A, Baccini, M, Forsberg, B, Bisanti, L, Kirchmayer, U, Ballester, F, Cadum, E & Goodman, P 2008, 'Effects of cold weather on mortality: results from 15 European cities within the PHEWE project', *American journal of epidemiology,* vol. 168, no. 12,pp. 1397-1408.

Anderson, G, Meneilly, G & Mekjavic, I 1996, 'Passive temperature !ability in the elderly', *European journal of applied physiology and occupational physiology,* vol. 73, no. 3-4, pp. 278-286.

ASHRAE 2013, *ANSl/ASHRAE standards 55-2013, thermal environmental conditions for human occupancy,* ASHRAE, Atlanta, GA.

Australian Bureau of Statistics 2013, *Population Projections, Australia, 2012 (base) to 2101,* ABS, Canberra, viewed 18 March 2014, <http://www.abs.gov.au/ausstats/abs@.nsf/ Lookup/3222.0main+features52012 %28base%29 to 2101>.

Bi, P, Williams, S, Loughnan, M, Lloyd, G, Hansen, A, Kjellstrom, T, Dear, K &. Saniotis, A 2011, 'The effects of extreme heat on human mortality and morbidity in Australia: implications for public health', *Asia-Pacific journal of public health,* p. 1010539510391644.

Bills, R & Soebarto, V 2015, 'Understanding the changing thermal comfort requirements and preferences of older Australians', in *49th International Conference of the Architectural Science Association {02 Dec 2015-04 Dec 2015: Melbourne, Australia).*

BOM 2015, *South Australia in July 2015: cool and dry across much of the State,* Bureau of Meteorology, viewed 10/02/2016, <http://www.bom.gov.au/climate/current/month/sa/ archive/201507.summary.shtml>.

BOM 2016a, *Climate statistics for Australian locations*

Summary statistics ADELAIDE {KENT TOWN), viewed 25/3/2015, <http://www.bom.gov.au/climate/averages/tables/cw_023090.shtml>.

BOM 2016b, *South Australia in December 2015: Record warm, and dry in the south,* Bureau of Meterology, viewed 10/2/2016, <http://www.bom.gov.au/climate/current/month/sa/ archive/201512.summary.shtml>.

Cheng, L 2015, *Australia's poor housing contributing to cold-related deaths,* viewed 18/2/2015 2016, <http ://architecturea u.com/articles/a ustra lias-poor-housing-contributing- to-cold-related-deaths/>.

Critchley, R, Gilbertson, J, Grimsley, M & Green, G 2007, 'Living in cold homes after heating improvements: Evidence from Warm-Front, England's Home Energy Efficiency Scheme', *Applied Energy,* vol. 84, no. 2, pp. 147-158.

Day, R & Hitchings, R 2011, ''Only old ladies would do that': Age stigma and older people's strategies for dealing with winter cold', *Health and Place,* vol. 17, no. 4, pp. 885-894.

Department of Social Services, 2015. Home Care Packages. *My Aged Care,* Commonwealth of Australia. Available online at: http://www.myagedcare.gov.au/aged-care-services/home-care-packages

Drinkwater, B & Horvath, S 1978, 'Heat tolerance and aging', *Medicine and science in sports,* vol. 11, no. 1, pp. 49-55.

Foster, K 2015, 'Hip fractures in adults', in T Post (ed.), *UpToDate,* Waltham, MA.

Gasparrini, A, Guo, Y, Hashizume, M, Lavigne, E, Zanobetti, A, Schwartz, J, Tobias, A, Tong, S, Rocklov, J, Forsberg, B, Leone, M, De Sario, M, Bell, ML, Guo, Y-LL, Wu, C-f, Kan, H, Yi, S-M, de Sousa Zanotti Stagliorio Coelho, M, Saldiva, PHN, Honda, Y, Kim, H & Armstrong, B 2015, 'Mortality risk attributable to high and low ambient temperature: a multicountry observational study', *The Lancet,* vol. 386, no. 9991, pp. 369-375.

Hansen, A, Bi, P, Nitschke, M, Ryan, P, Pisaniello, D & Tucker, G 2011, 'The effect of heatwaves on ambulance callouts in Adelaide, South Australia', *Epidemiology,* vol. 22, no. 1, pp. S14-S15.

Hansen, A, Bi, P, Ryan, P, Nitschke, M, Pisaniello, D & Tucker, G 2008, 'The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia', *International journal of epidemiology,* vol. 37, no. 6, pp. 1359-1365.

Hitchings, R & Day, R 2011, 'How older people relate to the private winter warmth practices of their peers and why we should be interested', *Environment and Planning A,* vol. 43, no. 10, pp. 2452-2467.

Horvath, SM, Radcliffe, C, Hutt, B & Spurr, G 1955, 'Metabolic responses of old people to a cold environment', *Journal of applied physiology,* vol. 8, no. 2, pp. 145-148.

Howden-Chapman, P 2004, 'Housing standards: a glossary of housing and health', *Journal of epidemiology and Community health,* vol. 58, no. 3, pp. 162-168.

Howden-Chapman, P, Pierse, N, Nicholls, S, Gillespie-Bennett, J, Viggers, H, Cunningham, M, Phipps, R, Boulic, M, Fjallstrom, P & Free, S 2008, 'Effects of improved home heating on asthma in community dwelling children: randomised controlled trial', *Bmj,* vol. 337.

Lindemann, U, Oksa, J, Skelton, DA, Beyer, N, Klenk, J, Zscheile, J & Becker, C 2014, 'Effect of cold indoor environment on physical performance of older women living in the community', *Age and Ageing,* May 22, 2014.

Martin, CJ, Platt, SD & Hunt, SM 1987, 'Housing conditions and ill health', *British medical journal {Clinical research ed.),* vol. 294, no. 6580, p. 1125.

Mcintyre, D 1973, 'A guide to thermal comfort', *Applied ergonomics,* vol. 4, no. 2, pp. 66-72.

Nitschke, M, Tucker, GR & Bi, P 2007, 'Morbidity and mortality during heatwaves in metropolitan Adelaide', *Med J Aust,* vol. 187, no. 11-12, pp. 662-665.

Nitschke, M, Tucker, GR, Hansen, AL, Williams, S, Zhang, Y & Bi, P 2011, 'Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis', *Environ Health,* vol. 10, no. 1, p. 42.

Sturman, AP & Tapper, NJ 1996, *The Weather and Climate of Australia and New Zealand,* Oxford University Press.

Tinetti, ME, Liu, WL & Claus, EB 1993, 'Predictors and prognosis of inability to get up after falls among elderly persons', *JAMA,* vol. 269, no. 1, Jan 6, pp. 65-70.

University of the Third Age. n.d. Learning without fears. Available online at: http://www.adelaideu3a.on.net/

Wagner, J, Robinson, S, Tzankoff, S & Marino, R 1972, 'Heat tolerance and acclimatization to work in the heat in relation to age', *Journal of Applied Physiology,* vol. 33, no. 5, pp. 616-622.

Wilkinson, P, Pattenden, S, Armstrong, B, Fletcher, A, Kovats, RS, Mangtani, P & McMichael, AJ 2004, 'Vulnerability to winter mortality in elderly people in Britain: Population based study', *British Medical Journal,* vol. 329, no. 7467, pp. 647-651.

Williamson, I, Martin, C, McGill, G, Monie, R & Fennerty, A 1997, 'Damp housing and asthma: a case-control study', *Thorax,* vol. 52, no. 3, pp. 229-234.

Wolinsky, FD, Fitzgerald, JF & Stump, TE 1997, 'The effect of hip fracture on mortality, hospitalization, and functional status: a prospective study', *Am J Public Health,* vol. 87, no. 3, Mar, pp. 398-403.

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Thermal experiences of older people during hot conditions in Adelaide

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Thermal experiences of older people during hot conditions in Adelaide

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Abstract: This study examined the thermal experiences of older people during extreme heat and summer more broadly. A longitudinal field study of thermal comfort and thermal acceptability of conditions during summer 2015-16 was conducted as part of a larger project into the overall thermal comfort of older people in Adelaide, South Australia. The experiences and preferences of the participants were arranged into 3 categories: acceptable thermal sensation votes, warm and hot thermal sensation votes and votes recorded on extreme heat days when the maximum outdoor temperature was 35^{o} Celsius or above during the study period. In each category, participants reported sensations of 'warm' and 'hot' within the acceptable range of operative temperature and humidity suggested by ASHRAE Standard 55. Participants also expressed a desire to feel cooler within this acceptable range, and described conditions within this range as 'thermally unacceptable'. These results show that older people may be experiencing thermal conditions differently to younger people. Specifically, it appears that these participants have a desire for cooler temperatures than predicted by ASHRAE Standard 55. The study poses a series of challenges for future research to ensure comfortable and healthy homes for ageing Australians.

Keywords: thermal comfort, ageing, heat waves, Australia.

1. Introduction

Adelaide, South Australia has a temperate climate with a Köppen classification of Csa (McBoyle, 1971). It has warm summers, but frequently experiences periods of extreme heat. The frequency, length and intensity of these heat waves is likely to increase in the future (Meehl and Tebaldi, 2004). In Adelaide these extreme heat events are associated with increases in mortality, hospital admissions and ambulance call outs in the general population and these pose specific concern for more vulnerable groups, including older people (Bi *et al.*, 2011). As older people have a tendency to spend more time inside, it is important that internal conditions remain comfortable and safe during periods of extreme heat.

Whilst the earliest thermal comfort work suggested there was no difference in the conditions preferred by older people and younger adults (Rohles and Johnson, 1972; Fanger and Langkilde, 1975), more recent research has indicated that this may not be the case (Collins and Hoinville, 1980; Schellen *et al.*, 2010). Changes to physiology and perception amongst older people means they experience thermal conditions differently to younger people. As such, it is important to ensure they experience their surroundings in such a way that is not detrimental to their health.

This research examines the thermal comfort of a cohort of people aged 65 and over in Adelaide during summer 2015-16, including data from a number of extreme heat days which occurred between October and January. It investigates comfort, acceptability of the thermal environment and the thermal preferences of the occupants during warm weather. All of these variables are considered rather than the more traditional approach of simply making the assumption that the central category votes on a 7-point thermal sensation scale means conditions are acceptable and that no change for warmer or cooler conditions is preferred. The study was done to obtain a very specific picture of the actual experiences of the participants.

2. Methods

2.1 Participants

Participants were recruited from an earlier survey of housing and health in which they could volunteer for the more in-depth longitudinal study (Bills & Soebarto 2015). Participants were recruited through invitations distributed by local councils and church groups. Some participants were also recruited through the University of the Third Age. This paper focuses on the results from 15 households with a total of 17 participants (8 Female, 9 male). Data were from October 2015 to January 2016. Despite only December and January typically considered to be "summer", Adelaide experienced several extreme heat days in October and November 2015 and for this reason data from these months was also included in the study.

2.2 Protocol

Unobtrusive data loggers were installed in the bedrooms and living rooms of all participants. These recorded air temperature, humidity and globe temperature (as proxy of mean radiant temperature) every 15 minutes. Participants were asked to regularly complete short comfort vote surveys which included a vote on the ASHRAE 7-point thermal sensation scale (TSV) (ASHRAE, 2013) and the McIntyre 3-point thermal preference scale (TPS) (McIntyre, 1980). The comfort vote survey also asked participants to indicate their current level of clothing and their level of activity for the previous 30 minutes. Participants were also asked about ventilation via doors and windows, and whether ceiling fans or heating or cooling were in use.

2.3 Analytical techniques

The air temperature and humidity data at the times of the votes were analysed using the Graphic Comfort Zone Method of ASHRAE 55 (ASHRAE 2013) as the houses were air-conditioned at times. The comfort zone shown on the following charts includes clothing levels in the range 0.5-1.0 clo and a metabolic rate in the range 1.0 to 1.3 met. The thermal sensation votes (TSVs) were filtered to remove responses given when higher levels of clothing were being worn, or when higher levels of activity had been completed in the last 15 minutes before completing the survey. The comfort zone indicated by this method assumes an air-speed of less than 0.2m/s and a radiant temperature close to the recorded air temperature. In this study, globe temperature was on average within 0.04° of the measured air temperature and therefore no shifting of the comfort zone was required to accommodate for this. Whilst air speed was not measured in the houses in this study, it is the experience of the authors that air movement in houses in Adelaide rarely exceeds 0.2m/s, even with windows open. Whilst some of the buildings were fitted with ceiling fans, which could increase air speeds above 0.2m/s, their use was recorded only about 10% of the time. Typically, thermal comfort studies present the 'acceptable' range of TSVs (-1, 0, or +1 on the 7 point ASHRAE comfort scale); however, in this paper TSVs of 'warm' and 'hot' (+2 and +3 on the ASHRAE comfort scale) have also been analysed in order to demonstrate experiences during extremes in temperature.

3. Results

In all cases, there was a large overlap of instances where the TSVs indicated that conditions were acceptable or unacceptable, and conditions where a preference for change was recorded versus no preference for change. There is no clear threshold where conditions suddenly become acceptable, or where participants felt 'hot' rather than 'slightly warm'. A total of 400 votes were cast during December 2015 and January 2016.

3.1 Thermal comfort in December 2015 and January 2016

3.1.1 Acceptable thermal sensation votes

Upon initial examination of the 305 'acceptable' votes during December and January, it appears that they largely aligned with the range of conditions indicated by the acceptable range of operative temperature and humidity based on the Graphic Comfort Zone Method of ASHRAE 55 (figure 1). Upon closer examination, around 20% (60/305) of the 'acceptable' votes fell outside the comfort zone.

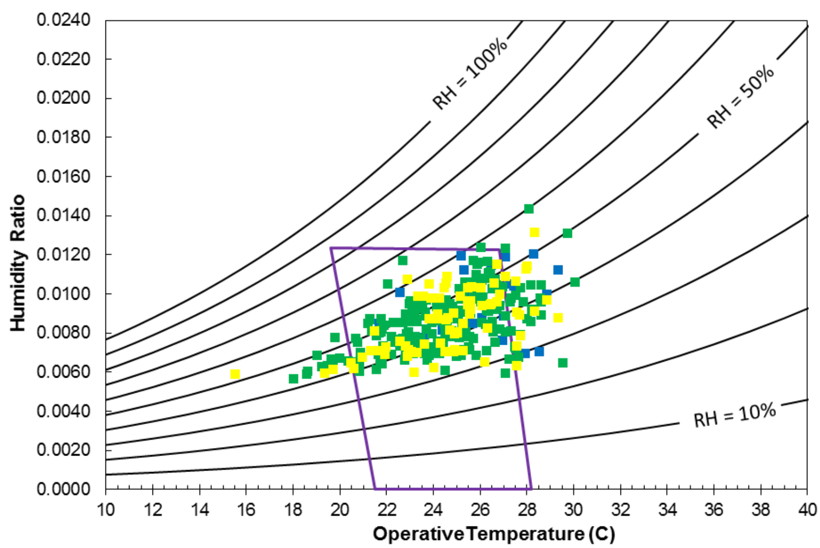

Figure 1: Operative temperature and humidity at times when acceptable Thermal Sensation Votes (-1, 0, or +1 on the ASHRAE thermal sensation scale) were recorded. TSV of -1 = blue, 0 = green and +1 – yellow. *Source: Adapted from ASHRAE 55-2013, Figure 5.3.1*

Out of the 245 'acceptable' votes that fell within the comfort zone, 9.4% (24/245) noted a preference for cooler conditions than they were currently experiencing (Figure 2). Whereas, out of the 305 'acceptable' votes, a preference for cooler conditions was indicated 36 times (11.8%). In other words, of the 36 votes cast indicating a preference for cooler conditions, 66% of the time (24 votes) the conditions fell within the comfort zone. Analysing this data using a two-dimensional Kolmogorov-Smirnov two sample test this finding is significant (d=0. 37, p<0.01).

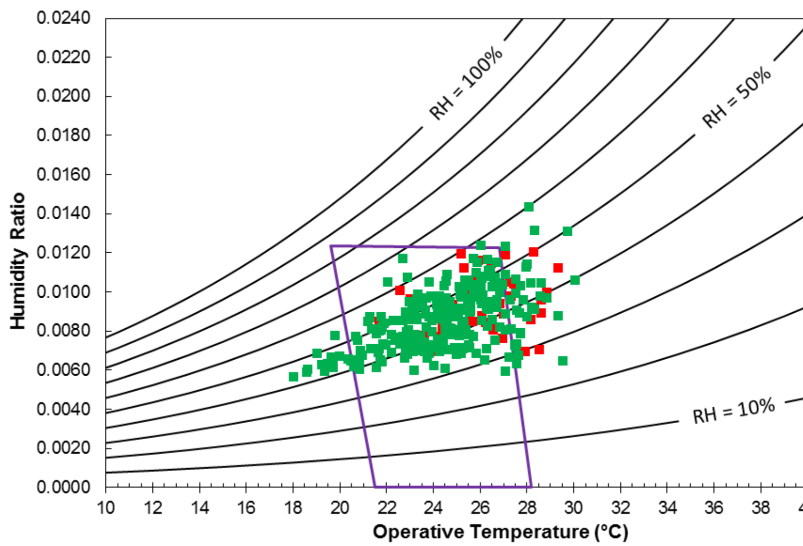

Figure 2: Operative temperature and humidity at times when participants recorded either a) a preference to be cooler (red), or b) no preference for change (green).

3.1.2 Warm and hot sensation votes

Out of the 400 votes, 55 indicated 'warm' and 'hot'. Interestingly, of these 'warm' and 'hot' votes cast during the summer months, 35 (64%) were cast during the conditions that were within the comfort zone specified by ASHRAE 55 (figure 3). Out of these 55 votes, 48 votes (87%) also preferred for cooler conditions regardless of the votes and 63% of these (30/48) occurred when the operative temperatures and humidity were within the comfort zone (figure 4). These indicate that older people may be experiencing discomfort in conditions that would normally be considered comfortable.

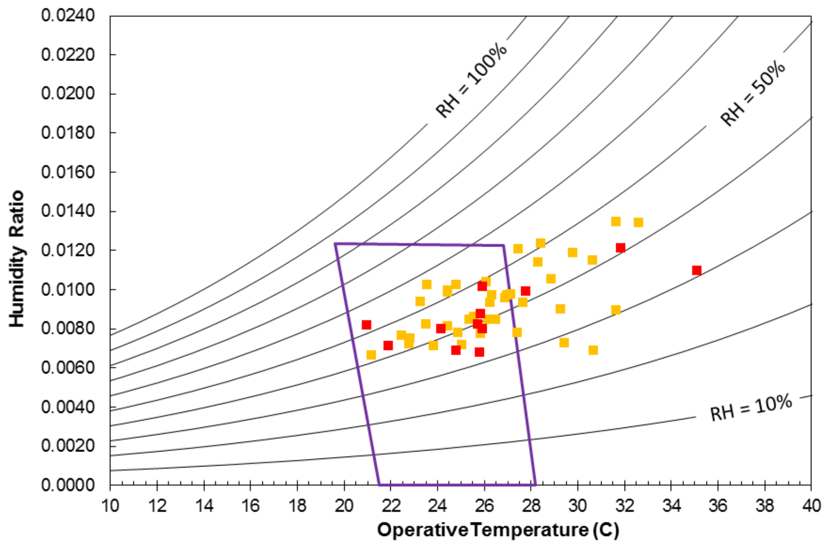

Figure 3: Operative temperature and humidity at times 'warm' (orange) or 'hot' (red) thermal sensation votes (+2 and +3 on the ASHRAE thermal sensation scale) were recorded during December and January.

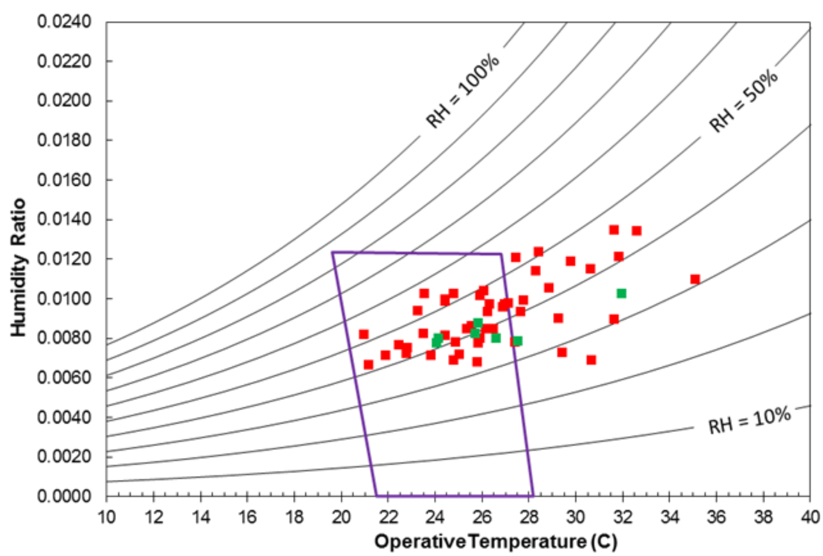

Figure 4: Operative temperature and humidity at times when 'warm' or 'hot' thermal sensation votes were cast, sorted by whether participants would prefer to be cooler (red) or had no preference for change (green)

3.2 Thermal Comfort on Extreme Heat Days

During extreme heat days (days when the maximum daily temperature was more than 35°C) a total of 209 votes were cast, with 27% (56/209) of the votes cast during conditions that were outside the comfort zone. Out of the 209 votes, 24% (51/209) voted 'warm' and 'hot' (TSV of +2 and +3), and interestingly, 63% of these (32/51) were cast when the indoor conditions were within the comfort zone (figure 5). Further, 77 of the total votes during extreme heat days (37%) indicated a preference to be cooler (regardless of the votes), and 49 of these instances (64%) were cast during conditions that fell within the comfort zone.

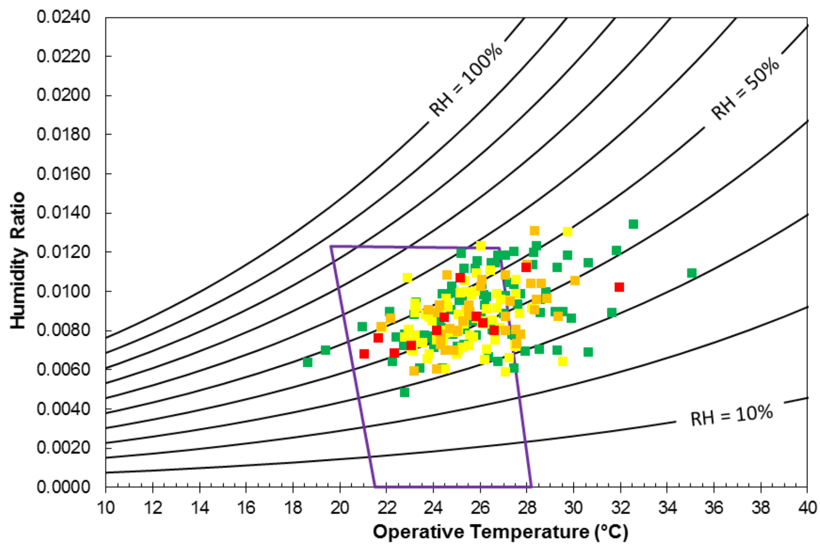

Figure 5: All thermal sensation votes cast on extreme heat days, where green = neutral (TSV=0), yellow = slightly warm (+1), orange = warm (+2) and red = hot (+3)

4. Discussion

These results show that whilst older people experience some thermal sensations similarly to their younger counterparts, there is a worrying trend of experiencing conditions usually considered 'comfortable' as unacceptably warm. There is often a preference for a change to cooler conditions than those suggested by ASHRAE as 'comfortable'; that is, falling within the acceptable range of operative temperatures suggested by psychrometric graphing.

The trend toward older people experiencing conditions that would normally be considered comfortable as unacceptable, and expressing a desire to be cooler when conditions are within the comfort zone is both interesting and confusing. Other researchers in the area of thermal comfort amongst older people have almost universally found the opposite; that older people in general need a warmer environment than younger people to achieve thermal comfort (van Hoof and Hensen, 2006; DeGroot and

Kenney, 2007; Schellen *et al.*, 2010). Previously this has been attributed largely to the slowing of metabolism that comes with age, requiring higher ambient temperatures to maintain heat balance. Further explanations have cited clothing levels and other behavioural mechanisms.

There is a significant body of evidence within the field of physiology that shows changes to a range of thermoregulatory functions, such as reduced sweating (Foster *et al.*, 1976; Dufour and Candas, 2007), and altered reactions of blood vessels in older people (Yochihara *et al.*, 1993; Schellen *et al.*, 2010) which ultimately leads to changes in the ability to control core temperature (DeGroot and Kenney, 2007). Thermal sensitivity has also shown to be decreased in older people (Natsume *et al.*, 1992; Taylor *et al.*, 1995). These physiological responses tend to give evidence to the general preference for warmer rather than cooler conditions; any physiological measurements were outside the scope of the current study.

In examining age-related differences concerning the ability to regulate room temperature, Taylor *et al.* (1995) posit that "it is possible that thermal discomfort reflects an integration of previous thermal experiences, with the elderly possibly having a greater history of exposure to such stresses, and perhaps being more accepting of the resultant sensations". This acknowledgement of the importance of an individual's thermal history is important when examining the results in this study. It is possible that living in Australia, widely regarded as having a hot climate, had led to an almost constant desire or preference for cool conditions. This includes in the winter, as previously indicated by earlier results from this longitudinal study where colder conditions than expected were deemed both acceptable and 'neutral' according to the thermal comfort votes during the winter months (Bills and Soebarto, 2015; Bills, 2016). So, whilst the results of this study are different from those of studies overseas, the experience of conditions as warm within what is usually considered a neutral zone is at least consistent within the Adelaide context. Much of the earliest thermal comfort work was conducted in Europe and America, where not only the climate but also the trends in heating and cooling usage differ greatly from Australia. It is perhaps then not surprising then that expectations of coolness outside of the standards derived from this early research exist in a place so very different in culture and environment.

Ultimately, it is a physiologist's job to determine the physiological responses of older people to warmer conditions, and a psychologist's job to analyse the behavioural and psychological responses. The role of the designer and building scientist is to use all the information available to them, and create living spaces which provide comfortable conditions for their occupants whilst nurturing good health. It is thus important that thermal comfort field work continue in varied contexts around the world to provide a greater understanding of how comfort expectations and preferences may change with cultural and environmental milieu. It may well be that for the Adelaide context, designing houses that stay cooler than standards normally suggest is important as people age in place. This would be best accomplished where possible through passive design principles so as to have minimal impact on household energy consumption.

5. Conclusion

In this study, older people showed a preference for conditions cooler than those predicted by existing thermal comfort standards. Whilst a majority of the acceptable votes cast did fall within the standards, of concern is the trend for sensations of 'warm' and 'hot' to also fall within these standards. When conditions were deemed 'unacceptable' and participants expressed a desire to be cooler, these instances again largely occurred at times where conditions met the current standards. This contradicts the current body of research which suggests older people generally prefer warmer conditions to their younger counterparts. Further research across a broad range of climatic and cultural situations should be considered to examine the effect these may have on perception, acceptability and preferences in regards to thermal comfort.

References

ASHRAE (2013) ANSI/ASHRAE standards 55-2013, thermal environmental conditions for human occupancy, ed., ASHRAE, Atlanta, GA.

Bi, P., Williams, S., Loughnan, M., Lloyd, G., Hansen, A., Kjellstrom, T., Dear, K. and Saniotis, A. (2011) The effects of extreme heat on human mortality and morbidity in Australia: implications for public health, Asia-Pacific Journal of Public Health, 1010539510391644.

Bills, R. (2016) Cold Comfort: Thermal sensation in people over 65 and the consequences for an ageing population 9th International Windsor Conference: Making Comfort Relevant (7th-10th April, 2016, Windsor, UK).

Bills, R. and Soebarto, V. (2015) Understanding the changing thermal comfort requirements and preferences of older Australians, 49th International Conference of the Architectural Science Association (02 Dec 2015-04 Dec 2015: Melbourne, Australia).

Collins, K. and Hoinville, E. (1980) Temperature requirements in old age, Building Services Engineering Research and Technology, 1(4), 165-172.

DeGroot, D. W. and Kenney, W. L. (2007) Impaired defense of core temperature in aged humans during mild cold stress, American Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 292(1), R103-R108.

Dufour, A. and Candas, V. (2007) Ageing and thermal responses during passive heat exposure: sweating and sensory aspects, European Journal of Applied Physiology, 100(1), 19-26.

Fanger, P. and Langkilde, G. (1975) Interindividual differences in ambiant temperatures perferred by seated persons, ed., Technical University of Denmark. Laboratory of Heating and Air Conditioning.

Foster, K., Ellis, F., Dore, C., Exton-Smith, A. and Weiner, J. (1976) Sweat responses in the aged, Age and Ageing, 5(2), 91-101.

McBoyle, G. R. (1971) Climatic classification of Australia by computer, Australian Geographical Studies, 9(1), 1-14.

McIntyre, D. (1980) Indoor climate, ed., Applied science publishers.

Meehl, G. A. and Tebaldi, C. (2004) More intense, more frequent, and longer lasting heat waves in the 21st century, Science, 305(5686), 994-997.

Natsume, K., Ogawa, T., Sugenoya, J., Ohnishi, N. and Imai, K. (1992) Preferred ambient temperature for old and young men in summer and winter, International journal of biometeorology, 36(1), 1-4.

Rohles, F. and Johnson, M. A. (1972) Thermal comfort in the elderly, ASHRAE Trans, 78(1), 131.

Schellen, L., Van Marken Lichtenbelt, W. D., Loomans, M. G. L. C., Toftum, J. and De Wit, M. H. (2010) Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady-state condition, Indoor Air, 20(4), 273-283.

Taylor, N. A. S., Allsopp, N. K. and Parkes, D. G. (1995) Preferred room temperature of young vs aged males: The influence of thermal sensation, thermal comfort, and affect, Journals of Gerontology - Series A Biological Sciences and Medical Sciences, 50(4), M216-M221.

van Hoof, J. and Hensen, J. (2006) Thermal comfort and older adults, Gerontechnology, 4(4), 223-228.

Yochihara, Y., Ohnaka, T., Nagai, Y., Tokuda, T. and Kawashima, Y. (1993) Physiological responses and thermal sensations of the elderly in cold and hot environments, Journal of Thermal Biology, 18(5), 355-361.

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Understanding the changing thermal comfort requirements and preferences of older Australians

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Abstract: Australia is faced with the challenge of housing and caring for an increasingly ageing population. As the human body ages its sensitivity to changes in the thermal environment diminishes. This paper discusses a recent survey of older people living in Adelaide, South Australia, about the conditions of their living environment, their general health conditions and the ways in which they operate their houses. Selected dwellings are being monitored to record indoor temperatures and humidity while a long term thermal comfort survey of the occupants is being conducted. This paper will discuss preliminary results of this thermal comfort survey for the summer period. The results found that in general the selected occupants perceived their dwellings to be thermally acceptable; however there are some potentially hazardous trends around the use (or not) of heating and cooling. Overall, the thermal comfort surveys in conjunction with the temperature and humidity data indicate a preference among older people for cooler temperatures than typically considered comfortable by the healthy adult population. Balancing these preferences for both temperature and mechanical heating and cooling usage is vital for creating an environment for health and comfort in later life.

Keywords: Thermal comfort; health; ageing population.

1. Introduction

As Australia's population ages, a number of challenges must be overcome to ensure a healthy later life for a large proportion of the population. One of these challenges is that of housing; having enough housing that meets the needs and wants of older people and provides a healthy environment as they age.

As the body ages, changes in the way that it adapts to different thermal conditions begin to appear. Studies into the thermoregulatory responses of older people have shown that sweating starts at higher temperatures than in younger adults, while shivering starts at colder temperatures than in younger adults (Anderson *et al.*, 1996). Both of these responses are also less vigorous than might be expected in younger people. Older people feel the cold more slowly than healthy adults – i.e., it must be a colder temperature before they will report feeling 'cold' than in younger test subjects (Yochihara *et al.*, 1993)

The result of this is a reduced capacity to maintain a healthy body temperature in both hot and cold conditions, potentially leading to hypo- or hyperthermia and associated health problems. Trends toward increased morbidity and mortality amongst older people during periods of hot and cold weather are well established and continue despite public health campaigns aimed at alerting older people to the health risks associated with extremes in weather (reference).

The effect of housing on the health and wellbeing of its occupants is well documented (Evans *et al.*, 2003; Howden-Chapman, 2004; Lawrence, 2004). This effect is multifaceted, and determinants can include physical factors such as cool temperatures, damp and lack of ventilation (Martin *et al.*, 1987; Williamson *et al.*, 1997). Extremes in both heat and cold have led to increases in hospital admissions and mortality of the elderly. Cold and damp conditions lead to exacerbation of respiratory diseases such as asthma (Williamson *et al.*, 1997), and extreme heat can cause renal and cardiovascular problems (Hansen *et al.*, 2008; Nitschke *et al.*, 2011). The degree to which occupants' experience these conditions as opposed to how the conditions themselves affect health is also of interest to researchers. As the perception of temperature and the physiological response to it change with age it is possible that an older person may perceive an environment to be thermally comfortable when in fact it may pose threats to their health. Whilst there are clear correlations between hospital admissions and external temperature and climate conditions, there has been little research on the indoor environment of the dwellings of the elderly, particularly on the effect of the occupants' perceptions of this environment on their health. In the home environment, thermal comfort models (eg ASHRAE, 2013) have been developed to predict the range of conditions most comfortable for occupants, both in air-conditioned and naturally-ventilated modes. Whilst these models have been used to determine the thermal comfort and occupant satisfaction levels of several cohorts, information about how those aged over 65 experience their thermal environment is scarce and whether these models are applicable to this cohort is still questionable.

Through cooperation between architecture and public health researchers, the research aims to examine the relationship between the thermal environment of homes of older people, their thermal comfort perceptions and their health. This paper presents the preliminary results of the study, conducted in Adelaide, South Australia, amongst independently living people aged over 65. The paper will discuss the general opinions of the respondents regarding their housing and health, as well as some detailed thermal comfort data from a small cohort participating in a thermal comfort survey.

2. Background

Whilst older people are particularly susceptible to extremes in heat and cold, there is little known about their experiences of their thermal environment, and indeed there is some controversy in the available research regarding the effect of age on perceptions of thermal comfort. A number of studies have shown that older people in general prefer a lower temperature than would be predicted by the PMD/PPV model of thermal comfort (Collins and Hoinville, 1980; Tsuzuki and Iwata, 2002), which contradicts expectations of a preference for warmer temperatures in those with lower activity levels. Another study found that older adults prefer a temperature within the PMV comfort range (Turnquist and Volmer, 1980). The general conclusion drawn by van Hoof and Hensen (2006) is that older people tend to perceive thermal comfort differently from the young, due to a combination of behavioural factors such as clothing and activity level, and physical factors due to the ageing process. What is not yet clear from the research is what effects this altered perception of thermal comfort has on health. For instance, an older person may not perceive the environment as being too hot, but the conditions may be hotter or more humid than is healthy for them.

There is however, evidence that the outdoor temperature is connected to health, especially in older people. A number of studies have shown increased health problems during periods of extreme heat and cold, including an increase in hospitalisations, ambulance call outs, and emergency department visits during heatwaves (Mayner *et al.*, 2010; Hansen *et al.*, 2011; Toloo *et al.*, 2014). There is also research that indicates cold weather is likely to increase the risk of falls in older people, especially older women (Lindemann *et al.*, 2014). This is of particular concern for older people who live alone, as 50% of older people are unable to get up after a fall without assistance, and thus these falls can be a cause of accidental hypothermia as well as other serious ongoing health problems(Voermans *et al.*, 2007).

There is very little research available on links between thermal comfort and health, particularly of the elderly. A report produced by the World Health Organisation (WHO) (Goromosov, 1968) concluded that the human body could only compensate for external temperature in a narrow range, given as between 15 and 25 degrees Celsius, with minimal energy expenditure. A further WHO study (WHO Working Group, 1982) showed minimal risk to health of sedentary people, such as the elderly, when housing was kept at a temperature of between 18 and 24 degrees Celsius. Whilst it is an important aspect of thermal comfort, there are other factors that determine whether a person finds their indoor thermal environment comfortable. There have been studies into some of these factors individually, such as humidity and ventilation, but there is little research on all factors collectively, their link to occupant satisfaction, and health.

3. Methodology

This study has been carried out in two stages – a questionnaire and a field study. In the first stage, people in the target age group of 65+ years living independently in Adelaide, South Australia, were asked to complete a survey about their housing and health. Participants for this survey were recruited by contacting targeted local government Home and Community Care (HACC) centres, local church groups, and University of the Third Age chapters. A 'hot desk' set up was also utilized in the local government community centres who assisted in survey distribution to assist those who might have questions about the survey or struggle with the length of the questionnaire. This stage was conducted as a paper questionnaire. This survey included questions about house construction and materials, the kind of heating and cooling installed and how this was used, the ability of the occupants to use various passive heating and cooling as well as mechanical systems, and questions about general health as well as specific symptoms during hot and cold weather. These symptoms included headaches, joint pain, dizziness, anxiety, respiratory and circulatory problems and fatigue. General demographic questions such as age, sex, income and country of origin were also included, as well as a request for the approximate yearly gas and electricity expenditure. Areas of the Adelaide metropolitan region identified as having higher vulnerability to heatwaves as determined by the heat related vulnerability index (Loughnan *et al.*, 2013) were targeted for participation.

Participants of the survey were subsequently invited to join the second stage of the study which aimed to investigate the thermal conditions in their homes and possible relationship with their health. This field study involved the installation of unobtrusive indoor data loggers in the participants' living and bed rooms to record air temperature, relative humidity and globe temperature every 15 minutes. Whilst these loggers were installed in the houses the participants were asked to regularly fill out a comfort vote survey based on section 7 of ASHRAE standard 55-2013. This is a short survey including the ASHRAE 7-

point thermal sensation vote, McIntyres's three point preference scale, as well as questions regarding the acceptability of the current conditions, clothing being worn, factors influencing their thermal comfort (for example, doors and windows being open, fans and cooling or heating operating) and the participants activity level immediately prior to completing the survey. In addition, the survey also asked whether the participants experienced heat or cold related symptoms in the 24-hours prior to the time they responded. The answers to these surveys were then matched with the data from the loggers to determine what conditions the participants find thermally comfortable and acceptable. Data were also analysed to investigate the relationship between the thermal condition of the space, the participants' thermal requirements and preferences, and their health condition.

4. General Survey Results

At the time this paper was being prepared, 59 surveys had been completed. The study is continuing and more participants are still being recruited. Out of those who have responded, females made up 74.5% (n=41) of respondents with 25.5% being male (n=14), with 4 respondents failing to indicate their gender. The majority of the respondents were aged between 65 and 80 (n=44), with only a small number (n=14) aged 81 years or older, and one participant failing to indicate their age bracket. Over 70% (n=41) were on either a full or part government pension, which accounts for the modal income being between $20,001 and $40,000. Despite having a slightly lower household income than the median reported by the ABS, household expenditure on electricity and gas was roughly equal to the national household average (Australian Bureau of Statistics, 2012) at approximately $32 per week.

Of the survey respondents, 4 noted not having any cooling installed, whilst all participants had some form of heating in their home. When asked about their heating or cooling use, 33% of respondents reported avoiding using their heating and/or cooling despite feeling uncomfortable. The majority (78%) of these respondents reported either not being able to afford the usage or not wanting to spend money on gas or electricity as their reasons for avoidance. Other reasons given included health concerns and a desire to 'save the environment'. One respondent reported that their air conditioner didn't work.

Most respondents reported only using their heating and cooling in response to their own comfort needs, with 'only when I feel too hot/cold' (45 and 53% of responses respectively) and 'only when it gets hot/cold inside' (29 and 25% of responses respectively) being the top responses. Very few (<5%) used their heating and cooling around the clock to create a constant thermal environment. The modal thermostat temperatures were 23 degrees in summer and 22 degrees in winter. Use of heating or cooling in the evenings before bed was also quite common, especially in the winter months with a third of respondents reporting this practice. Despite the pattern of mechanical heating and cooling usage, a majority of respondents reported their houses were 'always' or 'mostly' comfortable during both winter and summer.

5. Preliminary field study results

5.1. Participants and their houses

Of the 59 survey respondents, 23 were interested in joining the field study. Of these, 11 have had loggers installed in their homes so far but only six of these households have data reported in this paper due to the timing of installation and subsequent collection of data. The households represented in this paper include five two-person households and two single person households. Despite the option for two members to complete comfort votes, in these six households so far all votes have been completed by one participant only, with four females and two males completing comfort votes. All participants reported either 'good' or 'very good' health, although all respondents reported being on medications for chronic health conditions.

All participants lived in detached houses of either double brick (n=5) or brick veneer (n=1) type construction. All were long term residents with length of residence ranging from 13 – 48 years. All houses had some form of mechanical cooling and heating installed; however, three of those reported avoiding cooler use at least occasionally. Of the six houses, three had insulation in the ceiling and walls, two had insulation in the ceiling only and 1 had no insulation. All had external and internal window treatments on at least some windows. Five of the houses had ceiling fans installed in the main bedroom and the living area, with two houses having additional ceiling fans in the kitchen and other bedrooms. All houses had at least some windows which were able to be opened.

The monitoring period reported in this paper was 09/02/2015 – 25/05/2015. This encompassed both hot summer weather and some unseasonably cool autumn weather. Participants' houses were on average 2 degrees warmer than the average daily outside air temperature. On the hottest day during the logging period (average outside temperature of 34 degrees, maximum temperature of 41.6 degrees, low of 26.5 degrees) the houses were on average 7.1 degrees cooler than the average outdoor temperature, and on the coldest day (average outside temperature 10.3 degrees, low of 4.8 degrees, high of 15.7 degrees) on average the houses were 5.3 degrees warmer than outside air temperature. At their coolest period, the houses were 5 degrees cooler, and at their warmest 6.5 degrees warmer than the outdoor temperature.

5.2. Thermal Comfort Votes

A total of 452 thermal comfort votes were received from the six participants from whom data was collected. Of these votes, 40% were completed at conditions the participants felt were 'just right' (neutral vote of 4 out of 7-point scale), with an additional 37% occurring during conditions considered 'slightly warm' or 'slightly cool', 17% when conditions were 'cool', 5% when 'cold', and less than 1% each at 'warm' and 'hot'. Average thermal sensation vote (TSV) was found to increase with indoor temperature. Figure 1 shows the average thermal sensation vote for every 1 ^{o}C indoor temperature interval. Using the linear regression equation of TSV = 0.1897 Ti + 0.5287, an average neutral temperature would be reached at 23.9 degrees.

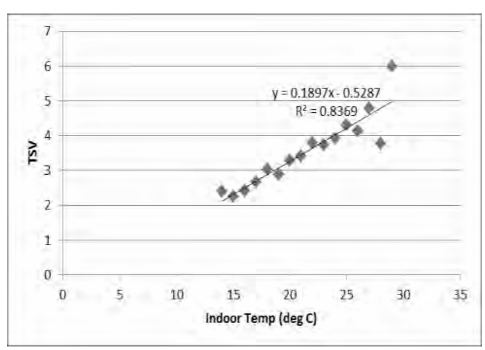

Figure 1: Average thermal sensation votes (TSV) compared with indoor temperature.

At the extremes of thermal sensation vote, some interesting trends have been observed. When reporting 'warm' or 'hot' conditions, participants were more likely to indicate a preference for change (75% and 100% respectively) than they were when they considered the conditions 'cool' or 'cold' (54 and 59% respectively). Even when voted 'slightly warm' more participants expressed a desire for change (57%) than when reporting feeling 'slightly cool' (24%). This indicates a preference for cooler conditions rather than warmer, and also a greater acceptability of cooler temperatures than warmer temperatures. It is worth noting, however, that there were a greater number of cooler days than warm days during the monitoring period, despite the fact that it was conducted during later part of summer to autumn, and therefore there were fewer thermal comfort votes during which people stated feeling 'warm' or 'hot' (see Figure 2).

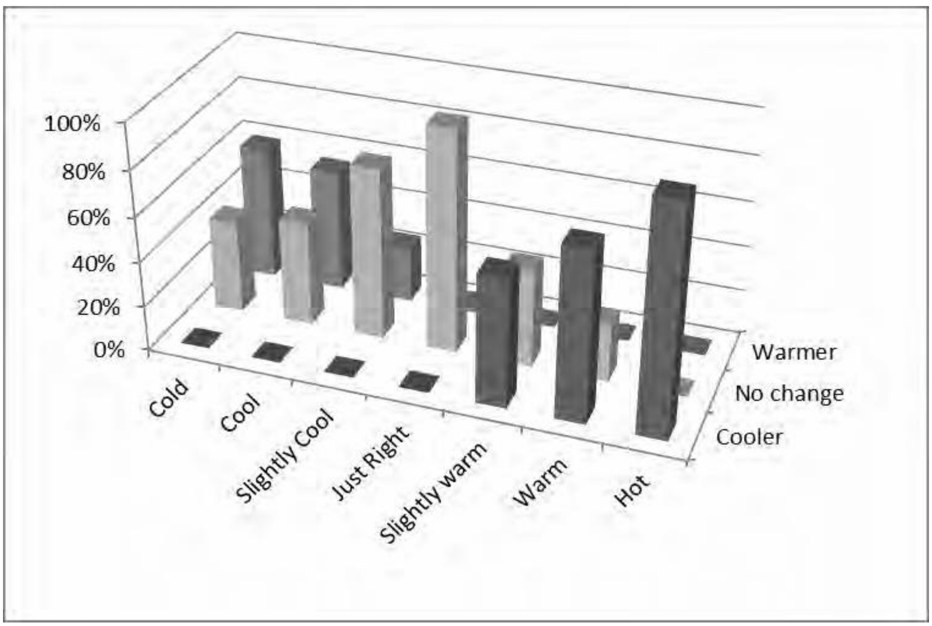

Figure 2: Preference for change during sensations of cold through to hot.

Participants were more likely to operate cooling during hot weather than they were to operate heating during cold weather. The largest percentage of responses who answered that yes, they had heating operating was 44% when the daily average was only 11 degrees. In contrast, at temperatures about 28 degrees and above 50% or more of respondents had cooling operating, with 100% having cooling operating at daily average temperatures of 31 and 33 degrees. This tends to once again indicate that cooler temperatures are more acceptable (therefore not requiring mechanical change) than warmer temperatures for the older people in this cohort.

This preference is confirmed when the thermal comfort vote data is entered into the Adaptive Thermal Comfort model. A larger number (43%) of neutral thermal sensation votes (slightly warm, just right, slightly cool) than expected are clustered below the usual 80% acceptability limits, indicating a preference for cooler conditions. When the 90% acceptability limits are examined, 60% of the votes fall below this line (see Figure 3).

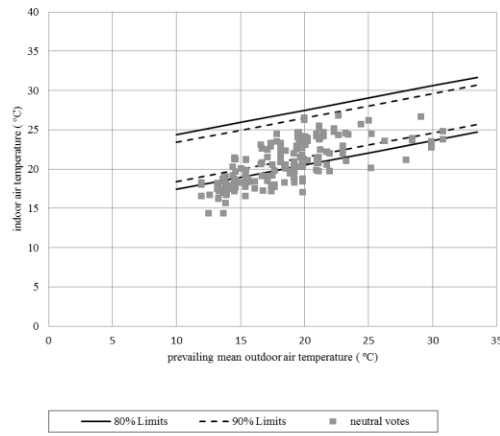

Figure 3: Neutral TSVs of the cohort compared with the acceptability limits of the general population proposed by the adaptive thermal comfort model.

When the indoor air temperatures and prevailing mean outdoor temperature are examined at times when participants indicated no desire for change in their thermal comfort levels, there are once again more votes clustered around the cooler end of the spectrum (42% lower than 80% acceptability, 59% lower than 90% acceptability) than expected (see figure 4).

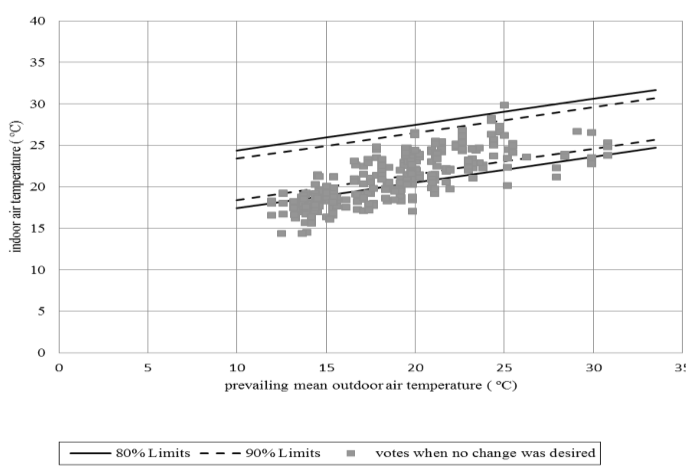

Figure 4: Conditions at which no preference for change was indicated as compared with the adaptive thermal comfort model acceptability limits.

These results exclude votes at the highest activity levels and the lowest and highest clothing ranges, meaning these preferences were not due to increased activity level or heavy clothing. This reduces the effect that adaptive behaviours may have on the results.

6. Discussion

6.1. General Survey

Results from the general survey indicate that the older people in this cohort do not consider their thermal needs as being any different from the general population. Heating and cooling was used in response to their own comfort, rather than in a way that creates a more consistent environment. Whilst this is reasonable for the general population, if there are indeed age-related changes in thermoregulation and temperature sensitivity taking place, this pattern of heating and cooling use may not be appropriate. Whilst many did not shy away from using their heating and cooling, concern must be raised about those who do avoid their usage when they are uncomfortable. This is especially true of those who are concerned about the financial impact of using these devices. Whilst frugality and resilience are common attributes amongst the older population (Hughes et al 2008, Abrahamson et al 2009), with increasing electricity prices there is concern that those with lower incomes may be more at risk during extreme heat and cold.

A further concern is the trend of many older people to keep the thermostat on their heating and cooling at the same temperature year round. For those concerned about the price of electricity, a thermostat set at 22 or 23 degrees in the winter may be having a dramatic impact on their energy usage. Estimates published by the Australian Government suggest every extra degree can impact heating and cooling energy use by 5-10% (Milne *et al.*, 2010). As long as the thermal needs of the older population can be met at lower temperatures, these should be considered, especially by those wishing to reduce their electricity bills.

6.2. Thermal Comfort Field Study

Overall the results from the field study show a trend toward the preferences of older people for cooler temperatures. There are a number of reasons that these older people's preferences may fall outside of expected norms. These include behavioural and attitudinal factors as well as changes in physiology which occur in later life. At this stage, however, any reasoning as to which factors are specifically at play amongst this cohort is pure conjecture, and future research is needed to determine which attitudinal or physiological factors have a greater influence over the preferences and perceptions of thermal comfort amongst older people.

In a recent study (Tod *et al.*, 2012) of attitudes toward cold in older people in the UK, particular values emerged which may be relevant to the results seen in this study. Firstly, amongst some older people, there was an idea that central heating could be detrimental to health. Rooms which were too warm were considered 'bad for you' and led people to live in colder conditions than they might otherwise. Secondly, there was an attitude of resilience and not seeing a need to change behaviours that had been acceptable all their lives. This is quite possibly linked to the well-established fact that people often don't see themselves as being 'old' (Abrahamson *et al.*, 2009) and therefore dissociating from the specific needs that come with age. The results of this thermal comfort study show cooler indoor conditions to be preferred, rather than simply being 'put up with', however the degree to which the two attitudes are related is complicated and warrants further investigation. Whilst attitudes of resilience and stoicism may influence a person's preference for particular conditions, the possibility of physiological factors being at play cannot be excluded. The participants in this study all but one reported good health, however, the fact that they are of an older age may mean various changes in physiological thermoregulation can occur. A lack of adequate thermal sensitivity in older people may potentially compromise health and wellbeing and may become a public health issue warranting help for older people to understand how best to manage their health in these conditions.

The current methodology does not allow for differences between physiological and attitudinal responses and further investigation is required once more participants have been identified and recruited. Of particular importance is whether the personal preferences of older people for these cooler temperatures are leading to a greater number of health problems for this population. Whilst a question relating to hot and cold symptoms was included in the thermal comfort vote survey in this study, there is so far insufficient data to determine whether a link between thermal comfort and health exists in this cohort. If so, there may be a need for strategies that can be implemented to address the thermal conditions of houses to create healthy indoor environments. Finding the balance between how older people prefer to feel and what is best for their long term health is the difficult but necessary task that is faced when dealing with an increasingly ageing population both now and in the future.

7. Conclusion

Overall, this study finds a high degree of satisfaction with the thermal conditions in their home amongst the older cohort examined. The older people studied accepted and preferred much cooler temperatures than what would be expected in a healthy younger adult population as predicted by the thermal comfort standard such as ASHRAE 55. Whether this has to do with personal behaviours and attitudes or a general change in physiological perception of the cold is not able to be determined in this study at this stage, nor are any potential health impacts of this preference. Ultimately, a balance between the preferences of the older people concerned as well as the relationship between thermal environment and health will need to be struck in order to provide the best housing solutions for older people.

References

Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., Adger, W.N. and Raine, R. (2009) Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK, *Journal of Public Health*, 31(1), 119-126.

Anderson, G., Meneilly, G. and Mekjavic, I. (1996) Passive temperature lability in the elderly, *European journal of applied physiology and occupational physiology*, 73(3-4), 278-286.

ASHRAE (2013) *ANSI/ASHRAE standards 55-2013, thermal environmental conditions for human occupancy*, ASHRAE, Atlanta, GA.

Australian Bureau of Statistics (2012) *Australian Social Trends, Sep 2012*. Available from: <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0Main+Features10Sep+2012>(accessed.

Collins, K. and Hoinville, E. (1980) Temperature requirements in old age, *Building Services Engineering Research and Technology*, 1(4), 165-172.

Evans, G.W., Wells, N.M. and Moch, A. (2003) Housing and mental health: A review of the evidence and a methodological and conceptual critique, *Journal of social issues*, 59(3), 475-500.

Goromosov, M.S. (1968) *The physiological basis of health standards for dwellings*, World Health Organization, Geneva.

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D. and Tucker, G. (2011) The effect of heatwaves on ambulance callouts in Adelaide, South Australia, *Epidemiology*, 22(1), S14-S15.

Hansen, A., Bi, P., Ryan, P., Nitschke, M., Pisaniello, D. and Tucker, G. (2008) The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia, *International journal of epidemiology*, 37(6), 1359-1365.

Howden-Chapman, P. (2004) Housing standards: a glossary of housing and health, *Journal of Epidemiology and Community Health*, 58(3), 162-168.

Lawrence, R.J. (2004) Housing and health: from interdisciplinary principles to transdisciplinary research and practice, *Futures*, 36(4), 487-502.

Lindemann, U., Oksa, J., Skelton, D.A., Beyer, N., Klenk, J., Zscheile, J. and Becker, C. (2014) Effect of cold indoor environment on physical performance of older women living in the community, *Age and Ageing*.

Loughnan, M., Tapper, N., Phan, T., Lynch, K. and McInnes, J. (2013) *A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities*, National Climate Change Adaptation Research Facility, Gold Coast.

Martin, C.J., Platt, S.D. and Hunt, S.M. (1987) Housing conditions and ill health, *British medical journal (Clinical research ed.)*, 294(6580), 1125.

Mayner, L., Arbon, P. and Usher, K. (2010) Emergency department patient presentations during the 2009 heatwaves in Adelaide, *Collegian*, 17(4), 175-182.

Milne, G., Reardon, C., Ryan, P. and Pavia, M. (2010) Heating and Cooling, in C. Reardon and A.G. Office (eds.), *YourHome: Australia's Guide to Environmentall Friendly Homes*, Deptartment of Climate Change and Energy Efficiency, Canberra.

Nitschke, M., Tucker, G.R., Hansen, A.L., Williams, S., Zhang, Y. and Bi, P. (2011) Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis, *Environ Health*, 10(1), 42.

Tod, A.M., Lusambili, A., Homer, C., Abbott, J., Cooke, J.M., Stocks, A.J. and McDaid, K.A. (2012) Understanding factors influencing vulnerable older people keeping warm and well in winter: a qualitative study using social marketing techniques, *BMJ Open*, 2(4).

Toloo, G., Yu, W., Aitken, P., FitzGerald, G. and Tong, S. (2014) The impact of heatwaves on emergency department visits in Brisbane, Australia: a time series study, *Critical Care*, 18(2), 1-9.

Tsuzuki, K. and Iwata, T. (2002) Thermal comfort and thermoregulation for elderly people taking light exercise, *Proceedings of indoor air*, 2, 647-652.

Turnquist, R. and Volmer, R. (1980) Assessing environmental conditions in apartments of the elderly, *ASHRAE Transactions*, 86(1), 536-540.

van Hoof, J. and Hensen, J. (2006) Thermal comfort and older adults, *Gerontechnology*, 4(4), 223-228.

Voermans, N., Snijders, A., Schoon, Y. and Bloem, B. (2007) Why old people fall (and how to stop them), *Practical Neurology*, 7(3), 158-171.

WHO Working Group (1982) *The effects of the indoor housing climate on the health of the elderly*, World Health Organisation, Graz, Austria.

Williamson, I., Martin, C., McGill, G., Monie, R. and Fennerty, A. (1997) Damp housing and asthma: a case-control study, *Thorax*, 52(3), 229-234.

Yochihara, Y., Ohnaka, T., Nagai, Y., Tokuda, T. and Kawashima, Y. (1993) Physiological responses and thermal sensations of the elderly in cold and hot environments, *Journal of Thermal Biology*, 18(5), 355-361.

Creating comfort and cultivating good health: The links between indoor temperature, thermal comfort and health.

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Abstract: There is a growing body of evidence that suggests human thermal requirements change as with age. This study aims to determine the conditions which will provide both a comfortable and healthy environment for the increasing number of older people in Australia.
A longitudinal study of thermal comfort and its relationship to health in 18 older households was undertaken in Adelaide, South Australia during 2015 and 2016. The comfort vote survey included measures of thermal comfort as well as a checklist of symptoms experienced in the last 24 hours. These surveys were matched to environmental measurements from the homes.
Results show two important relationships between thermal conditions and health:.

1. A quadratic relationship exists between reported symptoms and minimum and maximum indoor temperatures in the 24 hours proceeding the reported symptoms. These data indicate that both low and high indoor temperatures may be related to the health of the occupants.
2. A quadratic relationship also exists between the thermal sensation vote and the reporting of symptoms.

This research presents evidence that even with Adelaide's relatively mild winters, cold temperatures can have an impact on health, as well as the more extreme summer temperatures. This has implications for healthy housing design for an ageing population.

Keywords: ageing, thermal comfort, health

1. Introduction

Australia, like most countries in the developed world, has an increasing population of people aged 65 or over. People aged over 65 currently represent 15% of the population, and is expected to increase to more than 22% in 2055 (Commonwealth of Australia 2015). This demographic change poses challenges in many areas, including health and housing. It is the preference of most older Australians to 'age in place' and remain independent as long as possible. Given the known relationships between housing and health, it is thus important to determine whether the current housing available to older people is a healthy environment to age in. This study considers the thermal comfort of the occupants as well as their self---reported health in order to examine which conditions may create a healthy, comfortable environment for people as they age in place.

As humans age, physiological changes result in altered thermal perception. The metabolism slows and thermoregulatory changes occur more slowly in older people than in younger adults (Dufour & Candas 2007). Whilst the earliest thermal comfort studies concluded there was no difference between the thermal comfort of older people compared to younger adults (Fanger 1973), more recent evidence shows decreased temperature discrimination amongst older people as well as altered responses to thermal stimuli (Natsume et al. 1992). Differences in thermal comfort amongst older people have been shown to exist, some show a preference for warmer conditions (Schellen et al. 2010) whilst others show cooler conditions are preferred (Bills 2016; Hwang & Chen 2010). These differences may be explained by variables such as context, expectation, acclimation, and the perceived ability to control the thermal conditions (Indraganti 2011).

There are well established links between housing and health, and temperature and health. Morbidity and mortality increase both during periods of extreme heat and prolonged periods of cold temperatures (Nitschke et al. 2007; Wilkinson et al. 2004), whilst various poor housing conditions, such as damp and poorly ventilated houses also contribute to poor health outcomes (Howden---Chapman 2004). Programs which have aimed to improve the quality of housing in regards to temperature control and increased insulation have shown improvements in occupant health (Critchley et al. 2007).

Since there are known impacts of housing conditions and temperature on health, it is thus important to ensure that the houses of older people provide conditions which will foster good health. However since it is also becoming apparent that older people perceive thermal sensations differently to their younger counterparts, it is important to understand what conditions will provide thermal comfort as well. This study aimed to determine the conditions at which older people were comfortable, and the conditions that minimised the presence of symptoms, to determine if an overlap in the conditions exists. The objective is to recommend a range of conditions which could then be applied in future policy decisions such as housing improvement, fuel subsidies, aged care and building regulations.

2. Adelaide in Context

Adelaide, South Australia is the 5th largest population centre in Australia with 1.3 million residents. The city has a larger proportion of people aged over 65 than the country's average, and it is growing at a faster rate than the Australian average (Government of South Australia 2017). According to the city's 30 year plan, this means a greater emphasis needs to be placed on affordable and appropriate housing for ageing in place, which is the preference of most older Australians. New buildings will be needed to accommodate this ageing population, but the existing housing stock cannot be ignored as its redevelopment is unlikely and it should also be able to provide affordable living for older people as well as a healthy environment for ageing in place.

Adelaide has a Köppen climate classification of Csa, with mild cool winters and warm to hot summers (Sturman & Tapper 2006). This climate has historically led to houses which cope better in the summer months than in the cooler months, although more recent buildings are likely to be air conditioned rather than relying entirely on passive methods of temperature control. Most houses are fitted with some sort of cooling and heating appliances, however in older houses these tend to be retrofitted rather than centralised systems. The usage of these systems by older people has been explored in this study as such patterns can help inform design decisions both for new developments and for improving existing houses.

3. Methodology

Research was carried out in two stages: a survey of housing and health amongst Adelaide residents aged 65 and over, and a field study into the thermal comfort and health of some of the survey participants.

3.1. Participants

Participants aged 65 and over were recruited to complete a survey of housing and health, as part of which they could volunteer for the field study. The survey included a range of questions about their house, summer and winter comfort, heating and cooling appliances as well as questions regarding self---reported health and illness. Survey recruitment was conducted with the assistance of local councils, church and social groups. From these survey responses, a total of 18 households were recruited for the field study with 22 participants (11 male, 11 female) across these households. Data were collected between February 2015 and September 2016.

3.2. Field Study

Air temperature, humidity and globe temperature were recorded by unobtrusive data loggers in the bedroom and living areas in the houses of all participants (shown in Figure 1). These recorded conditions every 15 minutes. Participants were asked to regularly complete a comfort vote survey, which included measures of thermal comfort, preference and acceptability including the ASHRAE 7---point thermal sensation scale and the McIntyre 3---point thermal preference scale. Participants were also asked to indicate whether cooling or heating devices were in use, whether windows and doors were open and whether fans were in use. Participants were asked to indicate their current clothing level and recent activity level via diagrams of typical clothing and activities.

Participants were also asked to indicate whether they had experienced any health related symptoms in the previous 24 hours; they were provided with a list of known heat and cold related symptoms as well as a space to indicate other symptoms as they felt necessary. This list was compiled from a previous study which examined health effects of heat waves (Nitschke et al. 2014) with some symptoms added to reflect what is known about cold weather and its associated illnesses (Koskela 2007).

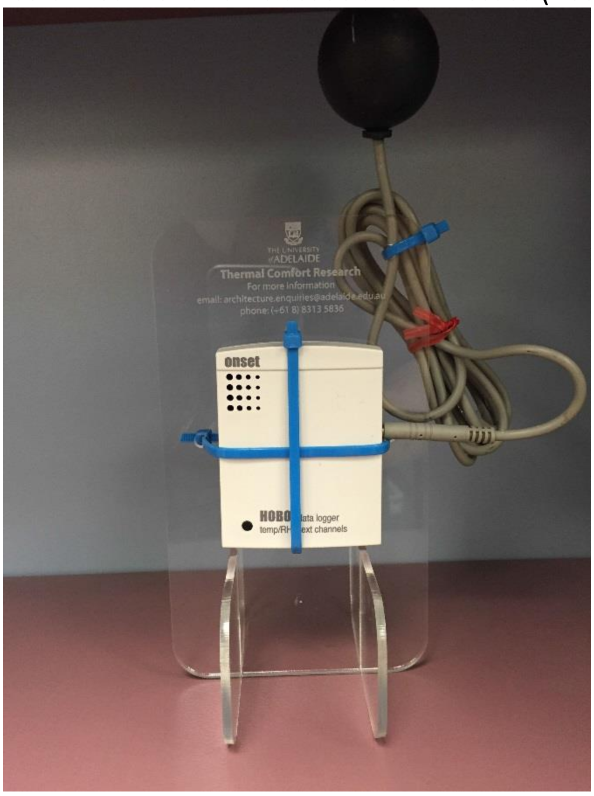

Figure 1 Data logger as placed in participants houses. Photo by author

3.3. Analysis

Survey data were analysed to determine any patterns of heating and cooling use that could impact on the health of the occupants. This included when heating and cooling devices were used and what temperature thermostats were set.

The data from the thermal comfort votes was matched with the temperature and humidity measurements from the data loggers. The previous day's minimum, maximum and average temperatures were also matched to each vote. These votes were then weighted to determine the average neutral temperature of the cohort. Votes were then filtered by whether symptoms were recorded. Those who reported chronic symptoms were excluded from further analysis, as these were not necessarily related to indoor conditions. Thus the results reported represent only the participants who did not report chronic symptoms. This allows clear relationships between conditions and symptoms to be investigated.

The number of votes where symptoms were reported was compared to the total number of votes for each criteria (TSV, maximum temperature, minimum temperature) to determine what percentage of votes presented with symptoms. These results were then graphed and regression analysis was performed.

4. Results

A total of 80 survey responses were collected and a total of 2667 thermal comfort votes were received from field study participants.

4.1. Patterns of heating and cooling use

An analysis of the typical pattern of heating and cooling appliance use was undertaken to determine the preference of the survey participants to use their appliances frequently or to utilise other methods to heat and cool their houses. Very few of the participants in the survey left their heating or cooling running continuously, preferring to use these systems largely in response to their own comfort. Over 40% of participants only turned on heating or cooling when they felt too hot (Figure 2) or too cold (Figure 3). Many participants only used their appliances during the day, and this same trend was noted amongst the field study participants. During the field study heating or cooling use was reported in the bedrooms 20% of the time and 30% of the time in living areas. This indicates a greater reliance on adaptive behaviours amongst these participants than on heating and cooling appliances.

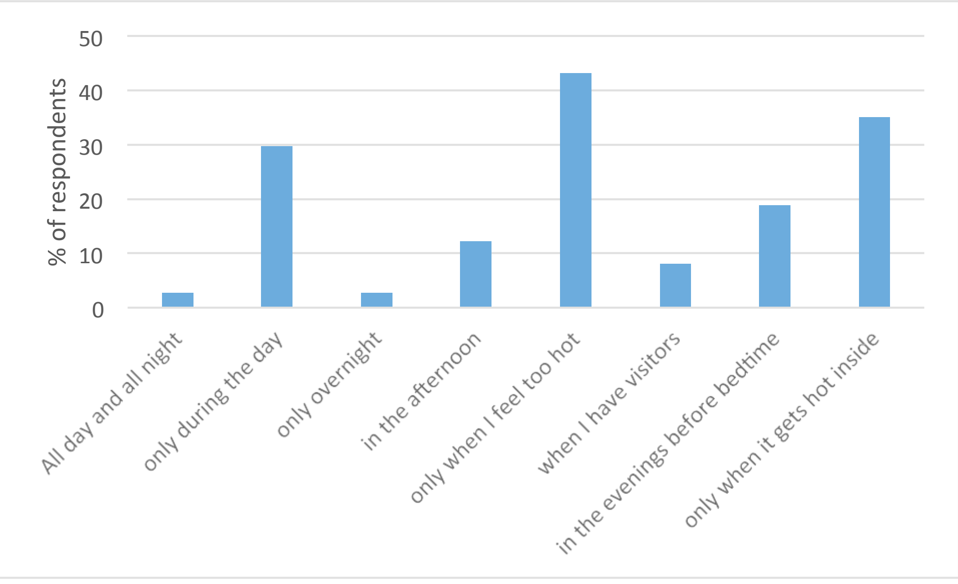

Figure 2 Air conditioning (cooling) use

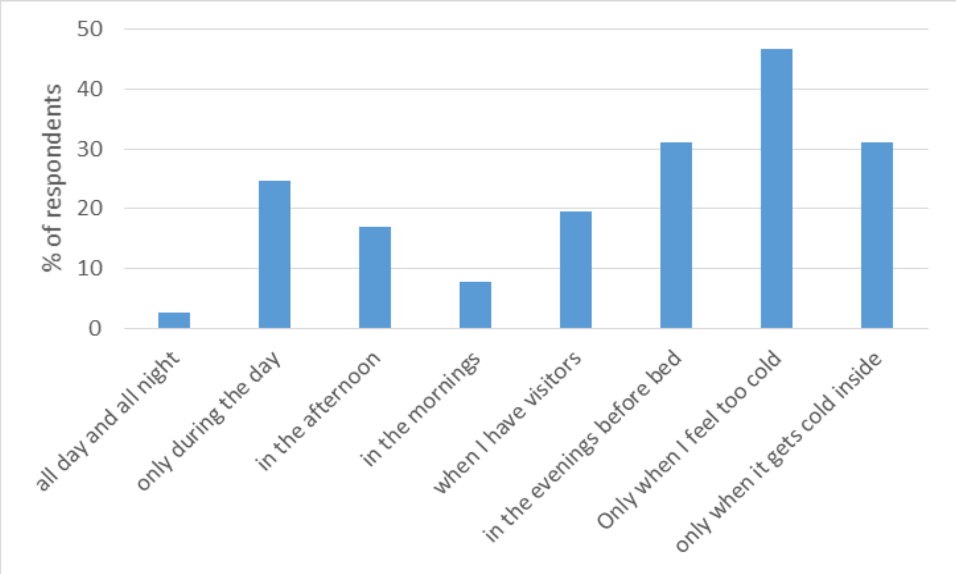

Figure 3 Heater use

4.2. Field Study

Participants in the field study were asked to indicate their thermal comfort with three different comfort measures; the ASHRAE 7---point Thermal Sensation Vote (TSV), the McIntyre 3---point thermal preference scale (TPV) and a simple thermal acceptability question, answering ‘yes’ or ‘no’ as to whether current conditions were thermally acceptable (TAV). This allows the neutral temperature to be calculated, but also for comfort ranges to be established according to the various measures.

Figure 4 shows the relationship between TSV and the indoor temperature binned at 1K intervals for the summer months (Dec – Feb). Figure 5 shows the similar results for the winter months (Jun – AUG). The slope of the regression lines is taken to indicate the occupants’ sensitivity to temperature variations. That is, the steeper the line the more sensitive or less tolerant to change of the indoor conditions of the cohort. This results show that the occupants in this study are much more sensitive to changes in the winter period. Weighted linear regression analysis give a neutral (TSV = 0) temperature of 22.0°C in summer and 19.7°C in winter.

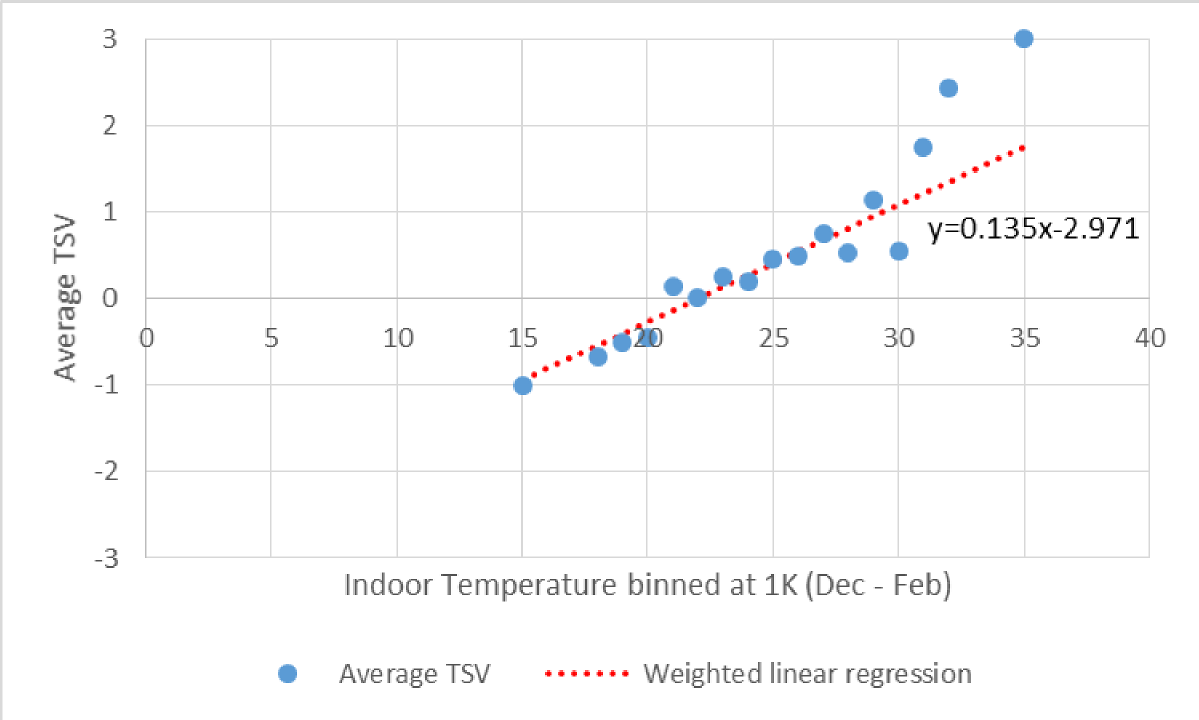

Figure 4 average TSV for each °C in summer months (Dec – Feb)

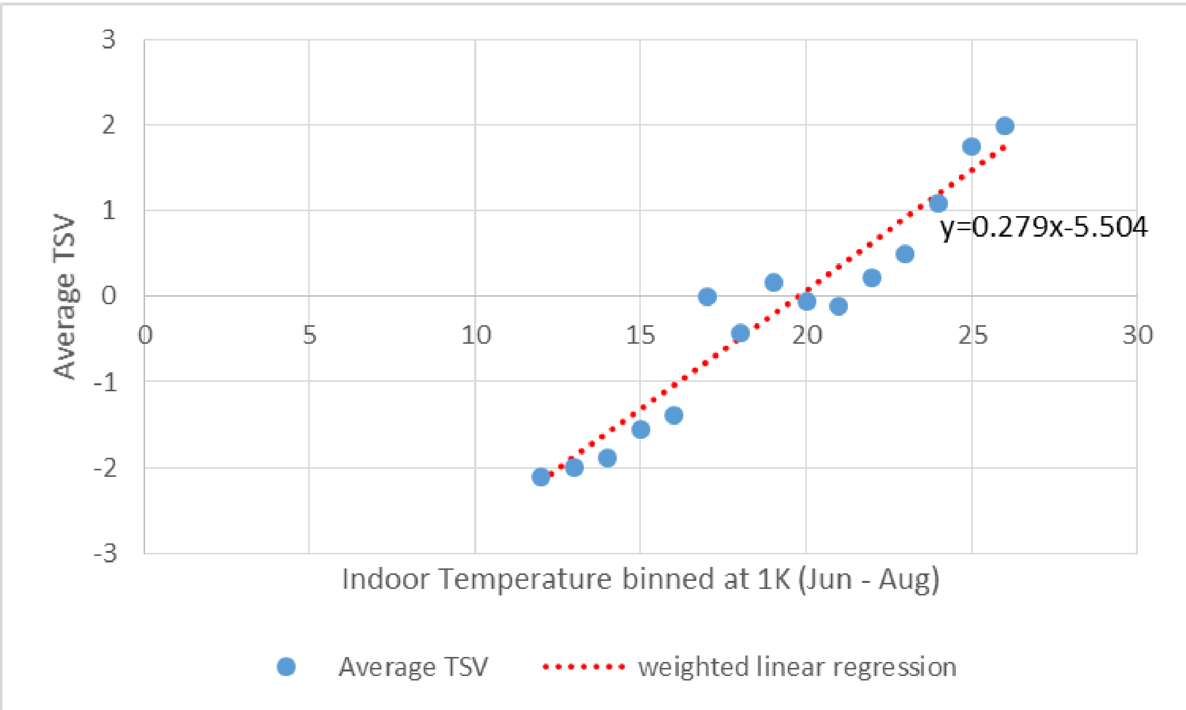

Figure 5 average TSV for each °C in winter months (Jun ‐‐‐ Aug)

4.3. Preference for Change

Three different measures of thermal comfort were examined by the field study. Comparing these measurements shows that there are differences between the different measures of acceptability; a neutral vote does not necessarily indicate an acceptable vote or that a participant desires no change in conditions.

To examine the differences between these measures of thermal comfort, qualifying data were plotted into a psychrometric chart and compared with the ASHRAE‐‐‐55‐‐‐2013 standard.

Votes were deemed to qualify for inclusion if the criteria set by the ASHRAE---55---2013 standard (ASHRAE 2013) were met: clothing of between 0.5 and 1 clo and a met rate of between 1 and 1.3.

When assuming the three central thermal sensation votes on the ASHRAE 7---point scale as 'acceptable', votes fall outside of the comfort zone indicated in red 27% of the time (Figure 6). When the TPV was zero, indicating no preference for change in thermal conditions, votes fell outside the comfort zone 25% of the time (Figure 7). When considered conditions to be thermally acceptable, votes fell outside the comfort zone 29% of the time (Figure 8).

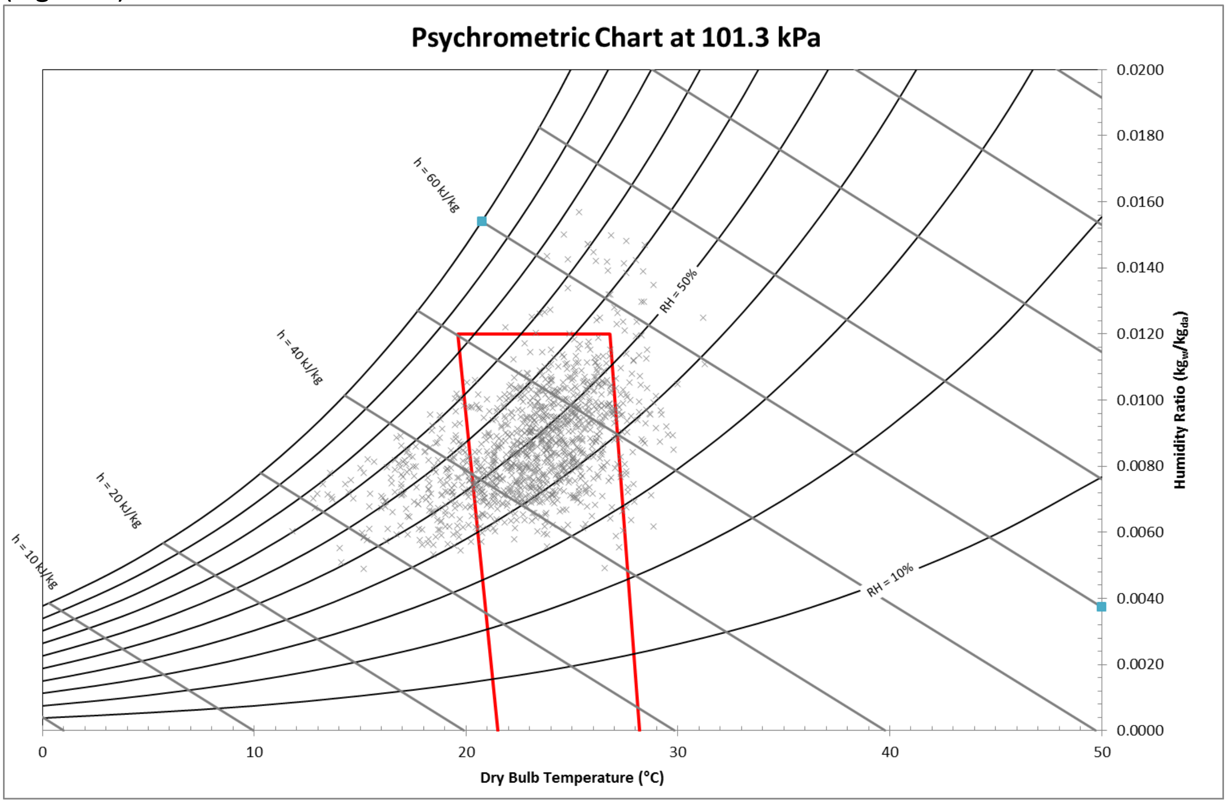

Figure 6 Psychrometric chart of the temperature and humidity at TSV vote ---1, 0 and +1 on 7---point scale, clothing 0.5---1.0 CLO, activity level 1.0---1.3 MET *(red lines indicate the acceptable range of operative temperature and humidity according to ANSI/ASHRAE 55---2013 – 1.0/0.5 CLO zones merged)*

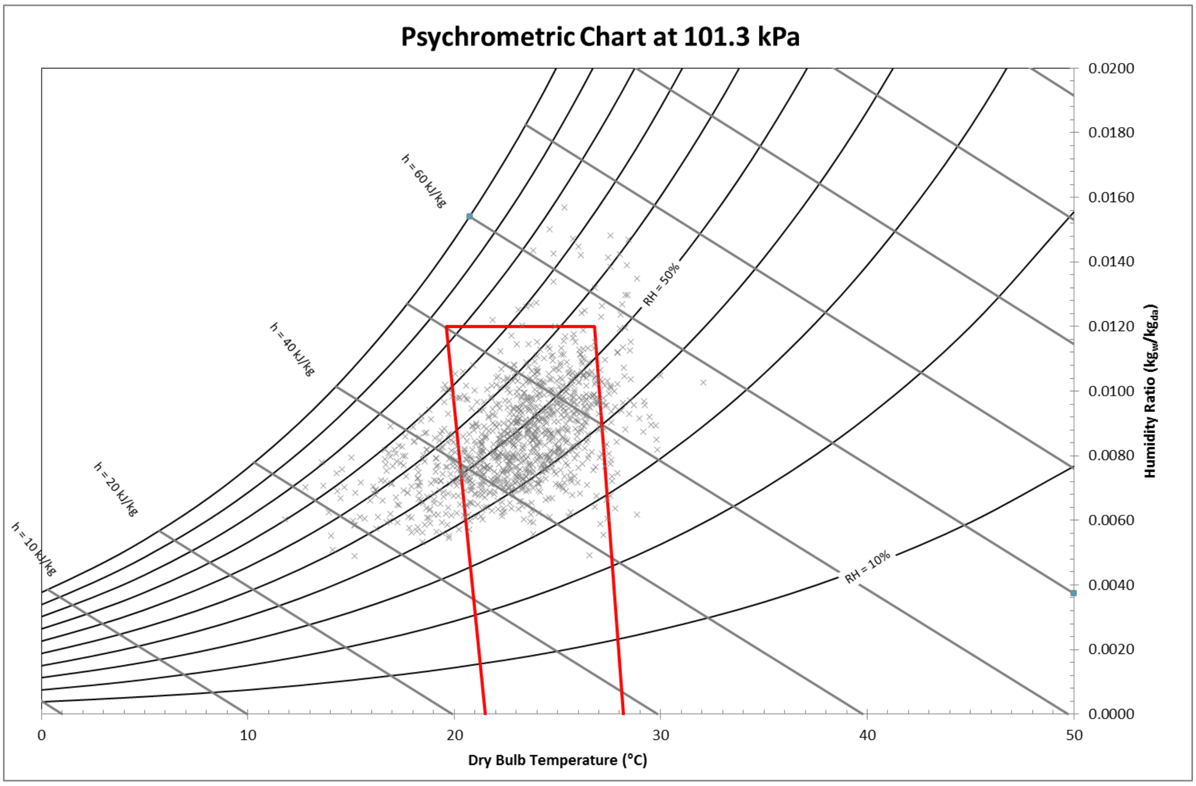

Figure 7 Psychrometric chart of the temperature and humidity at preference for no change on the McIntyre 3---point thermal preference scale, clothing 0.5---1.0 CLO, activity level 1.0---1.3 MET *(red lines indicate the acceptable range of operative temperature and humidity according to ANSI/ASHRAE 55---2013 – 1.0/0.5 CLO zones merged)*

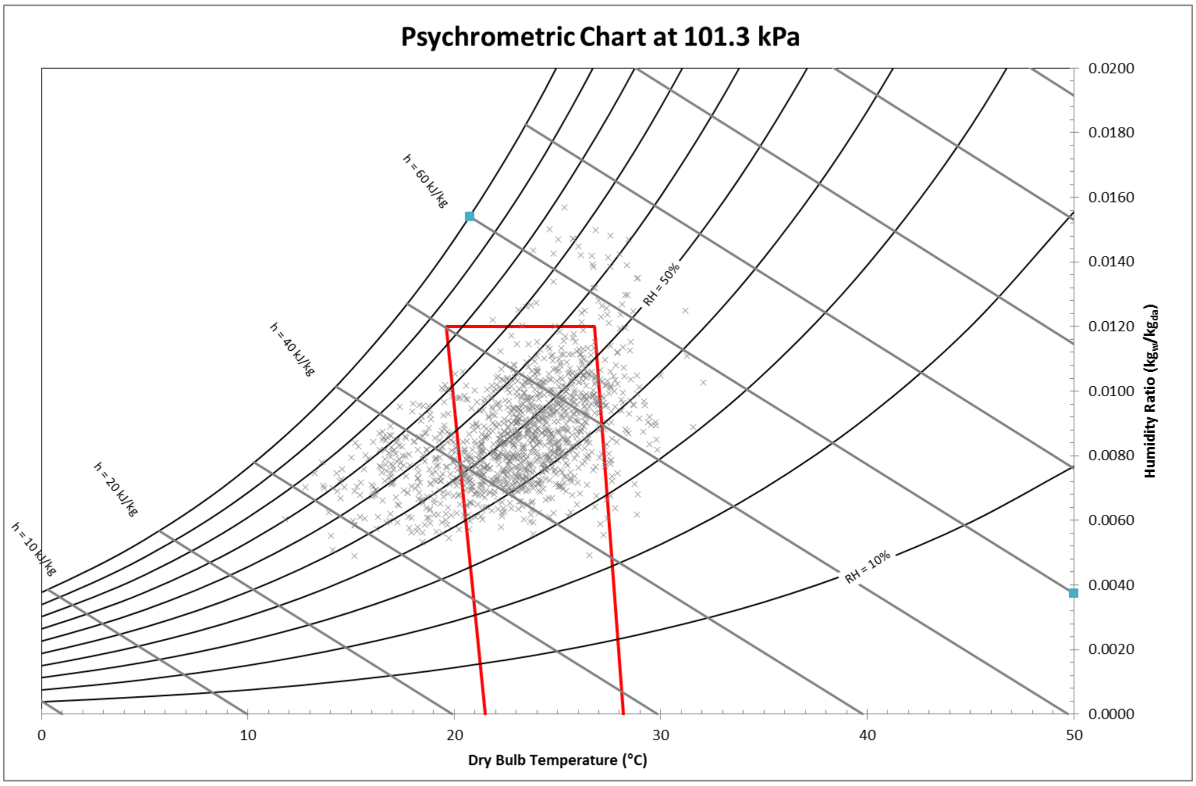

Figure 8 Psychrometric chart of the temperature and humidity when TAV was acceptable, clothing 0.5---1.0 CLO, activity level 1.0---1.3 MET *(red lines indicate the acceptable range of operative temperature and humidity according to ANSI/ASHRAE 55---2013 – 1.0/0.5 CLO zones merged)*

Whilst votes fall outside of the comfort zone both to the left (indicating votes at cooler temperatures) and to the right (indicating votes at warmer temperatures), a greater number fall on the cooler side Table 1. In each case, 66% of the votes outside of the comfort zone are on the cooler side.

Table 1 Percentages of votes inside and outside of the ASHRAE---55---2013 comfort zone

	TSV	TPV	TAV
Within Comfort Zone	**73.3%**	**75.9%**	**71.3%**
Outside Comfort zone	**26.7%**	**24.1%**	**28.7%**
Cooler than comfort zone	**17.7%**	**16.0%**	**18.8%**
Warmer than comfort zone	**9%**	**8.1%**	**9.9%**

In Figure 9, TSV is compared with an unacceptable TAV and a TPV≠0 indicating a preference for change. The curves of the quadratic functions fitted to these variables have a minimum that falls slightly left of a TSV of 0. (Figure 9). Overall this indicates a greater acceptability of cool and cold TSVs than warm and hot, and slightly higher likelihood of a preference for change at positive TSVs than at negative ones, and thus a more frequent indication of a preference to be cooler rather than warmer. .

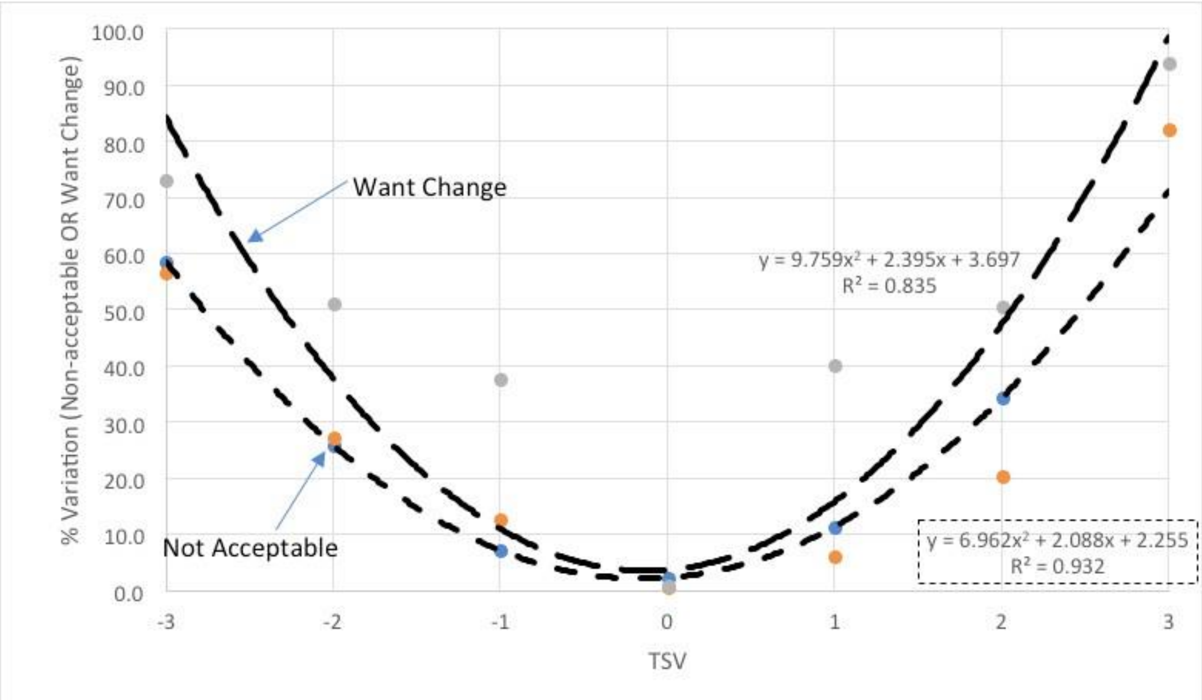

Figure 9 Preference for Change and Unacceptable thermal conditions compared with TSV

When participants were asked whether conditions were acceptable, as opposed to indicating their current sensation or desire for change, the range of conditions was wider and more votes fell outside of the ASHRAE---55 comfort zone. There are times when conditions are deemed 'acceptable' but the participant still indicated a preference for change. Whilst it may seem a simple exercise in semantics, in the older population it is important to consider the conditions that will be 'accepted' or 'tolerated' as well as the conditions that are preferred or considered neutral. A reluctance to use heating and cooling appliances has been previously discussed amongst older residents of South Australia

(Hansen et al. 2011), with local government officials reporting older people refusing to turn on air---conditioning due to the cost and behaviours linked with past resilience and ability to survive without the 'luxury' of heating and air conditioning. This may be linked to the wider range of conditions that are 'acceptable' to older people; these are conditions that can be 'put up with' despite the preference to be cooler or warmer.

In order to determine a range of acceptable temperatures for this cohort, the percentage of acceptable votes was binned by 0.5K intervals, as shown in Figure 10.

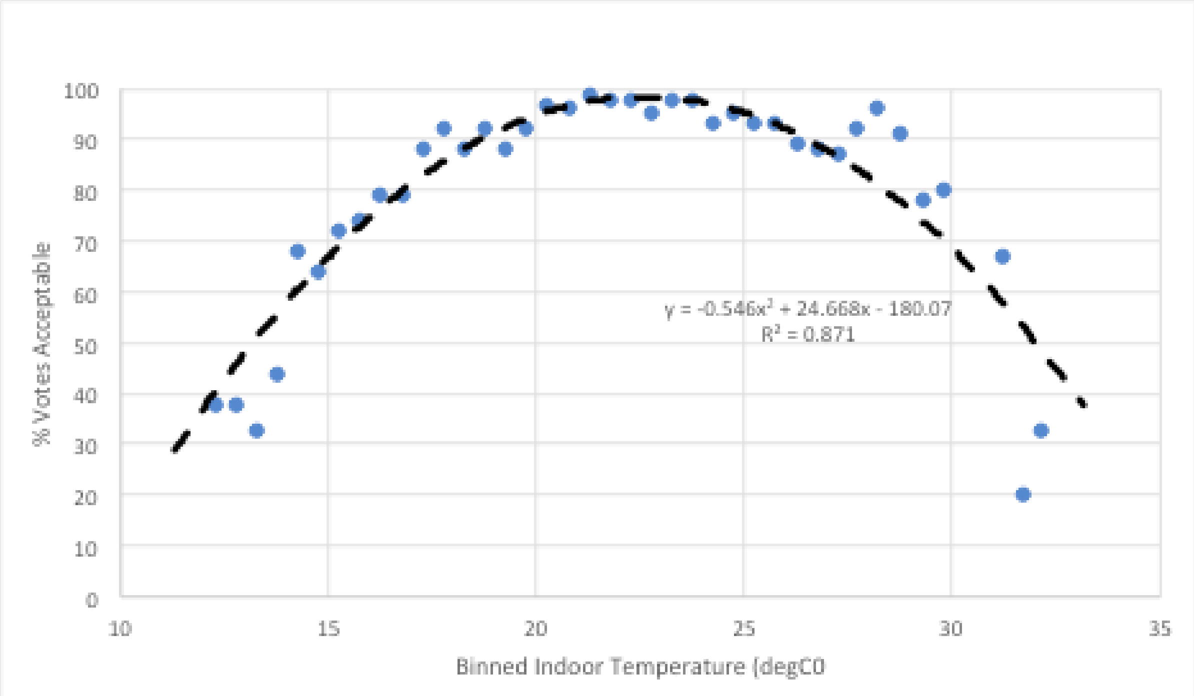

Figure 10 Acceptable votes by binned indoor temperature

The maximum acceptability as determined by the equation of the line is 98.5%, occurring at 22.59°C. This is slightly higher than the summer neutral temperature, which is unsurprising given the TAV consistently gives a wider range of acceptable temperatures than either TSV or TPV. The trendline through this data was further extrapolated to determine the ranges of 80% and 90% acceptability (Table 2).

Table 2 Range of acceptable temperatures for 80% and 90% acceptability

	Low (°C)	High (°C)	Width (°C)
80% Acceptable	16.77	28.4	11.63
90% Acceptable	18.64	26.53	7.89

There are several trends across this thermal comfort data. Firstly, participants overall had a lower neutral temperature in winter than in summer. Their experience of the thermal environment shifted and they were less tolerant to changes in the temperature than in the summer months, as indicated by the slope of the weighted regression lines (Figures 3&4). Despite this, participants are more likely to report feeling thermally comfortable and find conditions acceptable at cooler temperatures than predicted by the ASHRAE---55 standard.

4.4. Overall health

During the study period, 256 votes reported symptoms which is equal to 9.6% of the total comfort vote forms returned. The breakdown of these symptoms can be found in Table 3.

Table 3 Breakdown of total symptoms reported by type

Headache	19
Dizziness	9
Racing Heart	2
Unexplained Tiredness	25
Coughing	13
Joint Pain	76
Sleeplessness	100
Other	12
Total	**256**

Of these symptoms, 160 were reported by participants with chronic symptoms; those who reported symptoms in every vote were excluded to gain a clearer picture of the effects of temperature and thermal comfort on presentation of thermally symptoms.

4.5. Thermal Conditions and Health

To determine the impact of the thermal environment on the health of the participants, the presentation of symptoms was compared with both the thermal sensation of the occupant and the temperatures recorded in the home.

First to be considered was the relationship between TSV and the presence of symptoms in otherwise healthy participants. The percentage of votes with symptoms at each point on the 7---point comfort scale was determined and graphed (Figure 11), with results weighted according to the total number of votes for each TSV.

In participants who did not present with chronic symptoms, TSV was related to the frequency at which symptoms occurred and that the relationship is represented by a quadratic function (Figure 11). Regression analysis showed that this relationship was significant ($p<0.01$). A greater number of symptoms were reported when positive TSVs were indicated than when negative TSVs were indicated suggesting a greater number of symptoms being reported during hot indoor conditions.

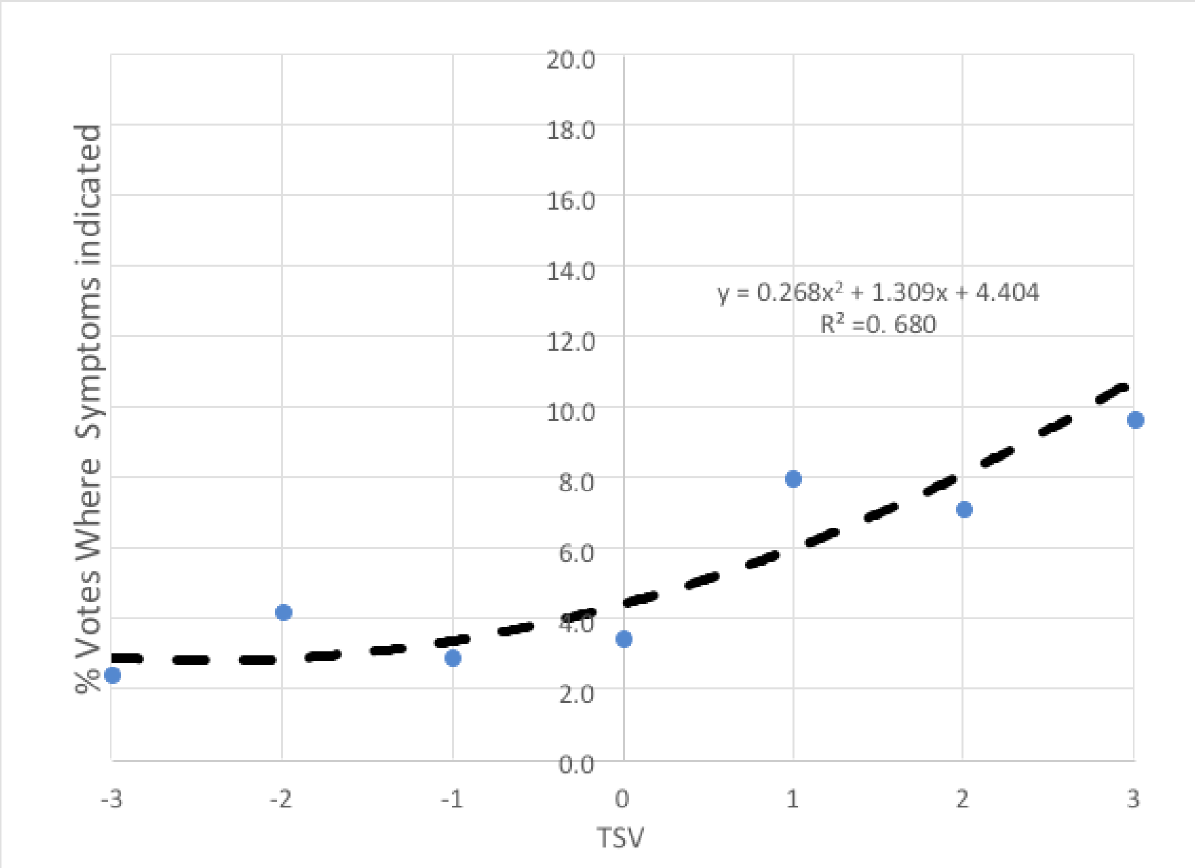

Figure 11 Percentage of votes where symptoms were reported at each thermal sensation vote score amognst otherwise healthy participants

The comfort vote survey asked specifically whether symptoms had occurred within the previous 24 hours. For this reason, the percentage of symptoms at each 1 degree Kelvin of the minimum and maximum indoor temperature for the previous day were plotted (Figure 12). This measurement, rather than the temperature at the time that the vote was cast, gives a more accurate representation of the effect of temperature over time on the health of the occupants.

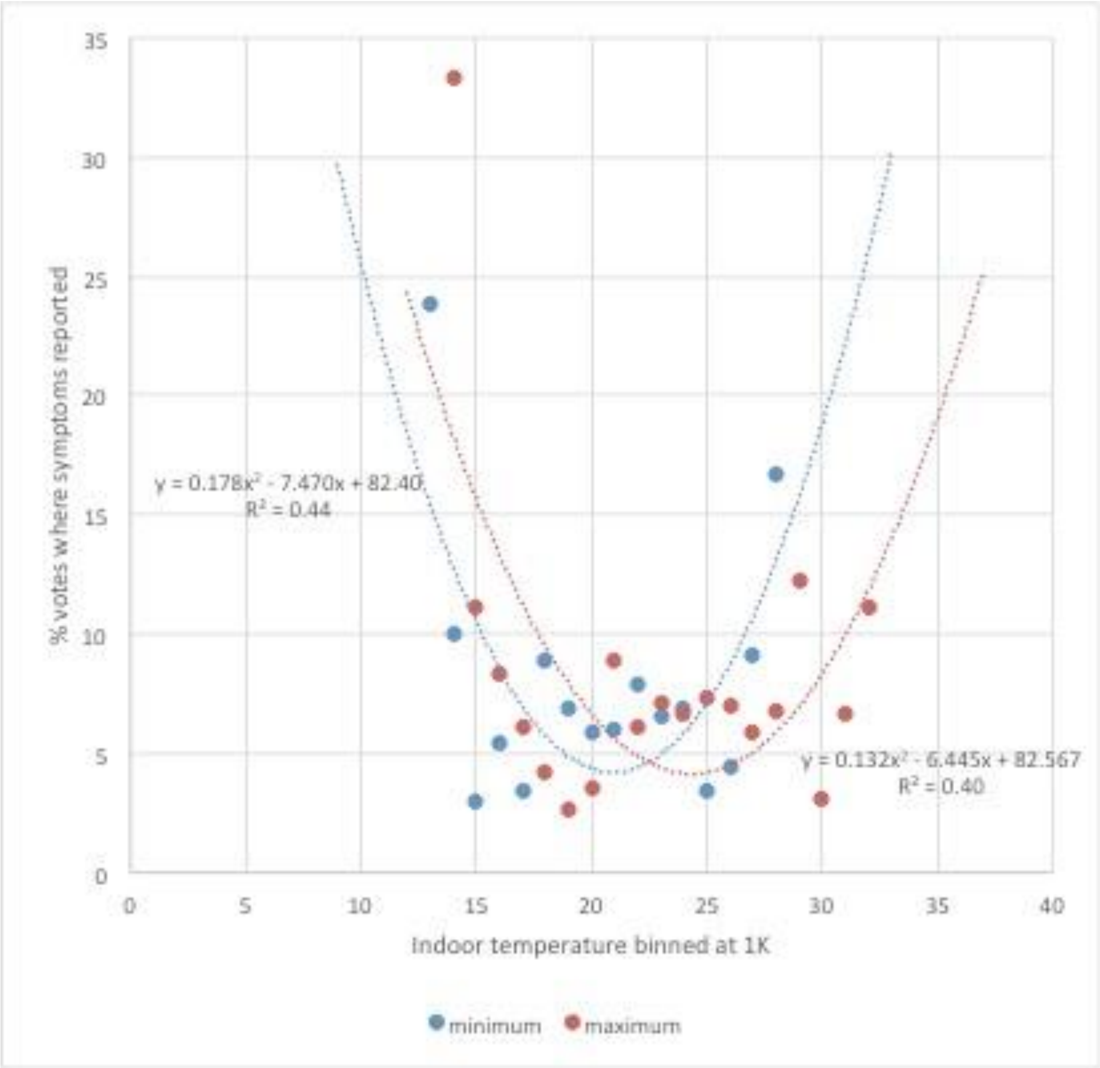

Figure 12 percentage of votes with symptoms amongst otherwise healthy participants at binned maximum and minimum °C for the previous day

This shows that the temperatures over the previous 24 hours have an influence on the number of symptoms experienced, with regression analysis showing these results to be significant for each variable ($p<0.05$). Overall this indicated that participants were more likely to suffer symptoms at extremes of temperature, with hot and cold maximum and minimum temperatures both related to an increased incidence of the reporting of symptoms.

The lowest point on the binomial curve in these graphs indicates the temperature, whether minimum or maximum, at which the fewest number of symptoms is predicted to occur. The lowest point on the 'minimum' equation is 21°C, whilst the lowest point on the 'maximum' curve is 24.3°C. This suggests a theoretical range of temperatures that should then be aimed at in the homes of older people to minimise the presence of symptoms. Of note is the fact that the safest minimum temperature is higher than the neutral temperature for this cohort in winter; this indicates that during colder months older people may not be keeping their houses adequately warm due to their own thermal preferences and behaviours.

4.6. Comfort Range vs Healthy Environment

The TAV consistently gives a wider range of temperatures that this cohort will find comfortable than TSV or TPV. Given the notion that older people may 'put up with' conditions they would prefer to change, this measure has been chosen to compare with the data regarding the presentation of symptoms.

Figure 13 below shows the quadratic functions fitted to the maximum (red) and minimum (blue) temperatures. The area shaded in green shows the range between the lowest point of each curve, which is a suggested range for reducing the presence of symptoms amongst older people. The area shaded in blue shows the range of conditions that would be deemed acceptable by 90% of participants.

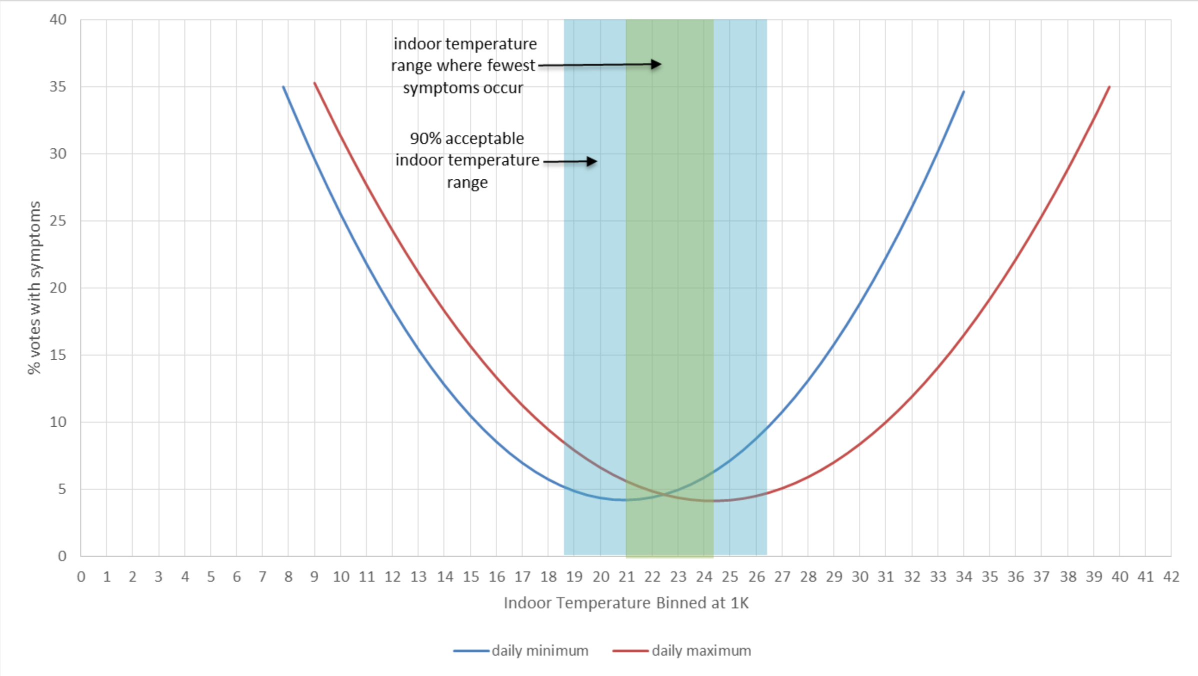

Figure 13 The quadratic functions of the trends of presentation of symptoms at daily minimum (blue) and maximum (red) temperatures. Shaded areas indicate the range of temperatures which would minimise the presence of symptoms (green) compared with the range of temperatures 90% of participants would find acceptable (blue).

This suggests that older people may be accepting of, and thus living with, conditions which may be associated with a greater risk of heat and cold related symptoms. However, the two ranges do overlap, so that most people would find conditions acceptable if they were within the green range indicated above. If there is a reluctance amongst this cohort to use their heating and cooling appliances as suggested by the study by Hansen et al (2011), there is an argument to be made for a program of housing improvement to use passive measures to bring the temperature range inside a house closer to that indicated by the green shading above.

5. Discussion

Up until recently, discussions around temperature and health within the Australian context typically revolved around heatwaves and the risks associated with extreme heat, especially given the predicted increase in such conditions as a result of climate change. This has shifted somewhat into an examination of cold related death and illness; despite mild winters there are surprisingly high numbers of death from cold related causes especially in comparison to Europe and America where winters are much colder (Bright et al. 2014). It has been suggested by public health researchers that this may be due to a lack of preparedness for cold; that clothing and housing utilised by Australians is not sufficient to maintain healthy winter temperatures (Barnett et al. 2017). This study has shown that it does not take very cold temperatures to being to see an increase in symptoms, and that anything below a minimum of 21 degrees is associated with increasing presence of symptoms. Given that the participants in the study had a neutral temperature lower than this in winter, it is thus a concern that winter heating practices, while seemingly providing acceptable thermal comfort, may not be providing the best environment for the promotion of good health.

It also shows that overheating is still of concern with high indoor maximum temperatures also being associated with increased numbers of symptoms. The relationship between the number of symptoms and positive TSVs, indicating a greater number of symptoms during warmer indoor conditions is also a concern, particularly for those who are unable to keep their houses cool during hot weather.

What is interesting about the results presented in this study is that the relationships are parabolic; symptoms increase with warmer minimum temperatures as well as colder temperatures. This phenomenon has been observed during heatwaves in Australia and worldwide; increases in morbidity and mortality are often during extended hot periods when night---time maximum temperatures remain high and there is no relief from high temperatures (Nicholls et al. 2008). Many participants in this study reported that they did not use any HVAC systems during the night; during hot nights in summer this means if natural cooling is not possible due to high outdoor temperatures, there will be no relief from hot conditions and this may lead to health problems.

The information collected in this study is a small sample however the trends seen suggest that indoor conditions are indeed linked to the presence of symptoms and that improvements to housing in South Australia may be a valid preventative health strategy. Similar strategies have been implemented in other countries and have been shown to be correlated with improved health amongst occupants (Thomson et al. 2009). These programs have primarily focussed on winter conditions; what remains to be seen is whether creating houses that are not just warmer in winter but also cooler in summer can help to also prevent heat related symptoms. Housing improvement programs have the added benefit of improving energy efficiency and potentially decreasing expenditure on energy costs, which for some older people and other vulnerable groups may have additional benefits, as energy poverty in Australia has also been linked to poor health outcomes (Chester & Morris 2011). Further study into the relationship between housing performance, energy efficiency and health are warranted to determine the potential efficacy of housing improvement as a preventative health strategy into the future.

6. Conclusion

This study has shown a relationship between indoor conditions and the presence of symptoms in otherwise healthy people over the age of 65. This relationship exists between both the indoor minimum temperature and the indoor maximum temperature and is binomial, and thus the presence of symptoms was related to both high and low temperatures. There was also a quadratic polynomial relationship between TSV and the presence of symptoms, with the fewest symptoms being reported when the TSV was slightly cooler than neutral. The relationship between indoor conditions, acceptability of these conditions and the frequency of symptoms presents an opportunity to explore the potential of housing improvement as not just a way of improving thermal comfort but also as a preventative health measure.

1. Acknowledgements

The author acknowledges the assistance of Terence Williamson in the production of some of the graphics for this paper.

7. References

ASHRAE 2013*, ANSI/ASHRAE standards 55---2013, thermal environmental conditions for human occupancy*, ASHRAE, Atlanta, GA.

Barnett, AG, Stewart, I, Beevers, A, Fraser, JF & Platts, D 2017*, 'Thermal clothing to reduce heart failure morbidity during winter: a randomised controlled trial'*, BMJ Open, vol. 7, no. 10.

Bills, R 2016, *'Cold Comfort: Thermal sensation in people over 65 and the consequences for an ageing population'*, Proceedings of 9th Windsor Conference: Making Comfort Relevant, Network for Comfort and Energy Use in Buildings.

Bright, FM, Winskog, C, Walker, M & Byard, RW 2014*, 'A Comparison of Hypothermic Deaths in South Australia and Sweden*', Journal of Forensic Sciences, vol. 59, no. 4, pp. 983---985.

Chester, L & Morris, A 2011, *'A new form of energy poverty is the hallmark of liberalised electricity sectors'*, Australian Journal of Social Issues, vol. 46, no. 4, pp. 435---459.

Commonwealth of Australia 2015, *2015 Intergenerational Report: Australia in 2055*, Commonwealth of Australia, Canberra.

Critchley, R, Gilbertson, J, Grimsley, M & Green, G 2007, *'Living in cold homes after heating improvements: Evidence from Warm---Front, England's Home Energy Efficiency Scheme'*, Applied Energy, vol. 84, no. 2, pp. 147---158.

Dufour, A & Candas, V 2007, *'Ageing and thermal responses during passive heat exposure: sweating and sensory aspects'*, European Journal of Applied Physiology, vol. 100, no. 1, pp. 19---26.

Fanger, PO 1973, *'Assessment of man's thermal comfort in practice'*, Occupational and Environmental Medicine, vol. 30, no. 4, pp. 313---324.

Government of South Australia 2017, *The 30 year plan for Greater Adelaide*, Government of South Australia, Adelaide.

Hansen, A, Bi, P, Nitschke, M, Pisaniello, D, Newbury, J & Kitson, A 2011, *'Perceptions of Heat---Susceptibility in Older Persons: Barriers to Adaptation'*, International Journal of Environmental Research and Public Health, vol. 8, no. 12, pp. 4714---4728.

Howden---Chapman, P 2004, *'Housing standards: a glossary of housing and health'*, Journal of Epidemiology and Community Health, vol. 58, no. 3, pp. 162---168.

Hwang, RL & Chen, CP 2010, *'Field study on behaviors and adaptation of elderly people and their thermal comfort requirements in residential environments'*, Indoor air, vol. 20, no. 3, pp. 235---245.

Indraganti, M 2011, *'Thermal comfort in apartments in India: Adaptive use of environmental controls and hindrances'*, Renewable Energy, vol. 36, no. 4, 2011/04/01/, pp. 1182---1189.

Koskela, HO 2007*, 'Cold air---provoked respiratory symptoms: the mechanisms and management'*, International journal of circumpolar health, vol. 66, no. 2, pp. 91---100.

Natsume, K, Ogawa, T, Sugenoya, J, Ohnishi, N & Imai, K 1992, *'Preferred ambient temperature for old and young men in summer and winter'*, International journal of biometeorology, vol. 36, no. 1, March 01, pp. 1---4.

Nicholls, N, Skinner, C, Loughnan, M & Tapper, N 2008, *'A simple heat alert system for Melbourne, Australia'*, International Journal of Biometeorology, vol. 52, no. 5, pp. 375---384.

Nitschke, M, Hansen, A, Bi, P, Pisaniello, D, Newbury, J, Kitson, A, Tucker, G, Dal Grande, E & Avery, J 2014, *Adaptive capabilities in the elderly during extreme heat events in South Australia*, SA Health, Adelaide.

Nitschke, M, Tucker, GR & Bi, P 2007, *'Morbidity and mortality during heatwaves in metropolitan Adelaide'*, Med J Aust, vol. 187, no. 11---12, pp. 662---665.

Schellen, L, van Marken Lichtenbelt, W, Loomans, M, Toftum, J & De Wit, M 2010, *'Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady ‐ state condition'*, Indoor Air, vol. 20, no. 4, pp. 273---283.

Sturman, AP & Tapper, NJ 2006*, Weather and climate of Australia and New Zealand*, Oxford University Press.

Thomson, H, Thomas, S, Sellstrom, E & Petticrew, M 2009, *'The health impacts of housing improvement: a systematic review of intervention studies from 1887 to 2007*', American journal of public health, vol. 99, no. S3, pp. S681---S692.

Wilkinson, P, Pattenden, S, Armstrong, B, Fletcher, A, Kovats, RS, Mangtani, P & McMichael, AJ 2004, *'Vulnerability to winter mortality in elderly people in Britain: Population based study'*, British Medical Journal, vol. 329, no. 7467, pp. 647---651.

Appendix H

Human Research Ethics Committee Approval

THE UNIVERSITY of ADELAIDE

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CRICOS Provider Number 00123M

11 September 2014

Associate Professor V Soebarto
School: School of Architecture and Built Environment

Dear Associate Professor Soebarto

ETHICS APPROVAL No: **H-2014-199**

PROJECT TITLE: **Cool or cook: Thermal comfort, affordability and health in housing for ageing Australians**

The ethics application for the above project has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Humanities and Social Sciences and Faculty of the Professions) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants. You are authorised to commence your research on **11 Sep 2014**.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled *Project Status Report* is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/ethics/human/guidelines/reporting. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the Information Sheet and the signed Consent Form to retain. It is also a condition of approval that you **immediately report** anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol; and
- the project is discontinued before the expected date of completion.

Please refer to the following ethics approval document for any additional conditions that may apply to this project.

Yours sincerely

PROFESSOR RACHEL A. ANKENY
Co-Convenor
Low Risk Human Research Ethics Review Group (Faculty of Humanities and Social Sciences and Faculty of the Professions)

ASSOCIATE PROFESSOR PAUL BABIE
Co-Convenor
Low Risk Human Research Ethics Review Group (Faculty of Humanities and Social Sciences and Faculty of the Professions)

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Applicant:	**Associate Professor V Soebarto**
School:	**School of Architecture and Built Environment**
Project Title:	**Cool or cook: Thermal comfort, affordability and health in housing for ageing Australians**

The University of Adelaide Human Research Ethics Committee
Low Risk Human Research Ethics Review Group (Faculty of Humanities and Social Sciences and Faculty of the Professions)

ETHICS APPROVAL No: **H-2014-199** **App. No.: 0000019324**

APPROVED for the period: **11 Sep 2014 to 30 Sep 2017**

Thank you for your response dated 10.09.2014 to the matters raised. This study is to be conducted by Rachel Bills, PhD student.

PROFESSOR RACHEL A. ANKENY
Co-Convenor
Low Risk Human Research Ethics Review Group (Faculty of Humanities and Social Sciences and Faculty of the Professions)

ASSOCIATE PROFESSOR PAUL BABIE
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