The Impact of Implicit and Explicit Occupants' Behaviour on the Efficient Use of Energy in Low-Income Households

Parisa Esmaeilimoakher

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DECLARATION

I declare that this thesis is my own account of research and contains as its main content work which has not been previously submitted for a degree at any tertiary education institution.

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Parisa Esmaeilimoakher

ABSTRACT

Accounting for approximately 40% of the primary energy use and one-third of the global greenhouse gas emissions, buildings significantly contribute to climate change. Due to increased demand and improved lifestyle, energy demand in the residential sector is growing sharply, placing additional pressure on the energy system. Therefore, this sector has considerable potential for energy savings at the national level.

In an attempt to make energy more affordable for low earners, this study used various tools and techniques to respond to the questions "what are the key factors affecting the energy performance of the residential buildings?" and "to what extent is the energy performance of a building influenced by its occupants and their activities?". The study revealed that the floor area of the dwellings, household size, and disposable household income, to a certain extent explain the variation in electricity consumption in the sample households. Monitoring the variation in indoor temperatures in a number of sample households with different types of the heating/cooling system further confirmed that thermal performance of buildings and the occupants' status of thermal comfort are significantly affected by their behaviour with respect to ventilating the house and the use of heating and cooling systems in the dwellings.

Thermal performance assessment of the sample dwellings with AccuRate software, Australia's benchmark tool for building energy assessment was performed using actual values for occupancy (number of occupants as well as heat gains from people), heat gains from lighting, key appliances, heating and cooling thermostat set-points, and time of use of appliances including heating/cooling systems. It was found that the AccuRate's base assumptions under-predict the number of internal heat gains in the households and thus calculates a greater need for heating energy and a lesser need for cooling energy than is actually required. The thermostat settings of heating and cooling appliances were found to have the highest impact on the thermal energy requirements of the households. Occupant behaviour in the households resulted in a

greater time of use of heating/cooling appliances with lower/greater temperature set-points than AccuRate's base assumptions. This meant that taking all factors (occupancy, internal heat gains, time of use and temperature set-points) into account, the predicted actual total thermal energy requirements of the households were, on the whole, significantly greater than the total energy requirements calculated using AccuRate's base assumptions. Further, it was found that significant total thermal energy savings of up to 50% – 70% could be found in households with adjustable thermostats if they followed the recommended thermostat guidelines of this study.

Overall, this research provides an insight into the energy performance of social housing dwellings in Perth, Western Australia. With these buildings constructed similar to the average residential buildings in Australia, the findings from this study may be further extended to the residential sector in Perth. However, evaluating the energy performance of a bigger sample of households is required for validating the outcomes.

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DEDICATION

To my parents

who always encouraged me to go on every adventure, especially the PhD journey,

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in memory of my late friend Marzieh who reminded me that life is a fragile gift and inspired me to bring love, laughter, and courage to all of life’s challenges.

LIST OF ABBREVIATIONS

ABS	Australian Bureau of Statistics
AC	Air Conditioning
ACBD	Australia Climate Data Bank
ACH	Air Changes per Hour
ACOSS	Australian Council of Social Service
ADEC	Average Daily Electricity Consumption
AHURI	Australian Housing and Urban Research Institute
AIHW	Australian Institute of Health and Welfare
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BCA	Building Code of Australia
BES	Building Energy Simulation
BOM	Bureau of Meteorology
CEFC	Clean Energy Finance Corporation
CHIA	Community Housing Industry Association
CO2	Carbon Dioxide
COAG	Council of Australian Government
CRA	Commonwealth Rent Assistance
DF	Damping (Decrement) Factor
DGSE	Daily Global Solar Exposure
DHI	Disposable Household Income
EDHI	Equivalised Disposable Household Income
FHL	Foundation Housing Limited
GHG	Greenhouse Gas
HH	Household
HILDA	Household Income and Labour Dynamics in Australia
HoH	Head of Household
HUD	The U.S. Department of Housing and Urban Development
HVAC	Heating, ventilation, and air conditioning
IEA	International Energy Agency
IHG	Internal Heat Gains
MJ	Mega Joule
NatHERS	Nationwide House Energy Rating Scheme

NCC	National Construction Code
NEPP	National Energy Productivity Plan
NOAA	National Oceanic and Atmospheric Administration
NV	Night-time Ventilation
PJ	Peta Joule
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RMY	Reference Meteorology Year
RPD	Relative Percentage Difference
SHIP	Social Housing Investment Package
SIH	Survey of Income and Housing
SOMIH	State Owned and Managed Indigenous Housing
WHO	World Health Organization
WACOSS	Western Australian Council of Social Service

LIST OF PUBLICATIONS

(i) Esmaeilimoakher, P., T. Urmee, T. Pryor and G. Baverstock (2016). "Identifying the determinants of residential electricity consumption for social housing in Perth, Western Australia." Energy and Buildings 133: 403-413.

(ii) Esmaeilimoakher, P., T. Urmee, T. Pryor and G. Baverstock (2017). "Influence of occupancy on building energy performance: a case study from social housing dwellings in Perth, Western Australia." Renew. Energy Environ. Sustain. 2: 44.

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CHAPTER 1

INTRODUCTION

Overview of Chapter

This chapter presents the scope, context, and significance of the research. It highlights the problem of energy poverty in low-income social housing in the Australian context and discusses the negative impact of energy poverty not only on households' finances but also on the health and wellbeing of individuals within these households. After outlining the research problems, the chapter presents the research questions that guide the entire research project, the aim and objectives of the project, and scope of the study, followed by the structure of the thesis.

1.1 An Overview of Energy Consumption in Buildings

Buildings account for 36% of global final energy consumption and nearly 40% of total direct and indirect greenhouse gas (GHG) emissions (IEA 2018a) and thus, this sector highly contributes to climate change (Ren et al. 2011; Wang et al. 2010). A report by the International Energy Agency revealed that final energy use in buildings grew from 2,820 million tonnes of oil equivalent (Mtoe) in 2010 to around 3,060 Mtoe in 2018 (IEA 2019). Hence, reducing energy consumption in this sector plays a vital role in accomplishing international energy conservation targets (Landsman 2016; Wada et al. 2012; Kuckshinrichs et al. 2010). It has been established that by taking fundamental actions such as improving building energy codes and standards, strengthening standards for building equipment and appliances, encouraging consumers to adopt appliances with higher energy efficiency, etc. buildings could be up to 40% more energy efficient by 2040 (IEA 2018a).

Despite their substantial contribution to global energy consumption as well as global GHG emissions (Pablo-Romero et al. 2017; Estiri 2015), residential buildings still remain an "undefined energy sink" (Swan and Ugursal 2009a). Four factors make the energy consumption in residential buildings more complex than other sectors (Swan and Ugursal 2009a), (Amasyali and El-Gohary 2018) including:

- The diverse structure sizes, geometries and thermal envelope materials;
- The wide variety of occupants' behaviour that impacts building energy consumption (by as much as 100% for a given dwelling);
- Restrictions on successful collection of energy-related data from individual households mainly as a result of privacy issues;
- The highly expensive cost of detailed sub-metering of household energy use.

Numerous energy studies have focused on different aspects of the issue including improving the energy efficiency of buildings, estimation of energy requirements, energy reduction and/or energy conservation, etc., by applying diverse methodologies, concepts, and methods of analysis (Belaïd 2017). Furthermore, various directives and regulations have been established worldwide, aiming to reduce energy consumption and GHG emissions and to promote sustainable development in this sector (Leroy and Yannou 2018). Some of these initiatives are educating the homeowners, introduction of regulatory instruments, energy conservation policies and regulations for governing the energy performance in buildings, and House Energy Rating Schemes (HERS) (Lyrian et al. 2015).

Energy consumption at the household level significantly affects energy consumption at the national level (Besagni and Borgarello 2018). Residential buildings consume energy and produce GHG at different stages of their lifecycle including construction, operation, maintenance and demolition. The operation phase (running space heating and cooling, hot water, lighting and other appliances for a good quality indoor environment) accounts for nearly 80-90% of the total emissions (Alves et al. 2015). Hence, this sector offers significant potential for reducing the carbon emission at the "country-scale" by controlling operational energy consumption at the "household-scale" (Tian et al. 2016; Lyrian et al. 2015).

Increased demand and improved lifestyle have resulted in a sharp growth in energy use in residential buildings and have placed additional pressure on the energy system (Esmaeilimoakher et al. 2016). The rapid advances in air-conditioning (AC) technologies and increasing affordability have raised the penetration of AC systems in modern lifestyle (Luo et al. 2018), which has ultimately resulted in higher energy consumption in residential buildings. It is anticipated that energy consumption in the residential sector will increase by an average of 0.3% per year between 2015 and 2040 (EIA 2017).

Although reducing energy consumption and the subsequent greenhouse emissions in this sector have been set as clear goals worldwide, the mission of untangling the key factors affecting energy consumption in residential buildings presents significant complexities (Belaïd 2017). The residential energy consumption is not only affected by the building and efficiency of the service systems and appliances, but also by socio-economic characteristics of the building users, and their behaviour (Guerra-Santin and Itard 2010). Optimizing energy performance of buildings and implementing energy saving regulations in the building sector (e.g. considering levels of insulation in different climates, use of energy-efficient systems, etc.) results in improving thermal properties of buildings. This in return, makes the role of occupants more determinant (Gaetani et al. 2016; Tianzhen and Hung-Wen 2013). The complexity and unpredictability of user behaviour, however, makes the evaluation of building energy performance highly complicated and difficult to anticipate (Esmaeilimoakher et al. 2016). Due to the lack of detailed socio-economic data, occupants' characteristics are often ignored as factors in building energy performance assessment tools (Brounen et al. 2012). As a result, the outcomes of energy analysis with these tools do not precisely reflect the actual energy status of buildings and need to be investigated.

Worldwide, the influence of different factors on building energy performance has been evaluated in numerous studies. Nevertheless, the extent to which, each factor may affect the energy performance of buildings significantly varies from one study to another. Indeed, energy consumption trends in residential buildings highly depends on the peculiarities of each country including climate condition, endowment, historical events (e.g. energy supply shortages), socio-cultural norms, market conditions, accessibility and diversity of energy resources, appliances and equipment used in homes, etc. (Lenzen et al. 2006; Belaïd 2017). To this end, understanding the various determinants of energy consumption in different locales is a fundamental step towards the design and implementation of effective policies to enhance the energy performance of residential buildings in that location.

1.2 The Status of Energy Consumption in Australia

In line with many other countries around the world, energy supply and use in Australia continues to grow (Department of Environment and Energy 2017). A report by the Australian Bureau of Statistics (ABS) revealed that between 2014-15 and 2015-16, Australia's gross energy supply increased by 6% (Australia. Bureau of Statistics 2018b). Nevertheless, in 2015-16, Australian energy consumption rose by 2.3 % (compared with an average growth of 0.6 per cent a year over the past decade) to its highest level ever of 6,066 PJ (Department of Environment and Energy 2017).

The residential sector accounted for 7.5% of Australia's overall energy consumption (**Figure** 1.1 **(a)**) (Australia. Department of Environment and Energy 2018a). Australian households are, therefore, directly responsible for a significant share (around 20%) of greenhouse gas emissions at the national level (McGee 2013). Nowadays, there is a trend towards building larger houses and the number of household appliances is increasing due to changes in lifestyle (Esmaeilimoakher et al. 2016). Hence, the amount of energy used by households across the country is substantial and improving energy efficiency in this sector will have a significant economic and environmental impact e.g. on reducing their operating cost.

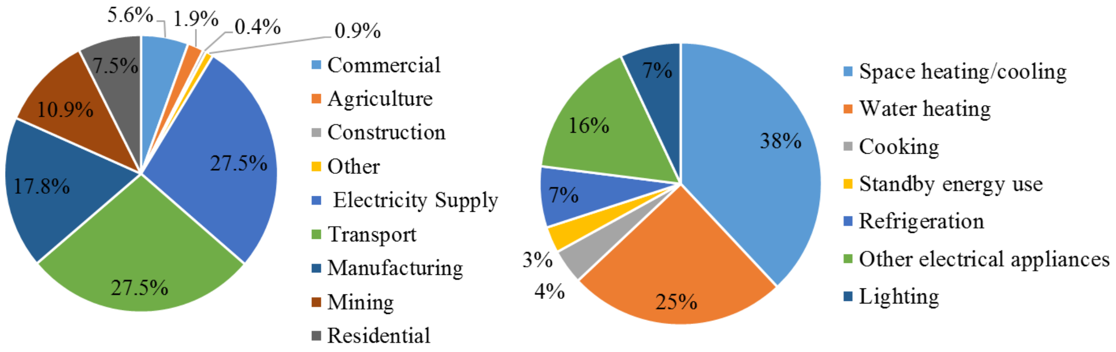

Figure 1.1 a (left) Australia's final energy consumption by industry 2016-17, b (right) Breakdown of energy use in an average Australian home

(Source (a): (Australia. Department of Environment and Energy 2018a))

(Source (b): Government of South Australia 2018)

Households use energy for a wide variety of purposes. While heating and cooling accounting for 40% of energy consumption in average Australian homes, appliances (including refrigeration and cooking) contribute to nearly one-third of the total residential energy use (**Figure** 1.1 **(b)**). Nearly 75% of Australian households use space cooling and 57% use a clothes dryer, both of which are large energy users (Chester 2013). More than 80% of Australian households also own a home computer (Chester 2013). By purchasing highly efficient appliances, in addition to cutting Australia's domestic energy bills by up to $471 million/year, a saving of over 2 million tonnes of GHG emissions/year can be obtained (Gunningham and Bowman 2016).

Almost all households in Australia use electricity as a source of energy while only 50% use mains gas (Australia. Bureau of Statistics 2014). Electricity and gas prices for Australian households have significantly increased in recent years and the trend is expected to continue (Swoboda 2013). The weekly expenditure on domestic energy (electricity and gas) for average households in Australia raised from $10.56 in 1984 to $40.92 in 2016 as shown in **Figure** 1.2.

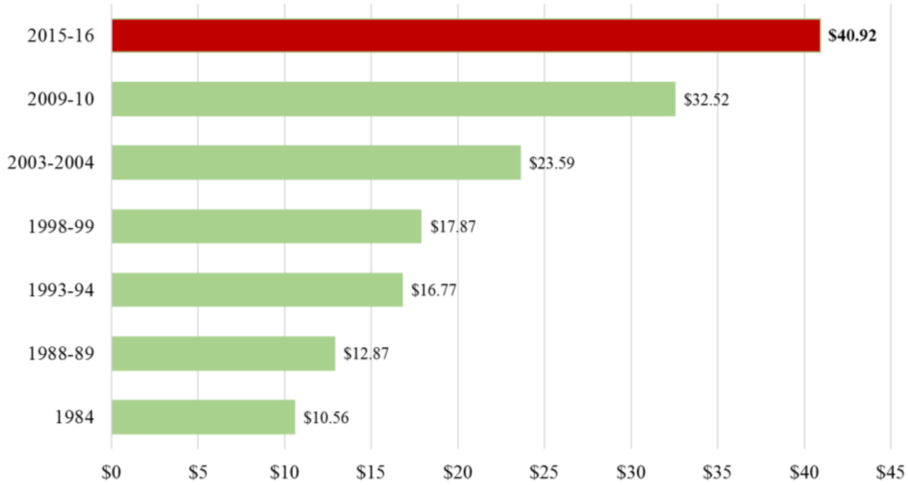

Figure 1.2 Weekly expenditure on domestic energy by average households in Australia

(Source: KPMG 2017)

In the 10 years (from 2008 - 2018), the average electricity and gas prices increased by 117.4% and 89.2% respectively (**Figure** 1.3) (ABC News 2018). These two expenses are, indeed, the two fastest-rising Australian households' expenses after tobacco as shown in **Figure** 1.3.

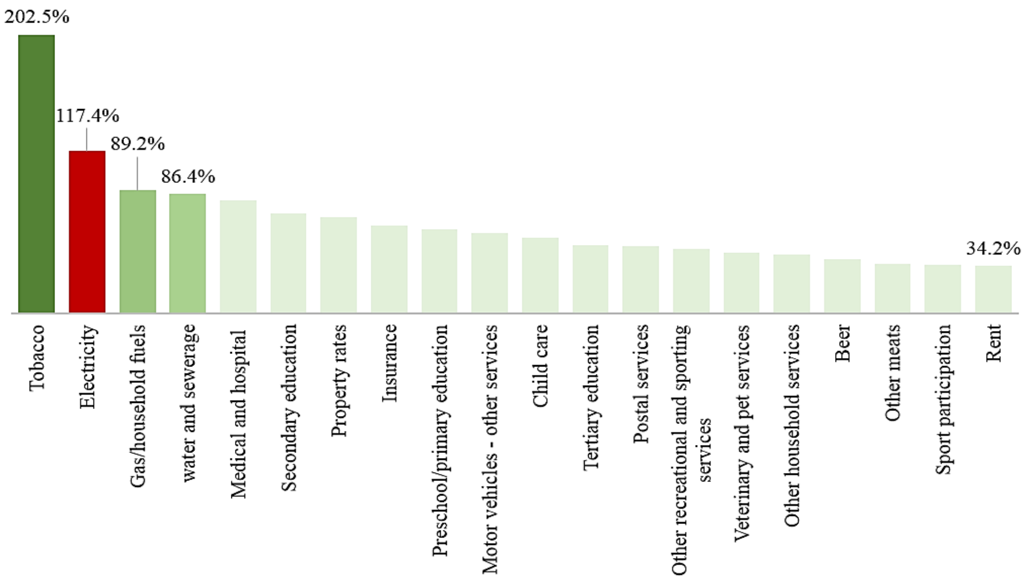

Figure 1.3 Top 20 fastest-rising expenses (% increase since June 2008-2018)

(Source: ABC 2018)

The ever-increasing energy prices are affecting householders across the economy including farmers, business, and individual households. Due to the significant increase in energy prices, Australian households are more concerned than ever about where the energy comes from, how it is used and how to safeguard it (Australia. Department of Environment and Energy 2018b). This is particularly a concern in the case of low-income households who are facing difficulties affording their energy expenditure.

1.3 Energy Issues Experienced by Low-Income Social Households in Australia

Housing affordability refers to the relationship between household income and expenditure including house prices, mortgage payments, and rents. In contrast, housing stress refers to a situation where a household pays more than 30% (a commonly used affordability benchmark) of its gross income on utilities (Australia. Institute of Health and Welfare 2018a). One of the common indicators for estimating housing affordability stress in Australia is called the “30:40” indicator. It means a household whose income level is in the bottom 40% of Australia's income distribution (referred to as lower-income households) and is devoting more than 30% of its income to housing expenditure is experiencing housing affordability stress (Australian Housing and Urban Research Institute 2016). It has been reported that over a million Australian households on low-income are currently experiencing housing stress (Australia. Council of Social Service 2018).

Despite the fact that many Australians are struggling with housing costs, the majority of those in housing stress are private renters (Steven and Rachel 2012). The failure of the private market to provide affordable and secure housing for low-to-moderate income Australian households compounded by ever-increasing housing prices had a negative impact on the ability of households with insufficient income to secure housing (Steven and Rachel 2012). Australia’s state and territory governments are the central points of housing assistance around the country to ensure that all Australian residents have access to secure, affordable and appropriate housing

(Australia. Department of Social Services 2017). Rental housing with adjusted rent based on household income, rental assistance in the private market, and home purchase assistance are some of the methods of housing assistance provided by Australian governments and community-based organizations to households in need.

In order to assist low-income households to have access to stable and affordable housing, “social housing” schemes have been established by Australian governments across different states and territories (Urmee et al. 2012). These rental housings are fully or partly funded by the government and owned/managed by the government or a community organisation. Despite the overall increase in the number of Australian households, however, the number of social housing dwellings has failed to keep pace (Australia. Institute of Health and Welfare 2018b), and hence, there is a severe shortage of social and affordable housing across Australia (ACOSS 2018a). In 2016, it was estimated that over 500,000 affordable rental dwellings were required for the lowest income households (ACOSS 2018a). In June 2016, nearly 394,289 households lived in social housing (Australian Government Productivity Commission 2017). At the same time, 147,884 applicants were on the waiting lists for public housing, 38,509 applicants were waiting for community housing and 8,199 applicants were seeking for State-Owned and Managed Indigenous Housing (SOMIH) housing. Therefore, a total number of 588,881 Australian households were either living in or seeking to live in social housing dwellings. This was around 6.3% of the overall households in Australia in 2016 (Australian Government Productivity Commission 2017).

Energy poverty is a term used for when households do not have access or cannot afford to have the basic energy or energy services to achieve day to day living requirements (González-Eguino 2015). These requirements may, however, vary in different countries. Consequences such as thermal discomfort, cutting back on food or other basic needs to save for energy bills, etc. threaten households’ life if energy cannot be paid for (Caritas 2016). Increased housing and utility costs are the main triggers of energy poverty in different Australia's states and territories (Bankwest Curtin Economics Centre 2016). Nearly 3 million households in Australia have no access to affordable domestic energy i.e. electricity and gas (Caught 2018). While an average Australian household is to some extent affected by the ever-increasing energy prices, the impacts on the economic wellbeing of low-income Australian households are more significant (Moore et al. 2017). Low-income households are most at risk of experiencing energy poverty due to three main reasons (Moore et al. 2017). Firstly, these households are facing greater difficulty in paying their energy bills, which often results in involuntary disconnection of the services when payments are due. Secondly, they may need to compromise their thermal comfort and use less heating/cooling so that they can afford their energy bills. And finally, these households may need to trade-off their fundamental needs including healthcare, food or education to be able to pay their energy bills.

Figure 1.4 shows the share of electricity and gas expenditure based on the sources of household income.

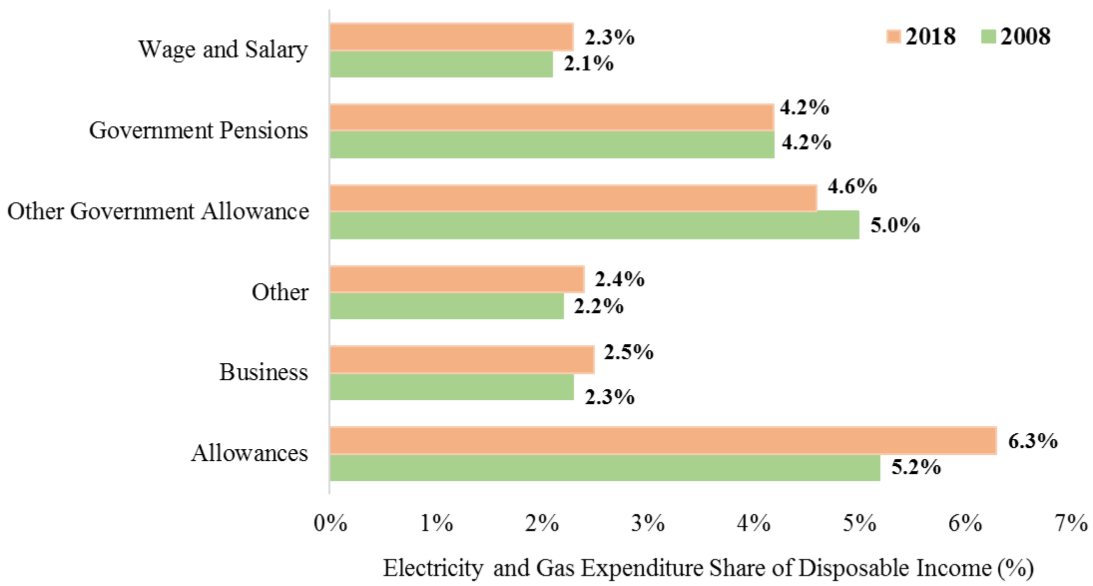

Figure 1.4 Share of electricity and gas expenditure for different sources of income

(Source: Household Expenditure Survey (HES), 2008 and 20018)

Households on low-income pay, unreasonably, more of their income on energy expenditure (ACOSS 2018b). While households whose main sources of income is wage and salary spent nearly 2.3% of their income on energy expenditure in 2018, households on allowances (i.e. Newstart, Parenting Payment Partnered, Austudy/Abstudy, Youth Allowance, Sickness Allowance) spent nearly 6.3% of their income on energy. This number has increased by 1.1% since the last decade.

Studies have shown that nearly 40% of low-income households in Australia are renters (ACOSS 2018b). These householders often live in older and less efficient buildings and use less efficient appliances, while having limited capacity to replace these appliances with more efficient appliances (Bouzarovski 2014). Hence, these households have less control over reducing their energy bills, which ultimately results in higher energy consumption and extremely high utility bills (relative to their income) (Center for Climate and Energy Solutions 2017). Taking into account the total housing cost including utility expenditure, these households are under immense financial stress. They reportedly struggle with their high energy expenditure to the extent that the only way to ensure payments can be made is by curtailing their energy consumption (Moore et al. 2017). These households may not be able to turn on the heating or cooling systems during extreme weather conditions, which will negatively impact on their physical as well as mental health. Therefore, it is imperative to put the needs of these disadvantaged households at the forefront of energy studies.

1.4 Energy Status of Social Housing Dwellings in Australia

Over recent years, social housing has been increasingly allocated to Australian households with complex requirements, including having a member with a disability or being on lower income levels (Australia. Institute of Health and Welfare 2018b). With the majority of social households mostly relying on pensions and other government allowances, as discussed in Section 1.3, these households spend more of their income on energy (ACOSS 2018b). Low-income households living in Australian social dwellings often have a legal responsibility to pay their rent as well as other charges, including charges for electricity and gas, and it is established that most of the social households encounter difficulties paying their utility charges (Esmaeilimoakher 2018). In some specific circumstances, some housing providers may get involved and assist the tenants by making payments to utilities on their behalf to prevent unnecessary disconnection of the service. However, the tenants need to reimburse the housing providers through different arrangements, such as smaller payments in instalments on top of their rent. This, in most cases, causes financial stress for low-income households (Gregory 2018).

Increasing the energy efficiency of buildings significantly reduces their reliance on mechanical heating and cooling, and hence, lowers the energy requirements, energy consumption and the subsequent energy expenditure. Concurrently, it results in improved thermal comfort, positive health and social outcomes for the occupants (Moore et al. 2017). Most of the social housing dwellings are not water and energy efficient mainly due to poor design of buildings, lack of proper insulation, inefficient lighting, and energy inefficient appliances used by the low-income residents (Urmee et al. 2012). The large stock of existing old and inefficient social dwellings suggests that there is a significant investment opportunity to further improve the energy efficiency in this sector (Urmee et al. 2012).

Although both tenants of social housing dwellings and the housing providers will benefit from the improved energy efficiency of social dwellings, each group is encountering some barriers, which make further energy improvement in this sector inaccessible. For the low-income social householders, lack of information, low level of education, and lack of access to external capital are the main impediments to improved energy efficiency (Urmee et al. 2012). For social housing providers, who are dedicated to providing as many houses each year as their budgets may allow, high capital cost, split incentives, and complex information are the main factors preventing them from incorporating high energy efficiency measures into social dwellings (Moore et al. 2017). As such, this sector offers substantial opportunities for further energy efficiency improvements through enhancing the awareness of both householders and housing providers about the positive impacts of improved energy efficiency on the finance, health and well-being of individuals.

1.5 Thermal Energy Performance of Buildings

Energy performance of buildings is simultaneously affected by building physics as well as the users of energy in buildings. This will be discussed in more detail in Chapter 2. Research has shown that building physical characteristics, to a certain extent, affect how occupants interact with the buildings as well as their energy use behaviour (Delzendeh et al. 2017). Occupants, on the other hand, affect the energy performance of buildings in two ways: directly and indirectly (Estiri 2015; Belaïd 2017). Although the direct impact of occupants on domestic energy demand has found to be significantly lower than the corresponding impact of buildings, they directly affect building characteristics through their choice of dwelling type, dwelling size, etc., which results in indirect influence on the building energy demand (Belaïd 2017). As such, the total impact of buildings on their energy performance constantly carries indirect impacts from occupants, which are inherent in the building effect (Estiri 2014). With these interconnected factors affecting the building energy performance, it is important to incorporate these factors into the process of building energy performance assessment.

The extent of influence that occupants may have on the energy performance of residential buildings depends on different factors including climatic condition, variation in their preferences and lifestyle, building automation and thermal properties of dwelling (e.g. thermal mass, insulation) (Wei et al. 2014; Guerra-Santin and Itard 2010). Since occupants living in social housing dwellings have limited choice for selecting certain types or sizes of dwellings, their influence on building thermal energy performance may vary from that of the private rented or owner-occupied dwellings. Therefore, identifying the factors that affect the thermal performance of these dwellings can be considered as the preliminary step towards enhancing energy performance in the whole sector. To the best of knowledge of the authors, no similar investigation has been performed using the actual information from the buildings and their occupants on the social housing dwellings in Western Australia. Therefore, this research would shed light on different aspects of the energy performance of these dwellings.

1.6 Research Questions

With the problem of high energy expenditure experienced by low-income Australian households and its adverse impact on the health and wellbeing of these disadvantaged households, and taking into account the existing barriers for enhancing their energy efficiency, several questions have been triggered that guide the process of designing and developing this research project:

(i) What are the various determinants of residential energy consumption and how do these factors affect energy consumption in low-income social households in Perth, Western Australia?

(ii) How do occupants' presence and their behaviour with respect to using heating/cooling systems and natural ventilation affect energy performance and occupants' thermal comfort in social housing dwellings?

(iii) What are the important considerations for modelling the thermal performance of low-income households?

1.7 Research Aims

The aim of this research is to "investigate the impact of implicit and explicit occupants' behaviour on the efficient use of energy in low-income households in social housing dwellings".

- **Implicit behaviour** implies the indirect influence of occupants on the building energy performance e.g. occupants' choice of appliances and their associated Internal Heat Gains (IHGs);
- **Explicit behaviour** implies the direct influence of occupants on the building energy performance e.g. adjusting the thermostat settings of heating/cooling systems.

1.8 Research Objectives

The main objectives of this research work are to:

(i) Develop an understanding of different (occupant related) factors that affect the energy performance of social housing dwellings and propose guidelines for optimal energy use in these dwellings;

(ii) Develop an understanding of the actual occupants' behavioural patterns and the impact on the energy performance of buildings and occupants' thermal comfort in social housing dwellings;

(iii) Evaluate the thermal energy performance of social housing dwellings using a modelling tool.

1.9 Scope of the Research

Evaluating the energy performance of residential buildings is a complex practice. Firstly, approaching occupants living in private dwellings and convincing them to participate in a project across extended periods are challenging and hence, it is likely to end up with a small sample and insignificant outcomes. The diversity of occupants' behaviour, which might affect a building's energy consumption by as much as 100%, lack of detailed energy-related information at the household level, and expensive cost of sub-metering and detailed monitoring (Swan and Ugursal 2009a) are only some of the issues that make residential energy assessment more complicated than other sectors. Therefore, the scope of the investigation in this study was limited to evaluating the energy performance of low-income social housing dwellings in Perth, the capital city of Western Australia.

Although non-aggregated electricity monitoring i.e. monitoring time of use and power draw of individual appliances such as air-conditioners, would have benefited the research greatly, there are difficulties of obtaining the permission from occupants of the dwellings and high cost associated with sub-metering in the main electricity circuit board. Therefore, actual behavioural monitoring was not performed as a part of this research project. The research monitored temperature changes in the dwellings to gain some insight into different occupant behaviour with respect to operating heating/cooling appliances.

1.10 Research Structure

This thesis is structured into eight (8) main chapters. The contents of the chapters are:

(i) Chapter 1 creates insight into the research problems, which led to several research questions, aims and objectives of the study. The chapter also details scope and limitations of the research as well as the research structure.

(ii) Chapter 2 explores and discusses the existing literature on the determinants of residential energy consumption at an international level, the current status of energy consumption in the social housing sector and the impact of the high cost of energy on the life and well-being of low-income social households in Australia. The chapter further discusses the process of thermal performance assessment of residential buildings using different tools and techniques, taking into account the existing discrepancy between the outcome from these tools and actual energy performance of buildings.

(iii) Chapter 3 explains the methodology of the project including the steps of the research, the research design including the design of the field survey and energy audit in the sample households, ethics protocol, participants' recruitment protocol, data collection, analysis, and modelling procedure.

(iv) Chapter 4 presents a comprehensive data analysis based on the findings from the household survey and energy audit in the sample households.

(v) Chapter 5 presents the findings from temperature monitoring in a few representative households and discusses possible reasons for trends in households' temperature profiles.

(vi) Chapter 6 presents the outcomes of a thermal energy performance assessment of the sample dwellings using AccuRate Sustainability and discusses the extent to which different factors might affect the energy requirements of sample dwellings.

(vii) Chapter 7 revisits the original research questions and discusses the overall findings of the study together with the limitations that in some way, influenced the outcome of the research.

(viii) Chapter 8 concludes the study by providing a summary of the research and the extent to which the proposed objectives were obtained, followed by recommendations for future related research.

Summary

Overall, this chapter has set the scene and defined a direction for the research to move forward towards achieving the research objectives. The proposed research problems and research questions are used to guide designing the research, while the research methodology provides a tool to derive results from the study. On this platform, this research is now ready for further exploration and discussion on the impact of implicit and explicit occupants' behaviour on the efficient use of energy in low-income households.

CHAPTER 2

THE LITERATURE REVIEW

Overview of Chapter

A comprehensive review of published articles, books, and reports in the field of energy efficiency in residential buildings is undertaken as a part of this study in order to understand what is already known about the energy performance assessment of residential buildings around the world and what factors determine the electricity consumption in this sector with the main focus on low-income social households in Australia. Evidence from this literature search is essential to justify why enhancing the energy performance of these vulnerable and disadvantaged households has been chosen as the prime candidate to drive this study.

2.1 Determinants of Energy Consumption in Residential Buildings

Residential energy demand is affected by a wide range of inter-related factors including dwelling characteristics, household attributes, behaviour and the lifestyle of householders (Estiri 2015). Although local climate influences the extent to which, different factors may affect energy consumption in dwellings in different locations (Andersen et al. 2011; French et al. 2007; Haas 1997; Jones et al. 2015; Kavousian et al. 2013; McLoughlin et al. 2012; Yun and Steemers 2011), this determinant is normally outside the scope of the influence of households (Estiri 2014).

Except for their direct impact on the building energy performance, households indirectly affect buildings' energy demand through their direct influence on building characteristics (Estiri 2015). For example, in the US, Estiri (2015) found that the annual energy consumption in households with higher income and education is higher not because they have extensive energy use behaviours, but because they are living in more energy-consumptive housing units including bigger single-family homes, with more rooms. **Figure** 2.1 shows the direct and indirect links between occupants and their behaviour, building and its equipment and energy consumption of buildings.

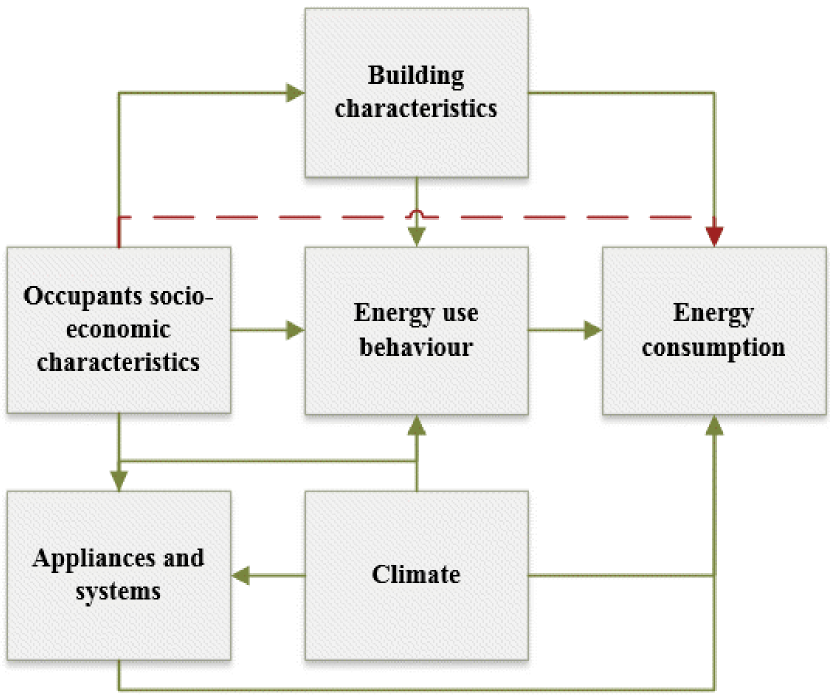

Figure 2.1 An empirical model for household energy consumption

(Adopted from (Yun and Steemers 2011), modified)

This interrelation between different factors makes the evaluation of residential energy performance more complex. Nevertheless, the extent to which each factor affects buildings energy performance is highly case dependent and varies depending on the peculiarities of each country i.e. climate condition, endowment, historical events (e.g. energy supply shortages), socio-cultural norms, behaviour and market condition, accessibility and diversity of energy resources, appliances and equipment used in homes, etc. (Lenzen et al. 2006; Belaïd 2017). This is why the energy studies conducted in different countries, which are based on the consumption data at household level significantly differ from one another (Rehdanz 2007; Meier and Rehdanz 2010; Guerra-Santin and Itard 2010; Wei et al. 2014; Pachauri 2004; Sardianou 2008; Yu et al. 2011; McLoughlin et al. 2012).

Determinants of energy consumption in the residential sector can be divided into contextual and behavioural domains (Wilson and Dowlatabadi 2007). While the contextual domain encompasses local climate, energy market, home appliances and building physical characteristics (e.g housing type and size, insulation level, etc.), the behavioural domain includes lifestyle, consumption behaviours and socio-economic characteristics of the households (Wilson and Dowlatabadi 2007). For a building to be energy efficient, different factors need to be addressed at the same level of importance. However, steering toward more efficient building design is difficult or sometimes impractical. For example, once the building is constructed, the elements of building condition conducive to efficient design, and not included during the design and construction phase (such as the building orientation, insulation, etc.) would be immutable unless major renovation is undertaken (Esmaeilimoakher et al. 2016). The efficiency of the appliances and how efficiently they are used in the households, however, are some of the major areas leading to the improvement of the energy efficiency in these dwellings. In the following sub-sections, diverse building and occupant-related factors, which according to the literature, affect the energy performance of residential buildings in some way are discussed in more detail.

2.1.1 The Impact of Building-Related Factors on Its Energy Performance

Worldwide, the significance of building characteristics on the variation of domestic energy consumption has been well studied. Different building-related factors that have been proved to have some impact on the residential energy consumption include dwelling type, year of construction, dwelling size (either as a measure of floor area or number of rooms), level of insulation, thermal mass, type of heating and cooling system, type of temperature control, etc. (Wei et al. 2014). In general, research on the influence of a building and its attributes for improving its energy efficiency is taken into account in 5 groups of application areas, namely the whole building, building envelope, windows and shadings, HVAC system, lighting and appliances (De Boeck et al. 2015). However, the extent to which different building-related factors were found to affect its energy performance varies. For example, while 42% of the variation in energy use for space and water heating (MJ/year) in Dutch residential stock was found to be attributed to building characteristics, only 29% of the variation of the U.S. households' energy use was linked to building features, over which, occupants have no control (Brandemuehl and Field 2011).

Free-standing dwellings have higher energy consumption than other dwellings (Wei et al. 2014; Zhou et al. 2008). In the U.S., the detached buildings were found to require more energy for the same level of thermal comfort than attached buildings, mainly because single detached houses have more exposed surface area compared to other dwellings, resulting in more heat exchange with their surroundings (Ewing and Rong 2008). Sardianou (2008), however, found that dwelling type has no significant influence on the residential energy demand in Greece. Having typically smaller size and benefiting from less exposed surface, apartments and row houses need noticeably less energy than (semi-) detached residences for the same level of thermal comfort (Brounen et al. 2012; Guerra Santin et al. 2009). Furthermore, among 300,000 Dutch dwellings, apartments and duplex homes were found to use substantially less energy for heating than the corner dwellings with the same size mainly due to the latter benefit of less exposed surface (Brounen et al. 2012).

A small negative correlation was established between the dwellings' age and local heating required in the living area by Guerra Santin et al. (2009) in the Netherlands. In New Zealand, newer houses were found to be warmer in winter than older houses (with no renovation), mainly because of the higher level of insulation, higher airtightness, and more efficient systems in newer dwellings (French et al. 2007). Kaza (2010) used the US Residential Energy Consumption Survey (RECS) data and demonstrated that year of construction mainly affects the energy requirement for heating (Kaza 2010). Generally, as a building becomes older, as a result of unavoidable wear and tear, the functionality of building components may fall, unless regular maintenance or replacement is undertaken. McLoughlin et al. (2012), however, disproved the direct impact of the dwelling age on its energy performance in Ireland as a result of the strong collinearity between the dwelling age and the HoH age. According to this study, younger HoHs mostly live in newer dwellings compared to the older HoHs.

Larger dwellings have more space to be heated and cooled. Therefore, as homes become larger (measured by either floor area or the number of rooms), energy consumption in dwellings increases (Andersen et al. 2011; Estiri 2014; Ewing and Rong 2008; Sardianou 2008). Additionally, the number of home appliances in larger houses is expected to be more resulting in higher energy consumption (Jones et al. 2015; Sardianou 2008). In a comparison between energy consumption for space heating and cooling by two households living in 1,000 and 2,000 square-foot buildings in the U.S., Ewing and Rong (2008) found that more energy was required for cooling, heating and all other usages by the household living in the larger house. Dwellings with more number of rooms consume more energy if each extra room is heated (Guerra Santin et al. 2009). A significant positive relationship was reported between the number of rooms and electricity consumption in Irish (Leahy and Lyons 2010) and Dutch (Bedir et al. 2013) dwellings. However, Brounen et al. (2012) found that with controlling the building size, each extra room in Dutch dwellings resulted in decreasing energy consumption by about 0.5 per cent.

In the Netherlands, an additional level of insulation resulted in a 3% reduction in the consumption of natural gas (Brounen et al. 2012). Nevertheless, the existing relationship between the level of insulation and gas consumption in this study was found to be non-linear, and hence, the impact of adding up an extra layer of insulation to a building that has already been insulated is rather smaller (Brounen et al. 2012). The use of external insulation may result in smaller indoor temperature fluctuation compared to that of internal insulation. It is, therefore, predicted that heavy walls with external insulation have the least indoor air fluctuation and thus, are appropriate for naturally ventilated buildings (Zhou et al. 2008). In terms of effectiveness, the greatest benefit was achieved with the insulation of the building façade, followed by double glazing, insulation on the ground and insulation of windows (Guerra Santin et al. 2009).

Thermal Mass and Building Energy Performance

Thermal mass is the ability of building materials to absorb and store heat energy and thereby, act as a thermal battery (Reardon et al. 2013a). While a lot of heat energy is required to change the temperature of materials with high thermal mass (e.g. concrete, brick, etc.), materials with lower thermal mass need less energy to change their temperature (e.g. timber). If used correctly in a building, thermal mass can store solar energy during the day-time and re-radiate it at night, when surrounding temperatures fall. This significantly affects occupants' thermal comfort and reduces the heating/cooling energy requirements in the building through moderating internal temperatures by flattening diurnal extremes.

The heat gain and loss of buildings are defined in relation to the ambient temperature and the level of activity within the space (Turner and Doty 2006). The heat loss refers to the quantity of heating energy required in space to maintain a certain level of thermal comfort or a specified level of indoor temperature at a certain outdoor temperature. The heat gain is, on the other hand, the total elements that determine the cooling load (cooling energy requirements) or the amount of heat that must be removed from a space in order to maintain a certain level of indoor temperature, which is divided into two groups: 1) Sensible and 2) Latent. While the former refers to the changes in the temperature of an object (or gas) through conduction, convection, and radiation with no changes in the phase of the object (e.g. liquid to gas), the latter is related to changes in phases. The sensible and latent heat emitted from different sources within an enclosed space has to be removed from the space and/or results in the rise in the indoor temperature and humidity in the space.

It is common knowledge that the air temperature changes quicker than the mass temperature due to the greater inertia of the mass. Therefore, when a source of heating/cooling is used in a zone, it is expected that the air temperature in that zone changes quicker than wall surface temperature, creating a sudden divergence of the air temperature from that of the wall surface temperature. The time delay as a result of thermal mass is called “thermal lag”, which significantly affects the thermal efficiency of a building (Strine Environments 2019). ‘Damping’ or “Decrement” Factor (DF), on the other hand, is the reduction in recurrent temperature on the inside surface compared to the outside surface of a material (Strine Environments 2019). Some materials have a lower decrement factor than others. For example, DF for 100-150 mm thickness concrete is 0.5 whereas, for 300 mm thickness concrete, DF is 0.25. It is implying that a thicker concrete wall evens out the internal temperature peaks and troughs, helping to maintain a constant temperature even with extreme ambient conditions. Temperature damping is, in fact, the characteristics of mass construction that describe how indoor temperature in a building is affected by the ambient temperature surrounding the building and heat flow, which is most important in warm and warming climates with a high diurnal range. Gregory et al. (2008) used decrement factor as a measure for the temperature difference between indoor and the desired room temperature over that of the difference between the outdoor and the desired room temperature, with a low decrement factor offering the least temperature fluctuation. The result showed that upon changing the outdoor temperature, the reverse brick veneer wall offers the least fluctuation in indoor temperature followed by cavity bricks and brick veneer and lightweight construction.

The energy requirement for maintaining comfortable indoor temperatures, to a certain extent, depends on the thermal storage capacity of building materials or their thermal mass (Karlsson et al. 2013). The energy saving potential of buildings associated with the use of adequate thermal mass pointed in the literature ranges from a few per cent to more than 80% (Aste et al. 2009). Material with high thermal mass has a long time lag and moderating effect on internal temperature swings (Ogoli 2003). Zhuo et al. (2008) divided the thermal mass into two categories: i) external thermal mass and ii) internal thermal mass. In this classification, the external mass is directly exposed to both indoor and outdoor temperature while the internal mass such as furniture and internal partitions are only in contact with the indoor environment (Zhou et al. 2008). Any changes in the amount of internal thermal mass in a building affects the decrement factor and the time lag of the indoor temperature (Zhou et al. 2008). The general perception of thermal mass in building mostly refers to external thermal mass such as external walls or roof (Kossecka and Kosny 2002; Zhang et al. 2006).

The appropriate use of heavy or medium thermal mass in buildings and its effective distribution is an effective design strategy, which moderates the extreme thermal conditions and enhances the thermal comfort inside the building (Baker 2008). The effective use of thermal mass can significantly reduce the diurnal temperature swings in a building and results in the higher thermal comfort of the building users (Gregory et al. 2008). However, the positive contribution of higher effective thermal capacities of building fabrics will be improved if it is coupled with other energy-saving strategies, specifically with other energy-saving measures and correct operation strategies such as enhanced night ventilation (Aste et al. 2015; Aste et al. 2009; Amos-Abanyie et al. 2013; Slee and Hyde 2011). The significant savings potential as a result of using thermal mass in buildings is known to be sensitive to many factors including utility rates, type of equipment, occupancy schedule, building construction and control strategy (Braun 2003).

Aste et al. (2009) used different test cells with walls having the same U-value but different dynamic thermophysical properties and found that the high inertia wall led to lower energy requirements ranging from 1%-10%. The study further revealed that while the role of thermal inertia significantly increases for cooling, it decreases in case of heating (Aste et al. 2009). Using four environmental test chambers with different thermal mass levels, Ogli (2003) established that the indoor temperature in low mass buildings closely follows outdoor conditions. In this study, the maximum indoor temperature can be predicted as a measure of maximum and minimum outdoor temperature (Ogoli 2003):

$$Tmax_{in} = Tmax_{Out} - 0.488 \text{ x } [Tmax_{Out} - Tmin_{Out}] + 2.44 \,, \qquad 2.1$$

Where,

$T_{max\ in}$ is the maximum inside temperature,
$T_{max\ out}$ is the Maximum outdoor temperature and
$T_{min\ out}$ is the minimum outdoor temperature.

Thermally heavy buildings in warm climates reduce energy consumption through decreasing cooling needs in summer (Al-Sanea Sami et al. 2012). An empirical study by Slee et al. (2013) in the coastal climate of Sydney revealed that an exponential relationship exists between the quantity of thermal mass and the internal diurnal temperature range of the space during summer. In other words, when adding extra thermal capacity to space, a point will come when adding extra thermal capacity no longer affects the internal temperature range (Slee et al. 2013). They have further observed that the volume of the space has no impact on the influence of thermal capacity on the indoor temperature, which was also supported by (Karlsson et al. 2013; Hall et al. 2010).

2.1.2 Influence of Occupants and their behaviour on Building Energy Performance

Households affect building energy performance in two ways: directly and indirectly (Estiri 2015; Belaïd 2017). Although the direct impact of households on domestic energy demand has been found to be significantly lower than the corresponding impact of building attributes, households directly affect building characteristics (e.g. their choice of dwelling type, dwelling size, etc.), which results in indirect influence on the building energy demand. Therefore, the overall influence of households on the building energy performance is just slightly lower than that of the building (Belaïd 2017) and that the total effect of building characteristics on energy consumption constantly carries an indirect impact from household characteristics, remaining inherent in the building effect (Estiri 2014). Taking into account the indirect (large) impact of occupants on energy consumption, the importance of incorporating households energy use behaviour and choice processes in managing residential energy consumption is drawing attention (Kelly 2011). The extent of influence that occupants may have on the energy use in residential buildings depends on a wide variety of factors including climatic condition, variation in preferences and lifestyle, occupants' engagement, building automation and thermal properties of dwelling (e.g. thermal mass, insulation) (Wei et al. 2014; Guerra-Santin and Itard 2010). In this study, the influence of occupants on the building energy performance is categorised into households' socio-economic characteristics and occupants' energy use behaviour. A summary of the existing literature is discussed in the following subsections.

Occupants' Socio-economic Characteristics

More energy is generally used by larger households (Oreszczyn et al. 2006; Sardianou 2008; Wei et al. 2014; Yohanis et al. 2008; Druckman and Jackson 2008). As the family size increases, the chance of moving into a larger house increases (Estiri 2014). Both bigger homes and larger household size are subsequently associated with an increase in total energy consumption (Estiri 2014). Similarly, Guerra Santin, et al. (2009) underlined the larger than expected impact of occupants on the energy required for space and water heating due to the influence of their behaviour on the type of dwellings and HVAC system. In France, domestic energy consumption is found to be highly dependent on an adaptation of household size to dwelling size (Lévy and Belaïd 2018). In an attempt to evaluate the significance of residential mobility on the energy consumption, Levy and Belaid (2018) employed logistic regression on the data from national surveys of 32,000 households in 2002 and 31,000 households in 2006 and showed that per person energy consumption in identical housing type and location depends on the household position in the life cycle whereas the consumption/m^2 remains relatively stable.

Household composition is paramount in a variation of residential electricity demand (Brounen et al. 2012; Druckman and Jackson 2008). The number and ages of children are the two significant factors for residential energy demand with the latter mainly affects both electricity and the gas consumption for heating (Brounen et al. 2012). Relying on a large sample of 300,000 dwellings, Brounen et al. (2012) further found that while elderly households consume more gas than another groups of households, households with teenagers consume more electricity due to watching more TV, use of personal computers, gaming devices, etc. commonly known as the “Nintendo-effect”. They also found that although the elderly may spend longer times in the house, their lower energy consumption is mainly linked with the type of appliances they may use. In their sample, the age of the head of the household was significantly related to gas consumption, but not electricity. In Japan, however, the number of individuals above 60 was found to mainly affect only electricity consumption (Hara et al. 2015). A detailed survey of 1721 Dutch households showed that elderly persons with higher income levels choose higher comfort level, resulting in more intense energy consumption (Brounen et al. 2013). The study further found that a negative relationship exists between the age of the households and lowering the temperature at night (Brounen et al. 2013).

Some studies found that with no difference in the neutral temperature, females prefer slightly warmer environment than males (Karjalainen 2007) mainly because their skin temperature is constantly lower than males (Li et al. 2008). Others, however, found no evidence that gender difference affects the temperature preferences of individuals (Brounen et al. 2012). While some researchers found no indication that the HoH gender affects households' electricity expenditure (Kim 2018), others reported that in households with women in charge of controlling the energy consumption and expenditure, the energy consumption is the lowest (Permana et al. 2015).

Disposable household income is highlighted as one of the key determinants of domestic energy consumption in different countries (Santamouris et al. 2007; Sardianou 2008; Druckman and Jackson 2008). In the UK, a positive relationship has been found between the disposable household income and both energy consumption and GHG emissions (Druckman and Jackson 2008). Similarly, income was found to be the key factor (out of diverse variables including household socio-economic, demographic, geographic, family and dwelling attribute that directly or indirectly affects energy requirements), results in variation in energy requirements across Indian households (Pachauri 2004). A more recent study on residential energy-saving behaviour in France revealed that households with good energy use behaviour will not change their habit due to a higher income (Belaïd and Garcia 2016). Lenzen et al. (2006) also observed significant differences in average energy requirement by households with equal income level, which perhaps was the result of the diverse geographical condition, energy conservation and technology and the lifestyle of households. In the Netherlands, disposable household income mainly affected domestic electricity consumption to the extent to which, each 1% increase in disposable income increases household electricity consumption by up to 11% (Brounen et al. 2012). In another study in the Netherlands, Vringer et al. (2007) undertook a consumer survey of 2304 Dutch households and found that a 1% increase in household income increases energy use by 0.63%. Guerra Santin, et al. (2009), however, found a small link between income levels and households' energy requirements.

Limited studies highlighted the tenure as an influential factor affecting residential energy performance. In Germany, household expenditure on heating and hot water system supply was found to be significantly lower for owner-occupied accommodation as they are more likely to invest in more energy efficient appliances (Rehdanz 2007). Druckman and Jackson (2008) also reported that although privately rented dwellings are less likely to have proper roof insulation or other energy-saving measures, higher energy efficiency attributed to different construction type (e.g. flat vs. (semi)-detached dwellings) on an average, outweighs the general lack of energy-efficient features that tend to be put in place by private landlords.

Occupants' Behaviour

Occupants interact with the building to enhance their comfort (Page et al. 2008). For example, they heat, cool or ventilate their environment to improve their thermal comfort or adjust lighting systems or blinds to optimize their visual comfort. Occupants' behaviour has a significant impact on energy use and indoor environmental quality in buildings. Adjusting thermostat for comfort, switching lights, opening/closing windows, pulling up/down window blinds, and moving between spaces are some example of occupants' energy use behaviour, which affects processes such as design optimization, energy diagnosis, performance evaluation, and building energy simulation (IEA 2018b).

The history of evaluating the influence of occupants behaviour on the building energy demand goes back to 1951 (IEA 2018c). **Figure** 2.2 creates an insight into the status of occupant behaviour-related studies cited on Google Scholar BibTex.

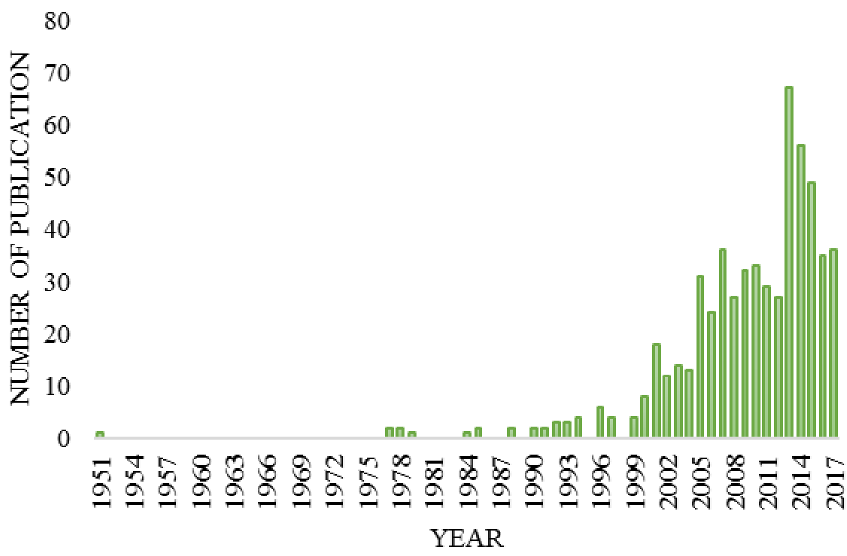

Figure 2.2 Publications on definition and simulation of occupants' behaviour

(Source: IEA-EBC Annex 66)

Since 2001, the significance of occupant behaviour in energy studies experienced growth and the number of studies focused on different aspects of occupants' behaviour noticeably increased (**Figure** 2.2). This clearly verifies the growing international concern over the impact of occupants' behaviour on the energy performance of buildings. Nevertheless, the models created for occupants' behaviour in buildings worldwide are often inconsistent, with a lack of consensus in common language, good experimental design and modelling methodologies (IEA 2018b).

Occupants react to both internal and external stimuli to either maintain or improve their thermal comfort (Valentina Fabi et al. 2013). Such actions result in changes in the indoor environment and subsequently, in the building energy performance (Valentina Fabi et al. 2013; Dubrul 1988). Overall, the influence of behavioural factors on the residential energy consumption can be characterized by both the occupancy pattern and building and appliances control potentialities. In some studies, the existing differences between occupants behaviour are found to account for the different energy performance of households of similar size and type (Yun and Steemers 2011; McLoughlin et al. 2012). Yousefi et al. (2017) performed sensitivity analyses and found that the impact of occupants behaviour on the heating and cooling energy requirement in the hot climate may be as high as about 90% and recommended the use of "near actual" user behaviour in energy simulation analysis and lifecycle assessments.

Households perform different activities to satisfy their needs (Lopes et al. 2015). To perform these activities, occupants use energy (heating, cooling, lighting, etc.) through activating energy behaviours. **Figure** 2.3 shows the energy consumption activation chain including the factors affecting energy behaviours.

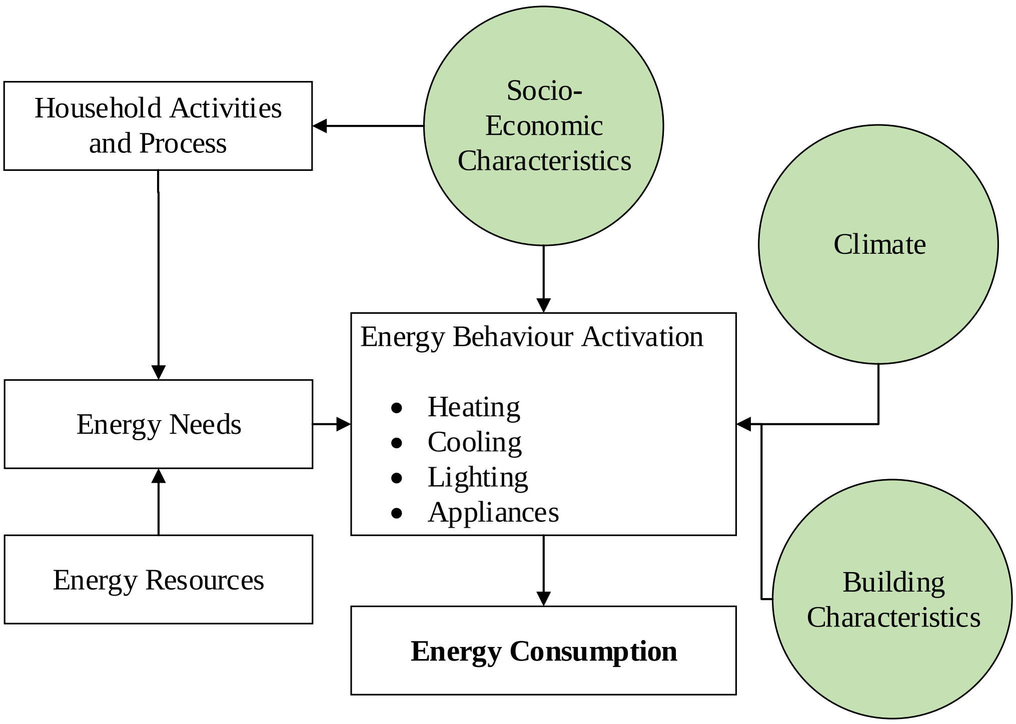

Figure 2.3 The existing chain between occupants' energy use behaviour and building energy consumption
(Adopted and modified from (Lopes et al. 2015))

Different factors such as environmental factors, building and system related characteristics (e.g. dwelling size and its energy efficiency, households' socio-economic characteristics, etc.) affect the existing relationship in the chain. Energy behaviours are referred to actions, which result in energy consumption including investment (e.g. purchasing new equipment and the choice of occupants to buy energy efficient appliances), maintenance (e.g. repair, maintenance, improving energy consuming appliances including the building), energy use behaviour (e.g.

day to day usage of building and equipment), management and provision of energy resources (e.g. planning time shifting activities to save energy, use of renewable sources of energy, etc.) (Lopes et al. 2012). In other words, energy behaviours are shaped by diverse personal and contextual factors, which are addressed differently in different disciplines. Due to its complexity and unpredictability, occupant behaviour is known to be the main cause of the discrepancy between the predicted and actual energy consumption in buildings (Valentina Fabi et al. 2013). Some studies, however, claimed that the design of building envelope plays a predominant role in adjusting occupants energy use behaviour and subsequently, the energy performance of a building (Valentina Fabi et al. 2013). With the possibility of enhancing the design of building physics (e.g. having a massive envelope, a closed façade and fixed shadings), therefore, the direct influence of occupants on the building energy demand can be minimised, which subsequently results in a more realistic outcome from simulation tools (Valentina Fabi et al. 2013).

Adjusting window position is known to be one of the most common adaptive actions mostly in the case of naturally ventilated buildings (Yun et al. 2009). Occupants' window opening behaviour is affected by a complex combination of their physical, comfort and behavioural models (Markovic et al. 2018). Even when the local climate is extreme, the right application of right building material and proper ventilation could passively modify the condition for occupants' thermal comfort (Ogoli 2003). Ventilating buildings affect the absolute temperature of the space (Aste et al. 2009). Adopting appropriate ventilation strategies reduces a building energy demand in summer (Aste et al. 2009). An unventilated space is significantly hotter in summer than the one constantly ventilated (Slee et al. 2013). In cold climate, however, buildings are ventilated only to let the fresh air in, not to heat or cool the building (Karlsson et al. 2013).

The importance of night-time ventilation for reducing the mean room temperature was the focus of many studies (Schulze and Eicker 2013; Pfafferott et al. 2003). In Germany, night-time ventilation reduced the day-time room temperature by 1.2 K (Pfafferott et al. 2003). In Belgium, performing night stack in a high thermal mass building reduced the daily cooling demand by 40% (Gratia and De Herde 2004). Some studies established that a combination of night-time ventilation and thermal mass is an effective passive cooling strategy (Reardon and Clarke 2013). For example, in a building with heavy thermal mass, night-time ventilation lowered the indoor temperature by 3– 6 °C with no air conditioning system (Shaviv et al. 2001). Nevertheless, other studies suggest that when there is low internal loads and heavy thermal mass, the impact of night ventilation is insignificant (Landsman 2016). Even buildings with lighter thermal mass can benefit from night-ventilation. For example, a maximum reduction of 3.9 °C achieved in a light-weight construction with an Air Changes per Hour (ACH) of around 10 (Wang et al. 2009).

Studies on modelling occupants' window opening behaviour can be divided into three groups (Fabi et al. 2013). The first group focus on the temporal aspects of window control (occupant arrival and departure, and evolution gave a particular window state). The second group, however, focuses on the thermal comfort (indoor temperature, outdoor temperature, adaptive comfort modelling, etc.), while the last group accounts for both (Fabi et al. 2013). Nevertheless, temperature is the most important factor in all three groups. In the case of naturally ventilated buildings, changes in indoor temperature are affected by the variation of outdoor temperature (Fabi et al. 2013). Although it is the indoor temperature that causes the actual discomfort and triggers changes in the window opening status, it is in fact, the outdoor temperature that causes that change. This creates a debate on which temperature is to be taken into account in these buildings.

In a study on assessing the thermal performance of a naturally ventilated building in the UK, Yun et al. (2009) developed a behavioural algorithm based on the probabilistic nature of occupants behaviour. The algorithm generates a time series of window states as a function of the indoor thermal stimuli, the previous window states and time of day. They further implemented their algorithm within a dynamic building simulation tool, ESP-r and found that in buildings with active window user occupants, the summer temperature could be up to 2.6 °C lower than buildings with passive window users (Yun et al. 2009). However, ventilation rate and the cooling effect depends highly on factors such as speed and direction of the wind, ambient temperature, indoor thermal conditions and type and design of the windows (Yun et al. 2009).

Occupants' behaviour with respect to the air conditioning system directly affects the energy performance of a building (Yao 2018). In order to calculate building energy requirements, the current simulation programs mostly use some fixed assumptions about operating the air conditioning systems and their settings as adjusted by occupants. In most of these models, a triggering temperature (turn on temperature) is set, under which, no air conditioning system will be turned on in the models (Yao 2018). However, this does not comply with real conditions, taking into account the stochastic nature of occupants' behaviour and change of their preferences over time. Using a combination of measured data, statistical analysis and logistic regression, Yao (2018) developed a stochastic behavioural model, which calculates the probability of time and temperature above which occupants turn on the AC and when they may turn off the system in a dwelling in Ningbo, China. Through incorporating this model into EnergyPlus, he found that the cooling energy requirements calculated using energy standards and assumptions over-estimates the cooling load and the total cooling energy requirements by 113% and 5.6 times respectively (Yao 2018).

The potential savings of energy behaviours may reach 20%, but values differ up to 100% between different studies (Lopes et al. 2012). In was found that the majority of the existing literature evaluated the influence of occupants' behaviour on the building energy performance in the form of standalone case studies, which to a certain extent, makes their outcomes case-dependent. As a result, the factors that might be found to be effective in one study may not be significant for another study. For example, using a sample of 128 residential households in Portuguese urban areas, Lopes et al. (2012) found that a significant correlation exists between the average daily electricity consumption in the households and the factors including weekly washes, stage of life, weatherising need, the households level of knowledge, energy-intensive appliances, and households lifestyle. In Europe, a combination of different energy efficiency strategies such as feedback, energy audits or combination of different strategies may result in energy savings of between 5-20% (Lopes et al. 2012). In the UK, Gill et al. (2010) performed a post-occupancy evaluation of 25 newly constructed low-energy dwellings and found that energy efficiency behaviour mainly affects the space heating energy consumption by 51%. The influence on electricity and water consumption was, however, relatively lower, accounted for 37% and 11% of the variance respectively (Gill et al. 2010).

2.2 Occupants thermal comfort in residential buildings

By increasing urbanization and accordingly the increase in the urban density of buildings in developed countries, the amount of time people spend in buildings significantly increases (80% - 90% of their time) (Rupp et al. 2015). Therefore, occupants' indoor comfort has to be taken into account at different stages of building design and construction. Compared to other comfort measures including thermal, visual and acoustic, thermal comfort is ranked by building occupants to be of greater importance, which highly influences the overall satisfaction with the Indoor Environment Quality (IEQ) (Frontczak and Wargocki 2011). Individual's perception of thermal comfort varies depending on diverse parameters such as physical boundary conditions to the adaptation capability of occupants as well as other difficult to measure variables (Castaldo et al. 2018). There are two types of differences associated with comfort: inter-individual and intra-individual (Wang et al. 2018). Inter-individual differences refer to the differences in the perception of comfort by different individuals. The intra-individual differences, on the other hand, points at different perceptions of comfort by the same person in the same environment at different points of time (Wang et al. 2018).

ASHRAE 55 defines thermal comfort as “the state of mind that describes the satisfaction with the indoor environment” (55-2010 2010). ASHRAE uses seven-point scale thermal sensation votes of a large group of people expressed between -3 to +3, which are self-reported perceptions (55-2010 2010). The ASHRAE seven-point scale with a constant unit of measuring human thermal comfort has been challenged by a number of researchers. For example, Schweiker et al. (2017) claimed that the ASHRAE seven-point scale is suitable for describing the one-dimensional relationship and cannot precisely describe human’s thermal comfort, which is affected not only by physiological factors but also by the psychological phenomenon (Schweiker et al. 2017). Djmila (2017) modified the concept of ASHRAE 7-points scale by dividing it into three groups:

(i) Vote that was made between the seven points of the ASHRAE scale (continuous scale),
(ii) Votes that were made on the major seven points of the ASHRAE scale, and
(iii) Votes that were made strictly according to the seven-point ASHRAE scale (discrete scale).

Indoor thermal comfort has been approached in two ways: steady-state and adaptive thermal comfort (Rupp et al. 2015). The first approach, which developed as early as the 1970s by Fanger for air-conditioned spaces based on the heat balance model of the human body is the most widely used thermal comfort index for assessing indoor thermal environments (Fanger 1982). Through using limited experimental data collected in a controlled climate chamber under the steady-state condition, Fanger used Predicted Mean Vote and (PMV) and the Predicted Percentage Dissatisfied (PPD) to predict the mean thermal sensation of a group of people (Rupp et al. 2015). The factors that are taken into account in the PMV include human metabolic rate, clothing insulation, air temperature, air humidity, mean radiant temperature and airflow velocity (Zhang, Yang, et al. 2018). Having relatively lower expectations, occupants in non-air-conditioned buildings in warm climates may sense the warmth as being less severe than what the PMV predicts. Therefore, the PMV model was later extended to the non-air-conditioned buildings in warm climates by incorporating an expectancy factor. (Ole Fanger and Toftum 2002). Furthermore, PMV which was developed based on the laboratory experiments (climate chamber), was not capable of simulating the factors such as solar radiation, air velocity, etc. which significantly affect occupants' thermal comfort (Zhang, Yang, et al. 2018). Corrected Predicted Mean Vote (CPMV) was used instead, to evaluate indoor thermal comfort in solar conditions (Zhang, Yang, et al. 2018).

However, PMV models can be seriously misleading when used to predict the mean comfort votes in everyday conditions, particularly in warm environments (Humphreys and Fergus Nicol 2002). This model is predominantly based on steady-state and human body heat balance theory (occupants' metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity). Factors such as behavioural, physiological, and psychological adaptive processes, which significantly affect the comfort temperature are not taken into account in the PMV models (Djamila 2017). This has been challenged by another approach known as adaptive thermal comfort (Nicol and Humphreys 2002; Humphreys et al. 2013; J. F. Nicol and Humphreys 2009). According to this model, if any changes in the built environment happen that creates discomfort in naturally ventilated buildings, people react in ways to restore their comfort (Rupp et al. 2015). Building users in this model are assumed to be active to their built environment (Dj et al. 2012), and who in some studies are referred to as the controllers of their surrounding environment (Alves et al. 2015; Rupp et al. 2015).

Adaptation is a two-way process. On one hand, people adapt themselves to their thermal environment by making changes to their clothing insulation or activities. They also adapt their thermal environment to their current requirements by such actions as opening windows, adjusting the blinds and turning on heating or cooling system (Humphreys et al. 2013). A wider range of thermal comfortable conditions and subsequently, a closer relationship with the external climate is, therefore, acceptable by the building users in the adaptive model.

Psychological and physiological characteristics of individuals differ. Except for physical conditions, thermal comfort is also affected by individual's preferences (Frontczak and Wargocki 2011). Therefore, not everyone is satisfied with the same condition (Schellen 2012). This may cause different responses to the existing thermal discomfort. On the other hand, humans respond to any perceived stimuli in an attempt to stay in balance. With diminishing body's natural ability to respond to environmental challenges, maintaining a narrow temperature band may negatively affect human health (Shipworth et al. 2016).

Some studies reported that in buildings where occupants have personal control over the air conditioning system, they will have a lower neutral temperature as well as the lower tendency for changing their thermal condition (Luo et al. 2014; Cao et al. 2014). In their study, Luo, et al. (2014) further claimed that a lower degree of personal environmental control did not necessarily equate to lower thermal expectations.

Gender and age are the two major sources of differences in individual's thermal comfort (Wang et al. 2018). Females are found to be more critical about their sensation of thermal comfort in an indoor environment and more sensitive to deviations from an optimum comfort environment (Lee and Choi 2004; Lu et al. 2018; Karjalainen 2012; Tiller et al. 2010; Wang et al. 2018). Kuntz et al. (2018) examined the comfort temperature for men and women in two office buildings, one air-conditioned and one naturally ventilated and/or air-conditioned and found that the overall comfort temperature was higher for women than that for men and the difference was more significant in the fully air-conditioned building (24.2 °C and 23.4 °C for women and men respectively). The study further revealed that in the building, which was ventilated using a combination of natural ventilation and air-conditioning system, the comfort temperature was lower for both men and women when the building was naturally ventilated compare to the same building during air-conditioning operation (Maykot et al. 2018). In a meta-analysis to understand whether female gender is a predictor of thermal dissatisfaction, females were 1.74 times more likely to express thermal dissatisfaction (ratio: 1.74, 95% confidence interval) (Karjalainen 2012). Li et al. (2008) studied the gender differences in thermal comfort for Chinese people based on the skin temperature and thermal comfort vote, with no significant difference on neutral temperature and found that females prefer a slightly warmer environment and therefore, their comfortable operative temperature is higher than that of men, mainly due to their lower skin temperature than their male counterparts. The study further revealed that females are more sensitive to temperature and less sensitive to humidity than males (Li et al. 2008). Others, however, found a very weak relationship between the age, gender and tenure and individual's perception of thermal comfort in the indoor environment (Pellerin and Candas 2003; Brounen et al. 2013).

Limited literature studied the influence of education on the individual's perception of thermal comfort in the indoor environment (e.g. (Frontczak and Wargocki 2011)). While some studies undertake survey among human participants, others review the results of survey-based studies on whether or not factors unrelated to indoor environment including occupants' education level play a role in the relationship between these factors and their perception of thermal comfort. For example, Yamtraipat et al. (2005) conducted a large questionnaire survey among 1520 volunteers (620 male and 900 female) from different climatic regions of Thailand and concluded that Thai people who possess higher educational degrees do prefer lower indoor temperature compared to those who are less educated. Interestingly, the study found that the neutral temperature of post-graduate level was the lowest (around 25.3 °C), while that of the lower education groups was higher (around 26.0 °C). This might be, to a great extent, affected by the individual's knowledge about how higher indoor temperature as a result of using a heating system affect the household energy consumption.

As an individual grows older, the body's response to temperature reduces (Djamila 2017). Some studies found that as the ability of the body to thermoregulate declines with age, the acceptable temperature range of thermal comfort is narrower in the elderly (Cheng and Hwang 2008; Hwang and Chen 2010; Hoof and Westerlaken 2013). Djamila (2017) reviewed the existing literature on the predictors of indoor thermal comfort and found that due to having different activity levels, thermal requirements of younger individuals differ from that of the elderly. In the study on the impact of moderate temperature drift on thermal comfort, Schellen et al. (2010) found that thermal sensation of elderly was lower than their younger counterparts with the elderly often preferred relatively a higher indoor temperature. The study further revealed that the thermal sensation of the elderly was only influenced by the indoor air temperature. In younger adults, however, it was also related to skin temperature (Schellen et al. 2010). In an experimental study on the thermal comfort requirements taking into account the subjects age, Tsuzuki and Ohfuku (2002) found that the metabolic rate for the elderly was only 70% that of the younger group as well as they have reduced warmth sensitivity in cold seasons and similarly reduced cold sensitivity in hot seasons. With reduced metabolic heat production, weaker skin vasodilatation and vasoconstriction and as a result, a lower skin temperature, the elderly subjects' would have a lower skin-to-ambient temperature gradient (Tsuzuki and Ohfuku 2002).

In order to address the above differences in perceiving thermal comfort by individuals, Wang et al. (2018) suggested that a paradigm shift is required from centralised air-conditioning systems to personalised systems. This is, however, not possible except through collecting individual physiological and psychological responses to the thermal environment, predicting individuals comfort by using machine learning algorithms and accommodating individual differences with Personalised Comfort System (Zhang et al. 2015). With the help of rapid technological advancement, this will to a great extent, minimise the thermal discomfort from individual differences in shared spaces and makes the satisfaction of all building users possible (Wang et al. 2018).

2.3 Housing Affordability and Low-income Households

Worldwide, housing costs can be a substantial financial burden to households. Nevertheless, in the majority of the countries, low-income households face a higher burden than their better-off peers (OECD - Social Policy Division - Directorate of Employment 2018).

Housing affordability is one of the key measures in describing the socioeconomic stability and development of a state (Dumičić et al. 2015). In European metropolitan areas, new construction is not keeping up with demand (The World Bank 2018), and hence, housing affordability in these countries is significantly declining.

Similar to other countries, housing is one of the basic requirements for health and wellbeing of Australian households by providing shelter, safety, security and privacy for individuals. Failure of the private market to provide affordable housing for low to moderate-income households, followed by the ever-increasing housing prices place a negative impact on Australian households with insufficient income (Steven and Rachel 2012). In Australia, state and territory governments are the focal points for funding, delivering and managing the affordable housing around the country to ensure that all Australian residents have access to secure, affordable and appropriate housing (Australia. Department of Social Services 2017). Government plays a focal role in the Australian housing market at two levels including structural level and direct interventions in the market (Australia. Department of Social Services 2017). Governments establish a policy framework by which the overall market operates. When either the market is unable to provide appropriate outcomes for specific groups of people, or where governments are seeking to achieve specific outcomes, they will directly intervene in the market through different schemes (Australia. Department of Social Services 2017). Since the early 1980s, housing affordability in Australia has declined (Thomas 2019). Australian governments and community-based organisations support low-income households to meet their housing costs through a range of programs called housing assistance (Australia. Institute of Health and Welfare 2018b). These programs include:

(i) Social housing with discounted rent based on tenant income
(ii) Assistance with rent in the private rental market
(iii) Home purchase assistance, or
(iv) Provision of services to assist in obtaining accommodation or sustaining tenancies

Social housing is the longest-standing and largest-scale Australian government intervention to assist people who are unable to sustain themselves in the private housing market (Government of Western Australia Housing Authority). It provides a stable, affordable safety net for people who are on low-incomes and have a range of other detriments. However, despite the growing number of Australian households, the number of social housing dwellings hasn't grown enough to maintain the balance (Australia. Institute of Health and Welfare 2018b).

Social housings are allocated based on the applicants' priority needs. Households are considered on the greatest needs if they were either experiencing homelessness or were at risk of homelessness at the time of allocation (Australia. Institute of Health and Welfare 2018b).

These households spend less time on waiting lists. Social housing differs from that of privately rented dwellings in three ways including:

(i) Allocation criteria

(ii) Discounted rate

(iii) Long-term tenancy

There are four types of social housing in different Australian states and territories (Australia. Institute of Health and Welfare 2016b) including:

I. Public rental housing

II. Mainstream community housing

III. State-owned and managed Indigenous housing (SOMIH); and

IV. Indigenous community housing

Table 2.1 presents the number of social housing dwellings in different Australia's states and territories in June 2017 (Australia. Institute of Health and Welfare 2018b).

Table 2.1 Total households in social households in different states across Australia

Social housing program	NSW	Vic	Qld	WA	SA	Tas	ACT	NT	Total
Dwellings number									
Public housing	110,221	64,170	51,263	33,836	37,281	7,065	11,077	5,000	319,913
SOMIH[(a)]	4,608	. .	3,324	. .	1,734	223	. .	5,032	14,921
Mainstream community housing*	34,398	14,278	11,512	7,847	7,484	6,115	883	385	82,902
Indigenous community housing*	5,066	1,720	5,232	2,649	934	76	. .	2,248	17,925
All programs	154,293	80,168	71,331	44,332	47,433	13,479	11,960	12,665	435,661
Dwellings (%)									
Public housing	71.4	80.0	71.9	76.3	78.6	52.4	92.6	39.5	73.4
SOMIH[(a)]	3.0	. .	4.7	. .	3.7	1.7	. .	39.7	3.4
Mainstream community housing	22.3	17.8	16.1	17.7	15.8	45.4	7.4	3.0	19.0
Indigenous community housing	3.3	2.1	7.3	6.0	2.0	0.6	. .	17.7	4.1
All programs	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(Source: AIHW National Housing Assistance Data Repository 2018)

Public housing provides appropriate, affordable and accessible housing for low-income households who are in housing need. This group of rental housing encompasses the publicly owned or leased dwellings, which are administered by state and territory governments. Nearly 206,000 applicants were on public housing waiting lists Australia-wide in 2013-14 (Australia. Institute of Health and Welfare 2016a). Although both public and social housing aim at providing affordable housing for the people in need, allocation criteria vary within the two groups (Umbro 2016). The difference between public housing and social housing is housing ownership. In public housing, the property is owned by a central or local government authority. However, social housing refers to rental housing, which might be owned or managed by the government, a not for profit organization, or a combination of the two. Community housing in Australia includes both social and affordable housing. Mainstream community housing, which is managed by not-for-profit organizations offer offers short-, medium- and long-term tenure to low-income individuals and families. The Aboriginal housing or the State-Owned and Managed Indigenous Housing (SOMIH) is, on the other hand, administered by the state and governments. This group of affordable housing is provided to households that have at least one indigenous member. The indigenous community housing that is managed by community housing organisations for indigenous tenants is funded in a variety of arrangements by state, territory and Australian governments. Note that VIC, ACT, and WA, do not have SOMIH programs.

Community housing sector plays a significant and growing role in providing housing support to Australian households. It is in fact, following a similar pattern as in North America and Europe (Clean Energy Finance Corporation 2016). Factors such as growing capacity of the community housing sector to raise private finance, providing housing in arrangements and locations in accordance with tenants' requirements, out-sourced housing services management and project development, and rent assistance from the Australian Government for supporting private rental housing, etc. are some of the causes of the growing role of community housing sector in Australia.

2.3.1 Energy Status of Low-Income Households

Raising energy prices is increasing concerns in many developed and developing countries. In order to develop appropriate policy solutions for providing secure, sustainable, competitive, and affordable energy for households, it is required to better understand who is most affected by energy poverty. As discussed in Chapter 1, energy poverty refers to a situation when households lack a socially and materially necessitated level of energy services - either do not have access or cannot afford (Bouzarovski 2014). The disadvantaged households struggling with the problem of energy poverty often spend more than 10% of their disposable income on energy services (OECD 2018). Low-income households are affected by persistent barriers to energy efficiency and hence, they are known to be more disposed to energy poverty (Ugarte et al. 2016). While these households have greater difficulty paying their bills, which may result in involuntary disconnections when the payments are due, they often need to curtail their energy consumption to ensure the payments can be made. This, in return, compromises their healthy thermal comfort (Moore et al. 2017). Some studies, however, revealed that most low-income households keep up with their energy bills through trading off their basic needs including food and healthcare to be able to pay their bills (European Parliment 2016).

Social housing is becoming a major area of interest for energy researchers (McCabe et al. 2018). Low-income households live in social housing have a legal responsibility to pay their rent as well as other charges including charges for electricity and gas (Esmaeilimoakher 2018). Due to the barriers imposed by their income, low- income households mostly live in older and non-refurbished buildings (European Parliment 2016). The low energy performance of these dwellings is further enlarged by the use of energy inefficient appliances in these households (European Parliment 2016). Since these low earners often cannot afford to replace their old appliances with new and more efficient appliances, it ultimately leads to higher energy needs, higher energy consumption, and hence greater energy expenditure to the extent that they often need to spend more for the same level of comfort experiencing by higher-income households with more efficient appliances (Bouzarovski 2014). A combination of energy inefficient building and less efficient appliances, household's low income and high energy bills create a vicious cycle that intensifies energy poverty in low-income households. **Figure** 2.4 shows the cycle of energy poverty in low-income households.

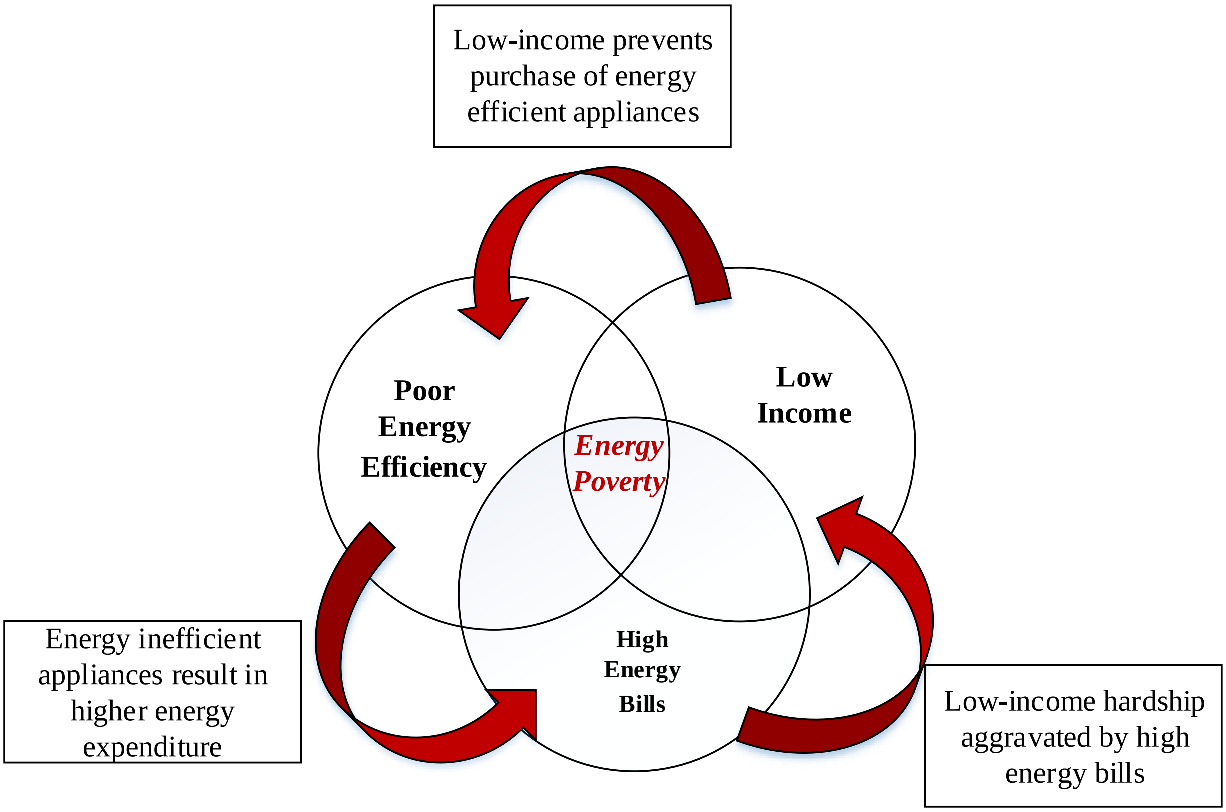

Figure 2.4 Cycle of energy poverty

(Adopted from: (European Parliment 2016))

Although numerous policies have been enacted aimed at energy conservation as well as carbon reduction in the housing sector, and despite it is established that most low-income households encounter difficulties paying their utility charges, there are fewer examples of policies that specifically focus on social housing arrangements (Moore et al. 2017). Applying energy efficiency policies that are explicitly designed for low-income households (instead of general social policies) could be more effective in assisting these households to manage their energy consumption, which ultimately results in eradicating or reducing energy poverty (Ugarte et al. 2016). The providers of social and affordable housing establish different arrangements to ensure that their tenants can maintain comfortable and healthy living conditions while affording their energy bills and other basic necessities such as food, healthcare, etc. (Cauvain and Karvonen 2018). The landlord-tenant relationship, which aims to accommodate this barrier for the tenants by repaying the installation cost with increased rent payments is one of the many examples of facilitating the issue for low-income households (NSW Department of Family and Community Services 2015). Various measures are designed in some EU member states aiming to protect vulnerable households against energy poverty including (OECD 2018):

(i) Financial support
(ii) Investment support
(iii) Consumer protection
(iv) Raising public awareness

Unlike financial support that mostly focuses on short-term relief, investment support, consumer protection, and raising public awareness aim at longer-term remedies such as improving the energy efficiency of building stock and home appliances, discounting vulnerable customers and improving public understanding energy-efficiency measures (OECD 2018).

Improving energy efficiency can reduce the reliance of building on mechanical heating and cooling and improve financial and health and well-being outcomes (Moore et al. 2017), (European Parliment 2016). In addition to reducing primary or final energy consumption and lowering GHG emissions, improving energy efficiency results in improved thermal comfort, positive health and social outcomes (European Parliment 2016; Clean Energy Finance Corporation 2016). These outcomes are more tangible in low-income households. For example, in the state of Victoria in Australia, residents of energy efficient houses purchased 45-62% less electricity and had lower utility bills, which resulted in financial savings of $1,050/year (Moore et al. 2017). Lack of energy efficiency is one of the main factors, which increases vulnerability to energy poverty (Bouzarovski and Petrova 2015). Overall, the impact of energy efficiency in low-income households can be split into three categories, including (Ugarte et al. 2016):

(i) **Environmental impact-** Reduced energy consumption and GHG emissions;

(ii) **Economic impact-** Cost savings, employment, energy security, etc.;

(iii) **Social impact-** Mitigation of energy poverty, improved health, occupants comfort, and wellbeing.

Despite the proven benefits of improved energy efficiency, diverse barriers to energy efficiency exist, which prevents individual and organizations to be more energy efficient (Schleich 2011). These barriers encompass (but are not limited to) behavioural, informational, economic and administrative impediments and result in energy gaps between potential energy efficiency measures and the measures actually implemented in real life (Thollander et al. 2010).

Lack of information, low educational level, and lack of access to external capital prevent low-income households from being more energy efficient (European Parliment 2016). For the housing providers, however, capital costs, split incentives (when the capital costs of an investment is paid by one party and this investment will result in reducing the cost for the other party who is responsible for the operating costs), and conflicting or complex information are only some of the causes that make enhancing energy efficiency inaccessible (Moore et al. 2017). Financial constraints are the key factors preventing social housing organisations from becoming more energy and water efficient (Urmee et al. 2012). Poor design of buildings in terms of energy efficiency, old properties, which are not very water and energy efficient, inappropriate or inefficient energy efficiency measures, lack of practical advice to assist the households to be more energy efficient, excessive use of electricity (where tenants do not switch off lights or appliances when not in use), installing inefficient lighting fixtures, energy inefficient appliances such as electric bar heaters, higher cost of energy efficient appliances, information barrier, and concerns over retrofitting old units to new technology and safety restrictions against installation of technology on roofs are some of the other factors making it difficult for some social housing providers to identify energy and water efficiency opportunities (Urmee et al. 2012; NSW Department of Family and Community Services 2015). Although the main goal of these organizations is providing as much housing each year as their budgets may allow, any additional costs may affect this responsibility, there are significant benefits for tenants in low-energy houses, which in return, reduce costs in other associated departments and broader society. Furthermore, the additional costs spending on enhancing the buildings energy performance could be reduced by at least 50% through the cost efficiencies in the design, materials, technologies and learnings from the process (Moore et al. 2017).

Energy Status of Low-Income Social Households in Australia

In Australia, the share of energy costs relative to Disposable Household Income (DHI) has increased by 32%, from about 1.7% in 2008 to 2.3% in 2018 (Australia. Bureau of Statistics 2018a). Unlike higher-income households, which spend an average of 1.5% of their income on energy costs, the lower income households are paying unreasonably more of their income on energy (nearly 6.4% or even more) (ACOSS 2018b). Low-income households are in fact, paying much higher energy costs relative to their income, which resulted in an increase in inequality and poverty (ACOSS 2018b). Survey data from the Australian Bureau of Statistics (ABS) revealed that households that receive most of their gross weekly income from government pensions spent an average of $61/ week on total energy costs (Australia. Bureau of Statistics 2012). This is close to 10% of their income. With the majority of social households rely on pensions and other government allowances or other government benefits, these households are spending more of their income on energy (**Figure** 2.5) (ACOSS 2018b).

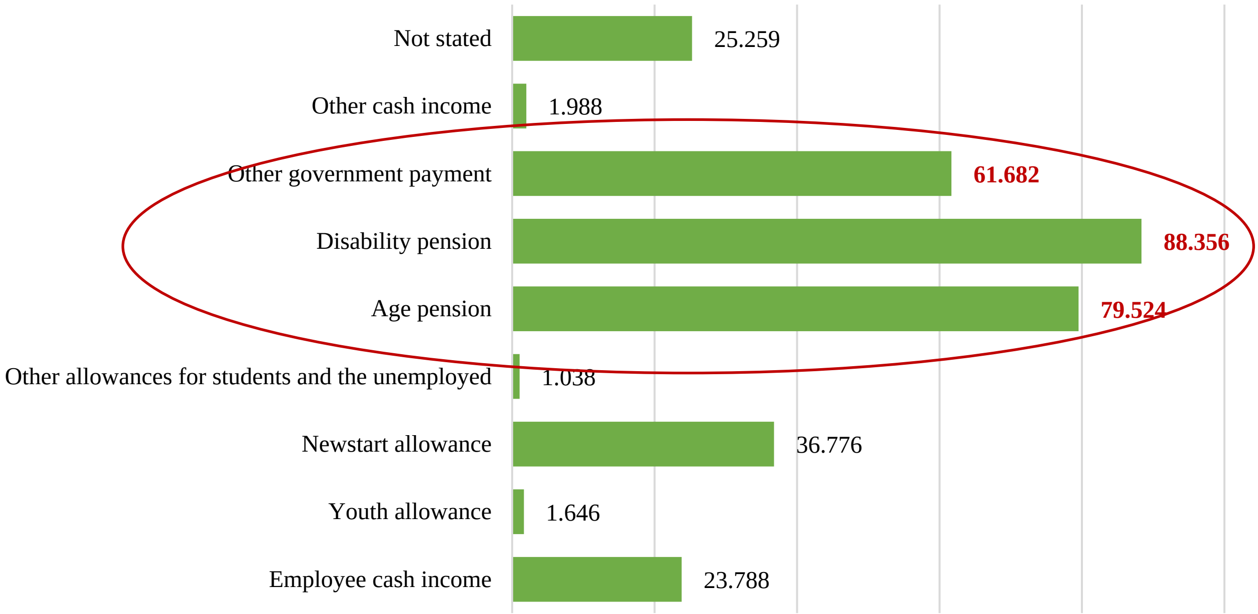

Figure 2.5 Sources of income of social housing households

(Source: AIHW 2018)

Nearly two-thirds of the most low-income households live in dwellings that are more than 20 years old (Clean Energy Finance Corporation 2016). The minimum energy efficiency requirements were, however, proposed as part of the Building Code of Australia (BCA) in 2000, and enacted in 2002, suggesting that the dwellings constructed after this time should meet the energy efficiency standards (Urmee et al. 2012). Therefore, it is less likely that the older dwellings were designed to be highly energy efficient. **Figure** 2.6 shows the share of households in by age of dwelling.

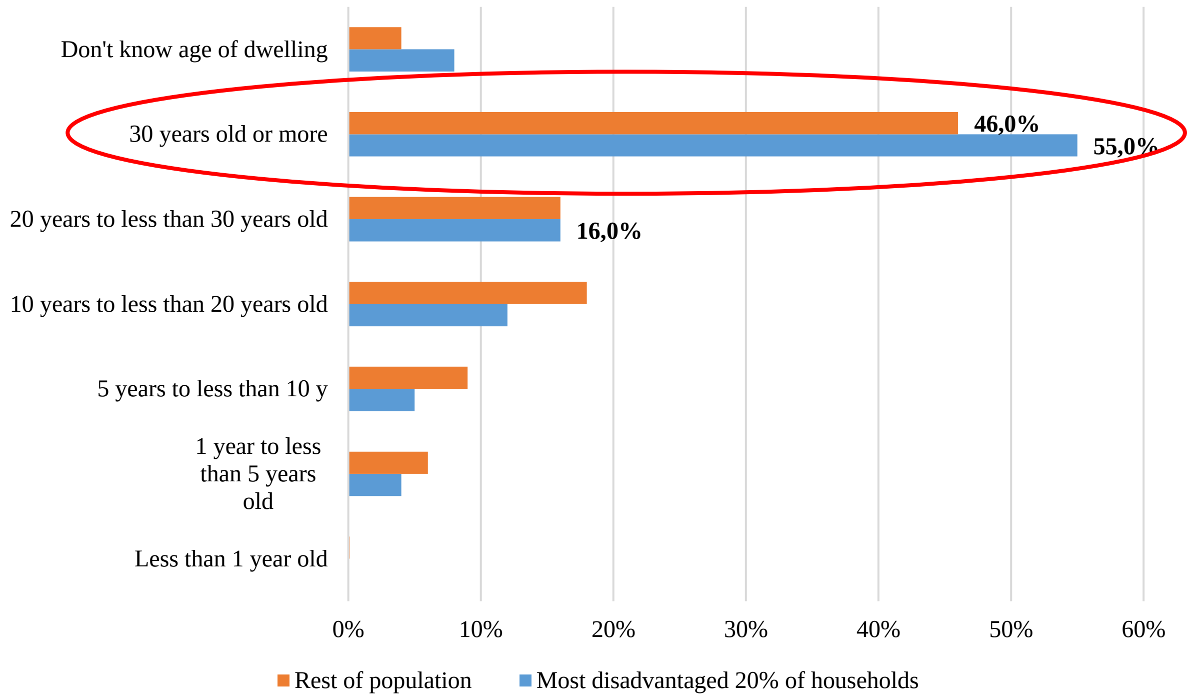

Figure 2.6 Breakdown of households in each category by age of dwelling

(Source: AIHW 2018)

A significant proportion of the heat gain or loss in buildings is caused by heat transfer through walls, roof, ceiling, floor, and glass etc. which are referred to as the building fabric or envelope. Thermal insulation is an important technology, which aims to reduce energy consumption and provide indoor thermal comfort to occupants by preventing heat gain/loss through the building envelope.

Incorporating energy efficiency measures during construction is often cheaper than retrofitting existing dwellings (McGee 2013). A 2011 survey on the 3377 community housing dwellings across Australia found that only about one-fifth of the surveyed dwellings were highly energy efficient (Urmee et al. 2012). The energy efficiency status of the rest was either good (33%), average (24%), or poor (24%). A significant percentage of these dwellings (around 90%) had no floor or wall insulation and 52% did not have any type of insulation (Urmee et al. 2012). These dwellings, which were mostly more than ten years old, were built prior to enacting the

BCA energy efficiency regulations, which require floor and wall insulation. **Figure** 2.7 shows the percentage of dwellings with floor, roof and wall insulation in this study.

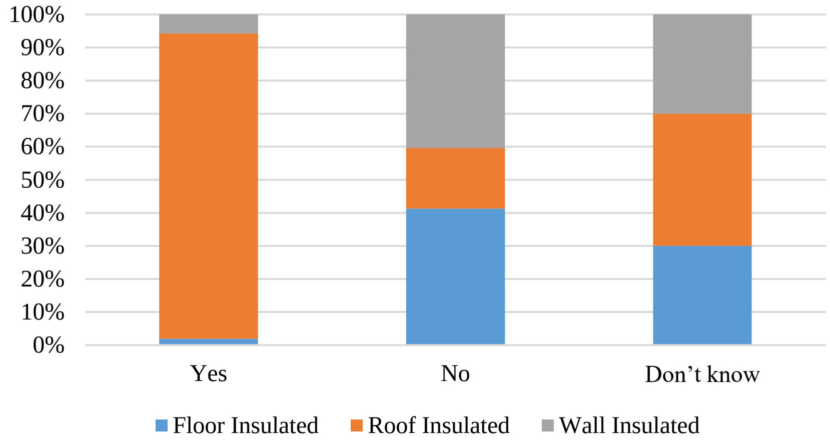

Figure 2.7 Insulation of floors, walls and roof

(Adopted from: (Urmee et al. 2012))

The large stock of (existing) inefficient social housing dwellings suggests that there is a significant investment opportunity in refurbishing these dwellings as well as replacing inefficient appliances used in the households (e.g. refrigerator and oven, which contribute to around 30% of domestic energy use) with new and more efficient appliances to improve energy efficiency in this sector (Urmee et al. 2012). While the immediate benefit from the improved energy efficiency of social housing dwellings targets the tenants through lower energy bills and improved occupants' thermal comfort, the upfront costs of improving energy efficiency are to be paid by the housing providers (Clean Energy Finance Corporation 2016). If tenants of social dwellings decide to improve the energy efficiency of their home through modification of the building fabric at their own cost, they need to obtain approval of the housing provider organizations (Gabriel et al. 2010). The gains in asset value from enhancing the energy efficiency of properties are, however, seized by the housing providers (Gabriel et al. 2010). Although improving the energy efficiency of the dwellings could concurrently assist the tenants as well as the housing providers, financial constraints are often the main barrier preventing the majority of community housing providers from becoming more energy and water efficient (Urmee et al. 2012). Therefore, for some social housing providers, sustainability and affordability could not be simultaneously achieved in the social housing sector (Urmee et al. 2012).

2.4 Tools For Evaluating the End-Use Energy Consumption in Buildings

For energy efficient design, labelling, scoring, rating, and retrofit efforts to succeed, an accurate analytical tool is required, to precisely predict the relevant metrics (B. Polly et al. 2011). As discussed in the above sub-sections, significant opportunities exist in refurbishing the social housing dwellings and improving their energy efficiency as well as in designing more energy efficient social dwellings. As such, thermal modelling of both existing as well as new buildings can be performed as an effective step towards enhancing the energy efficiency in this sector.

Energy modelling of a building is the process of virtual or computerized simulation of the building in order to calculate its energy requirements (B. Polly et al. 2011) as a function of different input parameters. Building Energy Simulation (BES) provides a clear understanding of the building energy consumption pattern (Shabunko et al. 2018). By changing the building design, fittings and appliances, and occupancy schedules, different scenarios can be developed, which enables the modeller to choose the optimum scenario before taking any practical action. Building energy performance is studied at various levels of resolution ranging from whole-building annual thermal performance assessment to those with higher resolution using monthly, weekly, daily, or even hourly data (Wilde 2014). The intense amount of input data, which is required for developing the models in some cases, makes the process to be time-consuming and costly. Energy modelling of buildings is performed due to different reasons. Some of the key areas are:

- Design energy-efficient homes

- Forecast buildings energy demand
- Produce labels, scores, and ratings
- Retrofit existing buildings for further energy and cost savings
- Quantify energy saving potentials through adaptation of new technologies
- Determine cost and performance criteria for new energy-efficiency technologies
- Provide quantitative analysis and data to support programmatic and policy-related decisions

The success of any of the above efforts depends largely on the accuracy of the analysis performed for each task as well as the capability of the modelling tool. Selecting an appropriate tool is in fact, influenced by different factors. The purpose of modelling, nature of the problem, limitation of time and resources, the expertise of the modeller, and capability of a specific modelling tool are some of the key factors affecting the selection of an appropriate modelling tool (Lopes et al. 2012).

Worldwide, different methods and techniques are used for evaluating the energy performance of buildings mainly as a function of input parameters. Availability of required data, model focus and purpose, and assumptions made by the modelling tool determine the level of detail of input parameters (Swan and Ugursal 2009b). In some countries, simulating building energy performance to demonstrate compliance with building energy codes and standards enacted is a prerequisite for getting the building documentation approved (B. Polly et al. 2011). However, in other countries, the process is optional, merely to create insight into building energy performance or evaluating the influence of different energy efficiency measures incorporated into building design on its energy performance. With different modelling tools having different capabilities and applicability, an appropriate modelling tool is to be selected that suits the purpose of the modelling and at the same time, take the most advantage of the available information. This information may include climate data, physical characteristics of buildings, occupants' socio-economic characteristics as well as their energy use behaviour, appliances, historical energy consumption, and/or macroeconomic indicators (Zhang, Robinson, et al. 2018). The strength of modelling tools is directly linked with their capability to estimate and correlate a wide range of input parameters to the building energy performance (Shabunko et al. 2018). According to the existing literature, two fundamental classes of modelling are used for evaluating buildings energy performance: 1) top-down models and 2) bottom-up models (Zhang, Robinson, et al. 2018). **Table** 2.2 summarises the strength and weaknesses of top-down and bottom-up approaches.

Table 2.2 Weakness and draw-back of modelling approaches

	Top-down	**Bottom-up Statistical**	**Bottom-up Engineering**
Examples	Econometric (based on the price and income), Technological (based on the broad features of the housing stock such as ownership of appliances), Mixed models	Regression, Conditional demand analysis, Neural network	Population distribution, Archetype, Sample
Strength	- Easy to develop based on the information provided by macroeconomic indicators - Long-term forecasting in the absence of any discontinuity using simple, aggregated and widely available data - The inclusion of macroeconomic and socioeconomic effects - Simple input information - Encompasses trends	- Encompasses occupant behaviour perceived from monthly bills and survey data - Determination of typical end-user - The inclusion of macroeconomic and socioeconomic effects - Uses billing data and simple survey information	- Model new technologies - Required detailed housing information as input data - No reliance on historical values - Determination of each end-use energy consumption by type, rating, etc. - Determination of end-use qualities based on simulation
Weakness	- Reliance on historical consumption information - No explicit representation of end-uses - Miss to identify the key area of energy improvements - Fail to model advances in technology due to reliance on historical data	- Multi-collinearity - Reliance on historical consumption information - Large survey sample to exploit a variety	- The assumption of occupant behaviour - Detailed input information - Computationally intensive - No economic factors

The selection of the most appropriate simulation tool can to a great extent result in saving the time and cost required for the modelling process. With the intention of choosing a fit-for-purpose modelling tool for our study, which is capable of creating models of sample dwellings, taking into account the project aim, time and different aspects of occupant-related factors that were intended to be evaluated in our study, a number of modelling tools were reviewed and shortlisted including EnergyPlus, and AccuRate Sustainability.

2.4.1 EnergyPlus

Developed by a U.S. federal agency in 1996 and released in 2001, EnergyPlus is a whole-building energy analysis and thermal load simulation program that combines the best features of BLAST and DOE-2 together with new capabilities (Crawley et al. 2001; The US Office of Energy Efficiency and Renewable Energy 2018). Although the initial focus of EnergyPlus was mainly on commercial buildings, its modelling capabilities were then expanded, which enabled it to be used for modelling residential buildings (The US Office of Energy Efficiency and Renewable Energy 2018). The tool is tested according to ASHRAE Standard 140 Methodology (The US Office of Energy Efficiency and Renewable Energy 2018), which comprises of three different types of tests including analytical tests, empirical tests and comparative tests (Office of Energy Efficiency and Renewable Energy 2019).

Apart from being an open source license, EnergyPlus has other features including:

- Variable time steps;
- Built-in template and external modular systems integrated with a heat balance-based zone simulation;
- Ability to model the radiant systems, lighting, and shading;
- Calculate thermal and visual comfort metrics;
- Integrated, simultaneous solutions;

- Sub-hourly, user-defined time steps for interaction between the defined thermal zones and HVAC systems;
- Text-based input-output and weather data files;
- Combined heat and mass transfer;
- Thermal comfort models based on the dry-bulb temperature, humidity and activity level;
- Daylighting controls, which takes into account the effect of reduced artificial lighting on heating and cooling;
- Estimating atmospheric pollutions (Crawley et al. 1999).

Despite its strengths, however, EnergyPlus has the following weaknesses:

- Firstly, it has not been designed with a standard user interface. It is in fact, a simulation engine that can work with other third-party interfaces. This allows the interface designers to take the advantages of EnergyPlus capabilities and produce quality tools for their targeted markets.
- Secondly, EnergPlus neither checks the input to verify its acceptability nor attempts to interpret the results, leaving the user as the focal part of the design and thermal engineering process.

2.4.2 AccuRate Sustainability

AccuRate is a commercial tool comprising of the Chenath simulation engine and a graphical user interface. Together with its previous generations (i.e. CARE, STEP and ZSTEP), the Chenath engine has been developed by CSIRO over five decades (Delsante 2005). Among different NatHERS software schemes across Australia, AccuRate is the benchmark (Chen 2016). For any software to be accredited to be used under NatHERS, it’s is mandatory that the outcome (the thermal energy requirements) be consistent with AccuRate.

NatHERS accredited software are equipped with climate data for different climate zones (overall 69 climate zones). AccuRate and the Chenath engine both use Reference Meteorological Year (RMY) weather files, which are compiled from the Bureau of Meteorology (BOM) raw climate data and give annual averages from the long-term observations for any particular location (Chen 2016). It should be noted that the BOM weather data from 1976 to 2004 is used for the RMY weather files currently used by AccuRate (Chen 2016). **Figure** 2.8 presents the monthly climate data for Perth (Climate zone 13) used by NatHERS software tools.

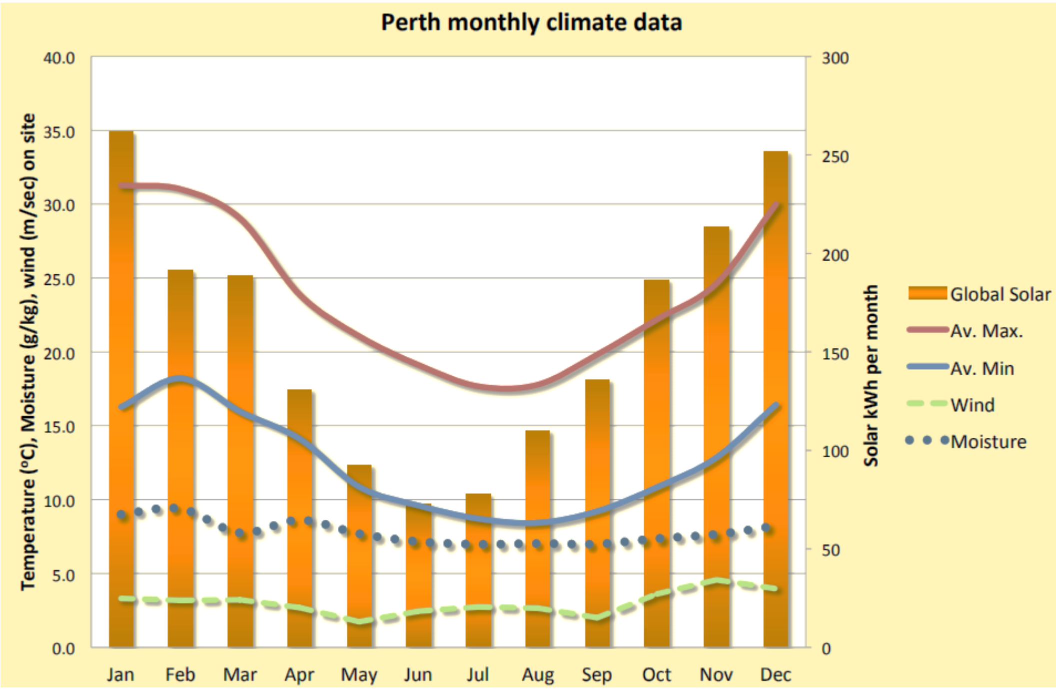

Figure 2.8 Perth monthly climate data used by NatHERS software tools

(Adopted from NatHERS Climate Zones and Weather files)

To create a better insight into the actual building energy performance, AccuRate was further expanded to encompass a number of extra features for non-regulatory purposes. The extended tool is called AccuRate Sustainability. AccuRate Sustainability is run in 2 modes: (1) Regulatory (rating) mode, and (2) Non-regulatory (non-rating) mode.

AccuRate Sustainability in the rating mode only rates the thermal performance of the building envelope. The input data required for modelling a building in the rating mode encompasses basic project data (i.e. project code, building class, dwelling type, climate zone, exposure, etc.), construction of different building elements (i.e. external walls, internal walls, doors, windows, roof, floor, ceiling, skylight, etc.), zones, shadings, and ventilation. In order to improve the software's usability and productivity, data input automation and streamlining features have also been implemented into the software.

Although AccuRate Sustainability in the rating mode takes into account occupants' behaviour due to its strong influence on the heating and cooling energy requirements in buildings, it does not allow the users to modify the assumptions made by the software regarding occupant behaviour. Different aspects of occupant behaviour incorporated into the rating mode as assumptions by the software include:

- Hours of heating and cooling
- Heating and cooling thermostat settings
- Operation of windows and other openings to increase ventilation
- Operation of adjustable outdoor window shading
- Operation of indoor window coverings

Additionally, in the rating mode, AccuRate Sustainability has no provision for supplying/eliminating heat or coolth in different zones of a building. Indeed, rating mode only calculates the star rating as a way of comparing the thermal performance of buildings and is valid only in the case where each building has similar appliances and hours of use. Otherwise, the effect of the design of each building on its thermal performance cannot be compared. As a result of using these assumptions, the heating and cooling energy requirements calculated in the rating mode deviate from that of actual energy consumption in buildings.

In order to mitigate the problem and in response to the limitation of rating mode in regard to its assumptions, mainly about building users and their choice of appliances in dwellings, AccuRate Sustainability – non-rating mode – was developed. Except for thermal performance assessment of building envelope, AccuRate Sustainability in the non-rating mode offers more flexibility through incorporating extra features, called Sustainability Models into models. The sustainability modules include space heating, space cooling, lighting, hot water, and water use. Furthermore, an Embodied CO2 module can also be activated in the non-regulatory mode for user information. **Table** 2.3 summarizes the capabilities of AccuRate Sustainability in both rating and non-rating mode.

Table 2.3 A comparison between AccuRate Sustainability in rating and non-rating mode

	Rating mode	Non-rating mode
Building envelope	✓	✓
Thermal bridging	-	✓
Space heating	-	✓
Space cooling	-	✓
Hot water module	-	✓
Water module	-	✓
Lighting module	-	✓
Embodied CO_2	-	✓

(Source: Accurate Sustainability Help)

Incorporating the sustainability modules into AccuRate Sustainability provides further flexibility to the software especially through incorporating diverse heating and cooling options provided in the AccuRate extensive library, or different types of lighting that might be used in average Australian households, etc. This, to a certain level, takes into account the occupants and their choice of appliances. However, these modules only work for voluntary assessments. In other words, the thermal energy requirements calculated by the software in the non-rating mode and presented in the final report does not take into account the energy consumption by the sustainability modules. These modules are in fact, incorporated into the software only to create a better insight for designers or energy assessors about energy consumption by different appliances that might be used in different households.

Apart from incorporating the sustainability modules through the AccuRate interface, AccuRate Sustainability in the non-rating mode creates even more flexibility by allowing warmth/coolth to be provided or eliminated in different zones of a building. This enables the software to calculate the thermal energy requirements, which is closer to the actual thermal energy consumption in buildings. Additionally, further adjustment mostly with respect to Internal Heat Gains (IHG) and thermostat settings can be made through the input Scratch file to the AccuRate engine. With all these adjustments, the thermal energy requirements calculated in the non-rating mode to a great extent represents the thermal energy performance of the modelled building.

In summary, the thermal energy performance of residential buildings is affected by a wide range of inter-related factors including climate, building characteristics, appliances and services, household attributes, and behaviour and lifestyle of householders. Out of different factors that directly or indirectly affect residential energy consumption, occupant behaviour has been reportedly found to be the most complex factor, which is difficult to be predicted or systematically quantified. The extent of this influence, however, depends on the climatic condition, variation in preferences and lifestyle, occupants' engagement, building automation and thermal properties of dwellings.

Worldwide, different methods and techniques are used for evaluating the energy performance of buildings mainly as a function of input parameters. Availability of required data, model focus and purpose, and assumptions made by the modelling tool determine the level of detail of input parameters. Although numerous complex and case-dependent models have been developed, simpler methods have always been preferred, depending on the aim of the investigation. Two modelling tools were studied including EnergyPlus and AccuRate Sustainability. Based on the scope of the project, available data, time limitation and the aspects of occupants behaviour intended to be incorporated into the models, the Australian benchmark AccuRate Sustainability, was selected for modelling energy performance of the building in this study.

CHAPTER 3

RESEARCH METHODOLOGY

Overview of Chapter

This chapter explains the methodology used in this research in the sense of 'reasoning' of a particular field. The methodology includes the processes of data collection, compilation and analysis using various tools and techniques. It further describes the process of household survey and energy audit, participant selection and recruitment process, and the ethical issues involved in conducting the survey. Different variables influencing the outcomes of the research are further introduced. Later, the proposed qualitative and quantitative methods for data collection and analysis are discussed in detail.

3.1 Steps of the Research

Figure 3.1 presents a snapshot of the methodology used for achieving the research objectives. To traverse from the starting point to the expected outcomes, various methods and techniques were applied and different tools were used, which are discussed in the following sub-sections.

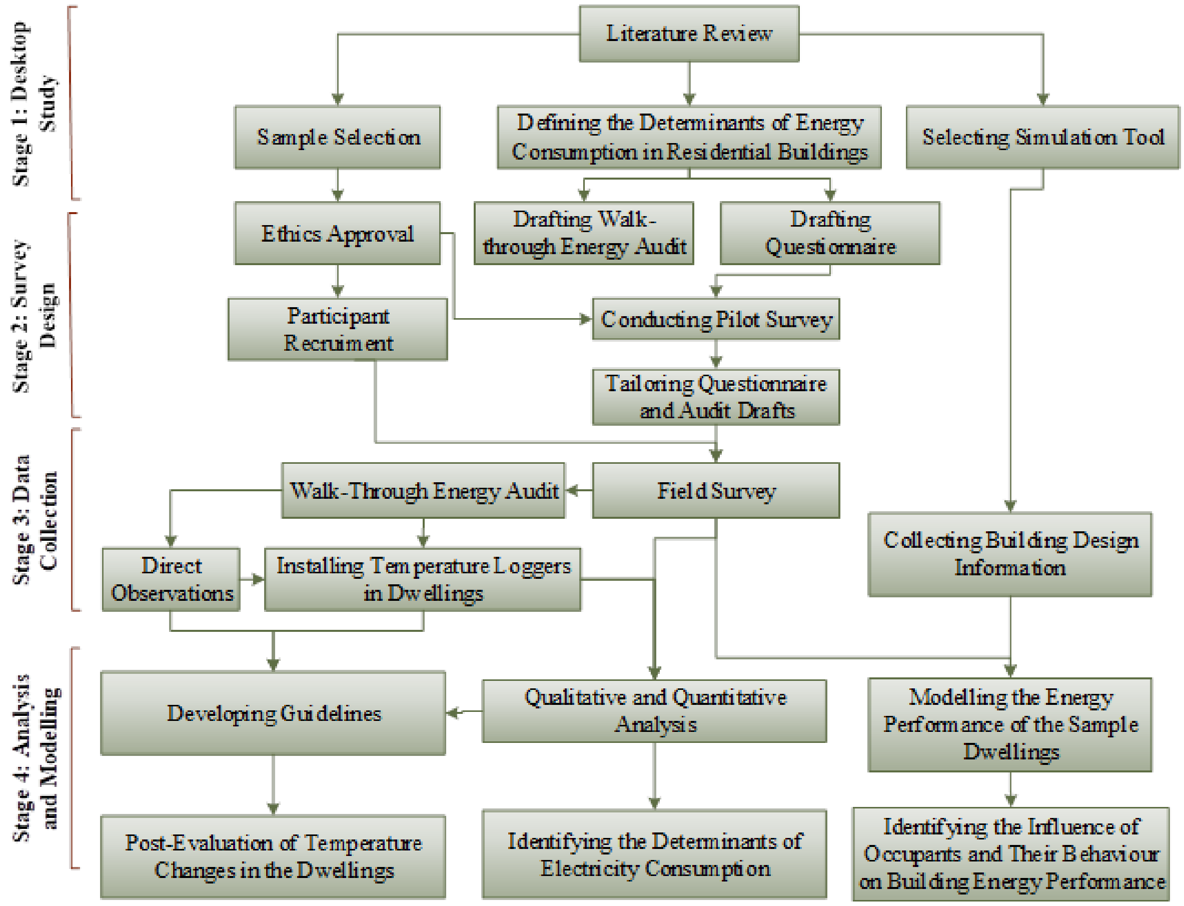

Figure 3.1 Flowchart of the research methodology

3.1.1 Stage 1: Desktop Study

Literature Review

An extensive review of the existing literature was conducted aiming to identify the existing knowledge gap in energy performance assessment of social housing dwellings in Perth, Western Australia. A detailed list of the key determinants of residential energy consumption was created from literature, comprising of both occupant and building-related factors. These factors were then used as the basis for drafting the survey questionnaire and walk-through energy audit in the sample households. The questions such as “what are the key factors that directly or indirectly affect residential energy consumption?”, “why has the influence of occupants in calculating a building energy consumption been mostly oversimplified to a number of controlled activity profiles and predefined scenarios?”, “how does occupants’ energy use behaviour mainly with respect to heating and cooling systems may affect a building energy performance?", etc. were some of the key areas intended to be discovered from the existing literature.

Sample Selection: Foundation Housing as the Survey Population

Foundation Housing (FH) is one of the largest affordable housing providers in Western Australia, accommodating over 2,000 households and multiple projects in the development phase across Perth and WA. Households managed by this organisation were selected as the survey population due to various reasons including:

- Diversity of social and cultural backgrounds of the occupants;
- Similar construction type and size as the average WA's dwellings;
- Data availability; and
- The high number of interested householders who were keen to work towards reducing their energy consumption.

Selecting Simulation Tool

After reviewing the available simulation tools used for evaluating the energy performance of residential buildings, taking into account the project's specific requirements, AccuRate Sustainability V2.3.3.13 SP3 was selected for creating models of the energy performance of the sample dwellings. AccuRate Sustainability can be run in 2 modes: rating mode and non-rating mode. In rating mode, a model of a dwelling is created to a fine level of detail using the information of building envelope. It then calculates the annual heating and cooling energy requirements and assesses a house's energy efficiency in any one of the 69 different climatic zones across Australia. The outcome of building thermal performance assessment with

AccuRate in this mode is expressed as a star rating between 0 and 10. The higher the star rating, the more efficient the building is in terms of thermal energy performance.

AccuRate Sustainability in the non-rating mode incorporates Sustainability Modules into the models including heating and cooling, lighting, water, and hot water. The total energy requirements calculated in the non-rating mode is, however, independent from the energy consumption calculated for the sustainability modules. In other words, the thermal energy requirements calculated in the non-rating mode and presented in the final report do not take into account the energy consumption by the sustainability modules. Indeed, these modules are incorporated into the software only to create a better insight into the energy consumption by different appliances that might be used in different households for the designers and energy assessors.

3.1.2 Stage 2: Survey Design

Designing the Survey Questionnaire

The questionnaire was designed, aiming to obtain detailed information about households' socio-economic characteristics and their energy use behaviour in the dwellings. The number of occupants in each household, individual's age, education, employment status, the total household's income range, years of residency in the dwelling, presence of occupants at home on a typical weekday and weekend, occupants' perception of thermal comfort in the dwellings during summer and winter, HVAC systems and how they were used in the households and lighting were the main areas addressed in the questionnaire. Appendix 3A presents the questionnaire designed for households. In order to ensure the simplicity and clarity of the questions, an informal pilot survey was conducted before starting the actual process. Some of the remarks found from this test survey included:

(i) Some respondents were reluctant to share their personal information including their household income;

(ii) Most of the respondents were uncertain about the occupancy pattern of their household or some aspects of their energy use behaviour such as the thermostat set-point of heating and cooling appliances, opening and closing windows throughout the day, etc.;

(iii) The definition, as well as the range of thermal comfort, was significantly different for individuals.

The questionnaire was then reviewed based on the feedback from the individuals to simplify or minimise the ambiguity of some questions.

Designing Energy Audit in the Dwellings

Walked through energy audit was designed aiming to detect where, when, why and how energy was used in the dwellings and to identify the potential opportunities to enhance the households' energy performance. To this end, the process was designed to collect as much information as possible on the energy consuming appliances used in the households including the electronics, heating cooling appliances, lighting, and their time of use, together with the information required for calculating their energy consumption including wattage, ampere, star rating, etc. In order to minimise the time spent in each dwelling, tables were created encompassing the possible appliances that might potentially be used in an average Australian household (Appendix 3B). **Figure** 3.2 presents the steps of conducting a walk-through energy audit in households.

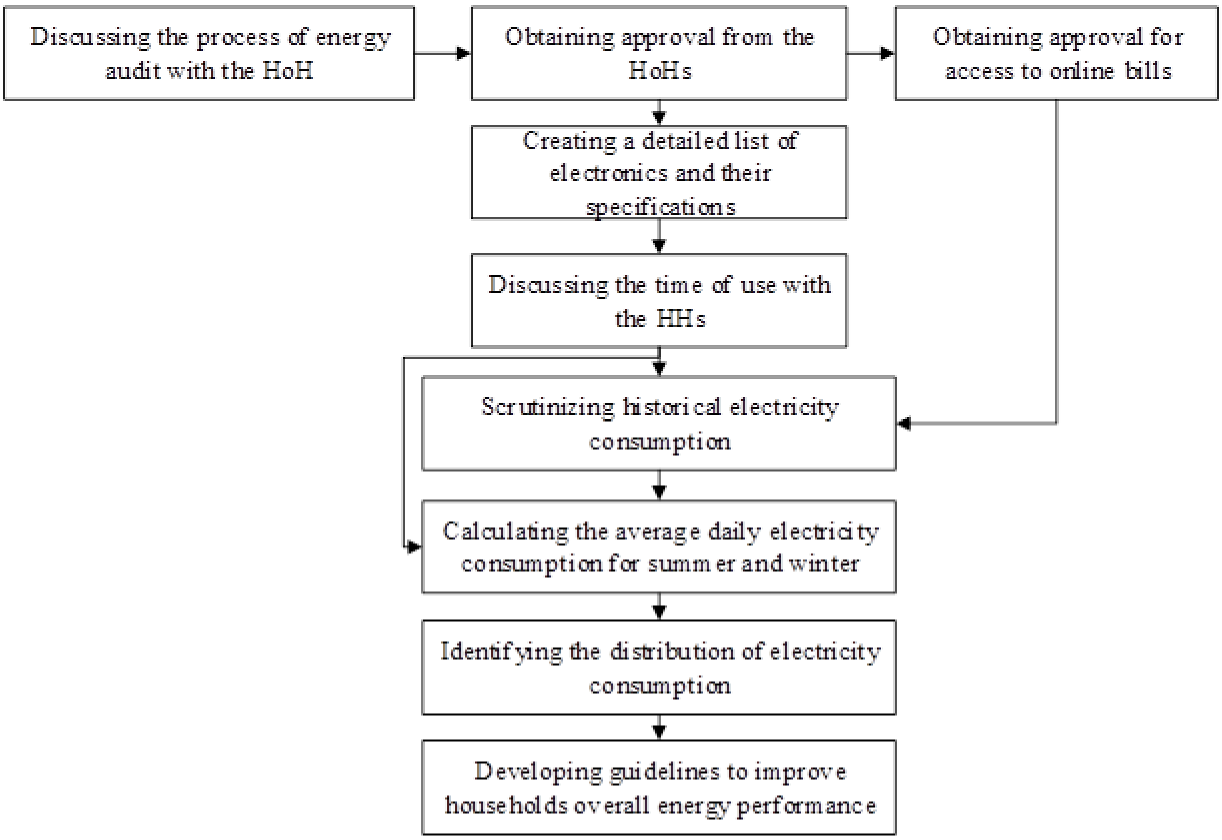

Figure 3.2 Walk-through energy audit in the sample dwellings

A walk-through energy audit in each dwelling started with discussing the step by step process involved with the household's representative. Permission from each representative was also sought to access their household's online utility bills in order to investigate the quantities and cost of energy input in the building and annual and seasonal changes in energy use and cost. The walk-through audit was then started by creating a detailed list of energy consuming appliances used in the house, and the information required for calculating their energy consumption as shown on the appliance's labels (such as wattage, voltage, and ampere). Similarly, the details of lighting fixtures were listed out in each dwelling. The households were then questioned about how the appliances were used by the occupants in their household. This information included the time of use of the appliances, the number of loads each appliance was used per day, the average time of use, the star-rating (where applicable), the annual energy consumption and the standby status of the appliances when they are not in use.

Two-year electricity consumption data was extracted from the households' online bills (during 2013 and 2014) and used as an indicator for evaluating the trend of their energy consumption. Subsequently, the Average Daily Electricity Consumption (ADEC) by different equipment was calculated in terms kWh/day during a sample summer and winter day. The process was then followed by identifying the distribution of electricity consumption by different electronics in each sample households and proposing guidelines for further energy conservation in the households.

Ethics Approval

Different disciplines, institutions and professions have their own ethical norms to assist their members to coordinate their activities and to establish a public trust of the discipline. Murdoch University is committed to the highest standard of integrity in research involving human participants. To accommodate this requirement, ethics approval was obtained from the Murdoch University Human Research Ethics Committee in August 2014 (Appendix 3C).

Standing on the direct interaction with the householders on one hand and conducting the walk-through energy audit, which required a detailed inspection of the electronic appliances, on the other hand, it was essential to ensure the safety aspects of the project. To assist that, the "Safety in Research and Teaching" workshop (SRTC) was attended by the researcher prior to conducting the field survey.

Participants' Recruitment Process

Participants were recruited through Foundation Housing. Based on the project specific requirements including the construction type (single detached dwellings) and the year of construction (2008 and after), a number of eligible households were selected by FH (a total of 169 households). A summary of the project's aims, objectives, the anticipated time of completion and the expected outcomes were sent to the potential households in order to provide a brief snapshot of the project. Interested participants were then, sent their preliminary consent to FH through phone, email or mail with reply-paid envelopes. Since the survey was conducted in the form of in-person interviews in individual dwellings, volunteers were then security-checked by FH for any possible criminal records due to the safety reasons.

Following the scrutinising process, a detailed description of the project was sent to the interested households in the form of "Information Letter". This letter explained explicitly what the participants should expect throughout the research including the interview process, walk-through energy audit and installation of temperature loggers. It also clarified any risks associated with the project at different stages as well as ensured householder's confidentiality and anonymity. The letter also ascertained the householders that withdrawal from the process could be done at any stage and it will not influence the services provided by FH. "Consent Forms" were also disseminated, seeking authorization from the head of the households for initiating the process. A copy of the "Information Letter" and the "Consent Form" is presented in Appendix 3D and 3E.

3.1.3 Stage 3: Data Collection

The following data were collected for evaluating the energy performance of the sample households:

- Building design and construction information
- Socio-economic and Demographic information of the occupants
- Diurnal temperature changes in the dwellings
- Electronics and how they were used in the households

Building Design and Construction Information

Information about the design and construction of buildings together with the original energy reports were required for thermal performance assessment of the dwellings. Where available, the required information was collected from the FH database. Otherwise, the information was collected from the councils upon obtaining approval from FH as the main property owner. In the cases when the process of collecting building design information took longer time than anticipated, the on-site measurements were done by the researcher and building drawings including site plan, floor plans, elevations, etc. were created in AutoCAD 2013.

Conducting Filed Survey and Walk-Through Audit in the Households

The household survey was conducted in the form of in-person interviews at the respondents' place of residence. The researcher (interviewer) acted as a neutral agent triggering the response in an interactional situation. Occupants' perception of thermal comfort and their energy use behaviour in the dwelling were sought in the form of well- defined scenarios by putting the respondents in the picture and helping them to respond to the questions by recalling a similar situation in the past. As a result of personal interaction between the respondent and the interviewer, the overall process was less formal and more conversational. In order to be fully present in the discussions and to carefully monitor occupants' energy use behaviour during the interview, the sessions were audio recorded.

Following the interview, the process continued by performing the walk-through energy audit in the dwelling. In order to understand the historical electricity usage pattern in households, electricity bills for the past two years were requested from the respondents. Where not available, the HoHs were asked for their permission and the online bills were collected from their energy providers' website. With two people collecting the information about the appliances, the overall process of energy audit in each dwelling took between 45-60 minutes.

Temperature Monitoring in Dwellings

In an attempt to evaluate how heating/cooling systems were used in the dwellings and to investigate how the dwellings were ventilated through opening doors and windows, temperature fluctuations were monitored in 5 selected households. The tiny, durable loggers called “Thermochron” were used to record temperature changes in the dwellings as well as the ambient temperature at the location of each dwelling.

The Thermochron family of iButtons are temperature data loggers, which record and store time, temperature, and optional humidity. The computer chip embedded in the Thermochron integrates a 1-Wire transmitter/receiver, a globally unique address, a thermometer, a clock/calendar, a thermal history log, and 512 bytes of additional memory to store user data. Thermochrons are recyclable, and under normal conditions, will log data for up to 10 years or 1 million temperature measurements. In order to program the loggers to record the temperature at desired intervals, read and download the data, the loggers are connected to a computer with 1-Wire master USB and the Blue Dot receptor. There are different types of thermochrons including DS1921G, DS1921H, DS1921Z, DS1922L, DS1922T, etc. each with outstanding specifications. **Table** 3.1 presents the basic specifications of some of these commonly used thermochrons.

Table 3.1: Basic Specifications of iButton Data Loggers

	**Temperature Range (°C)**	**Humidity Range**	**Temperature Accuracy* (°C)**	**Temperature Resolution (°C)**	**Humidity Resolution**	**Data Log Memory (Bytes)**
DS1921G	-40 to +85	N/A	±1	0.5	N/A	2048
DS1921H-F5	+15 to +46	N/A	±1	0.125	N/A	2048
DS1921Z-F5	-5 to +26	N/A	±1	0.125	N/A	2048
DS1922L	-40 to +85	N/A	±0.5, software correction (SC)	0.5 or 0.0625	N/A	8192
DS1922T	0 to +125	N/A	±0.5 (SC)	0.5 or 0.0625	N/A	8192
DS1922E	+15 to +140	N/A	±1.5	0.5 or 0.0625	N/A	8192
DS1923	-20 to +85	0 to 100% RH	±0.5 (SC)	0.5 or 0.0625	8-Bit (0.6%RH) or 12-Bit (0.04%RH)	8192

A high level of accuracy, rugged construction that enables the loggers to survive in harsh environments and rapid data transfer are some of the key features of these loggers. Other specifications include:

- Temperature accuracy of ±0.5 °C from -10 °C to +65 °C with software corrections;
- Measures temperature with 8-Bit (0.5 °C) or 11-bit (0.0625 °C) resolution;
- Operating temperature range: -40 °C to +85 °C;
- Sampling rate from 1s up to 273 hr;
- Number of readings: 8,192 (low resolution) or 4,096 (high resolution);
- Programmable recording start delay after an elapsed time or upon a temperature alarm trip point;
- Water-resistant enclosure (IP56) or waterproof if placed inside DS9107 iButton capsule.

In order to calibrate the loggers, they are exposed to reference temperatures in the factory. These reference temperatures include High Reference Temperature (Tr1), and Low Reference Temperature (Tr2). A third reference temperature, Tr3, is also used for post-processing of temperature readings. Thermochrons monitor time and temperature and store the collected data in their memory. Based on the project requirements, the number of daily temperature data required, taking into account the accuracy of the loggers (higher accuracy was preferred), Thermochron DS1922L was selected for recording temperature changes in the sample dwellings. Tr1, Tr2 and Tr3 for this group of loggers are +60 °C, -10 °C, and +25 °C respectively.

DS1922L loggers can record a total number of 4,096 high-resolution temperature values. Given that the loggers were programmed to record the temperature every 15 minutes, the information was needed to be downloaded from the loggers and the loggers needed to be reprogrammed every 42 days.

Five loggers were installed in each dwelling to record the ambient temperature at the location of each building:

- Two loggers in the main living area;
- Two loggers in one of the main bedrooms, and
- One logger outside of the dwellings.

The four loggers inside the buildings were fixed to an internal wall, where they were neither directly affected by heating/cooling appliances used in the dwellings nor influenced by direct wind flow as a result of cross ventilation through opening the doors and windows. **Figure** 3.3 shows the position of loggers in a sample dwelling.

Figure 3.3 Position of loggers on an internal wall

Although it was initially intended to install the loggers at the height of 1-1.5 meters above the floor, in the households with children present i.e. HH4 and HH12, the loggers were installed higher, around 60 cm below the ceiling. This was done for two reasons: firstly, it was intended to keep the loggers out of the reach of children for safety purposes. Secondly, if the loggers were touched at the time of recording the temperature, it would have had recorded the body temperature of the person instead of the air or wall surface temperature as intended, which was almost impractical to detect. Therefore, in order to ensure that the loggers remained intact and the recorded data are accurate, the loggers were fixed to the wall at a higher height in these households. One of the two loggers in each zone (living area and bedroom) was fixed to the wall with a piece of Blu-Tack, having a small sheet of Permifloor under the logger. Permifloor (thickness: 4 mm, heat flow in: RT 1.3 and RT 1.4, heat flow out: RT 2.0 and RT 2.8) is an insulation water-permeable moisture management system. By mounting the loggers on the insulation sheet, no direct contact was made between the logger and the surface of the wall. Therefore, the temperature recorded by the logger was the air temperature around the logger. The second logger in each zone was fixed to the same wall, about 5 cm away from the first logger. This logger was covered with a polystyrene cup, preventing it to be directly affected by surrounding air. When equilibrium occurred between the air trapped in the cup and the surface of the wall (through conduction heat transfer), the temperature recorded by the logger was the wall surface temperature.

3.1.4 Stage 4: Data Analysis and Modelling

Data were collected throughout this study including qualitative, quantitative and building design information (drawings) using diverse tools and techniques as discussed below:

Transcription and Documentation

The audio files recorded during the interview were transcribed into written text using Audio File Converter Software, NCH. In order to ensure the anonymity of surveyed households, each household was assigned a code, which used throughout the analysis. Interviews, photographs and all other reports were saved onto the university server as well as on Dropbox and an external hard drive, as a backup and kept in a safe and secure place.

Statistical Analysis

Microsoft Excel was used together with Minitab statistics package for preparing the quantitative data collected from the household survey, analysing them and transforming into meaningful solutions.

Modelling Tools and Techniques

Evaluating the energy performance of the sample dwellings was performed through different steps. **Figure** 3.4 presents a schematic view of creating models of the dwellings in AccuRate Sustainability in the non-rating mode and incorporating the household's real data into the models.

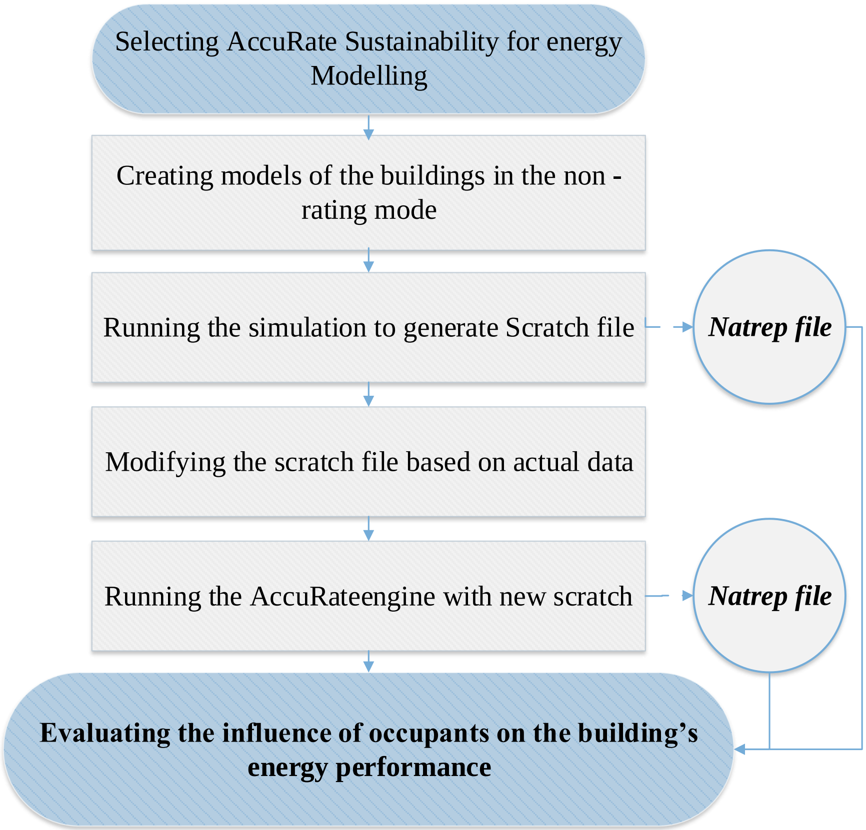

Figure 3.4 An overview of energy performance assessment of the sample dwellings

Creating models of the sample dwellings in AccuRate Sustainability in the non-rating mode and incorporating the households' real data into the models was performed through 5 Scenarios including.

(i) *Scenario 1* (BaseCase)

(ii) *Scenario 2* (BaseCase Adjust)

(iii) *Scenario 3* (BaseCase Adjust + Audit Survey (IHGs))

(iv) *Scenario 4* (BaseCase Adjust + Audit Survey (Thermostat Settings))

(v) *Scenario 5* (a combination of Scenario 3 and 4)

Each of these scenarios will be discussed more in detail where they used for calculating the thermal energy requirements of the sample households presented in Chapter 6 of this thesis.

Summary

The methodology was developed aiming to comprehend the links between occupants' presence and their energy use behaviour in buildings and the energy performance of a number of social housing dwellings in Perth, Western Australia. In order to enhance data validity, mixed methodologies have been adopted comprising of qualitative and quantitative approaches together with modelling the energy performance of the dwellings. Different data collection techniques have been used including survey and interview. Equally important, the analysis stands on long-term behavioural observations, which enriched the process of data collection. The next chapter of this study presents the analysis and interprets the findings that have been obtained from the household survey and walk-through energy audit in the sample dwellings.

CHAPTER 4

ENERGY CONSUMPTION AND OCCUPANT BEHAVIOUR IN SOCIAL HOUSING DWELLINGS- HOUSEHOLD SURVEY AND WALK-THROUGH ENERGY AUDIT

Overview of Chapter

In this chapter, the result of energy performance survey in social housing is presented and the outcome is discussed together with the findings from the walk-through energy audit conducted in these households. The survey aims to understand the occupants' behavioural patterns in terms of occupancy, the use of different appliances, and how occupants ventilated the house, which may significantly affect their energy consumption. It also discusses the occupants' sensation of thermal comfort during extreme seasons (i.e. summer and winter) in the buildings. In summary, using narrative data from series of research tools e.g. quantitative survey, qualitative interview, walk-through energy audit, this study aims to identify different areas of energy inefficiency in the households and address them to enhance their energy performance at the minimum cost.

4.1 Participants Recruitment: Foundation Housing Residents as the Target Group

As discussed in Chapter 1, large families (5 people+) on low-income are at a higher risk of Australia's ever-increasing energy prices. A few social housing providers in Perth were contacted out of which, Foundation Housing (FH), Perth office was volunteered to take part in this study. The selection of FH as the survey population offered several merits, which in fact, addressed the requirements of this research project. These are:

(i) Diversity of social and cultural backgrounds

(ii) Construction type

(iii) Access to the required information

(iv) Expected high response rate

Households managed by FH had a diverse ethnic origin. Therefore, the information collected from the survey on culture, social, economic, education, age and their income range of these households were effectively used to systematically analyse the influence of these factors on households' energy performance. Furthermore, while dwellings managed by FH were built similar to the average dwellings in Western Australia, the required information about households and buildings were collected from FH database. This, to a great extent, facilitated the process of data collection. However, when the information was not available in their database and where required, approval was issued by FH as the main owner of the properties and data was collected from the councils.

Previous studies by FH showed that a relatively high percentage of households were willing to participate in energy-related activities. Therefore, it was expected that the study would achieve a high response rate. A survey conducted by FH in May 2014 revealed that 256 out of 527 participants in the survey (approximately 49%) faced difficulty in paying their energy bills and were attentive to contribute in activities, which in some ways were related to reducing energy/utility costs (NSW Federation of Housing Associations 2014). This was followed by repair and maintenance-related actions to make the dwellings more efficient (44%) (See **Figure** 4.1).

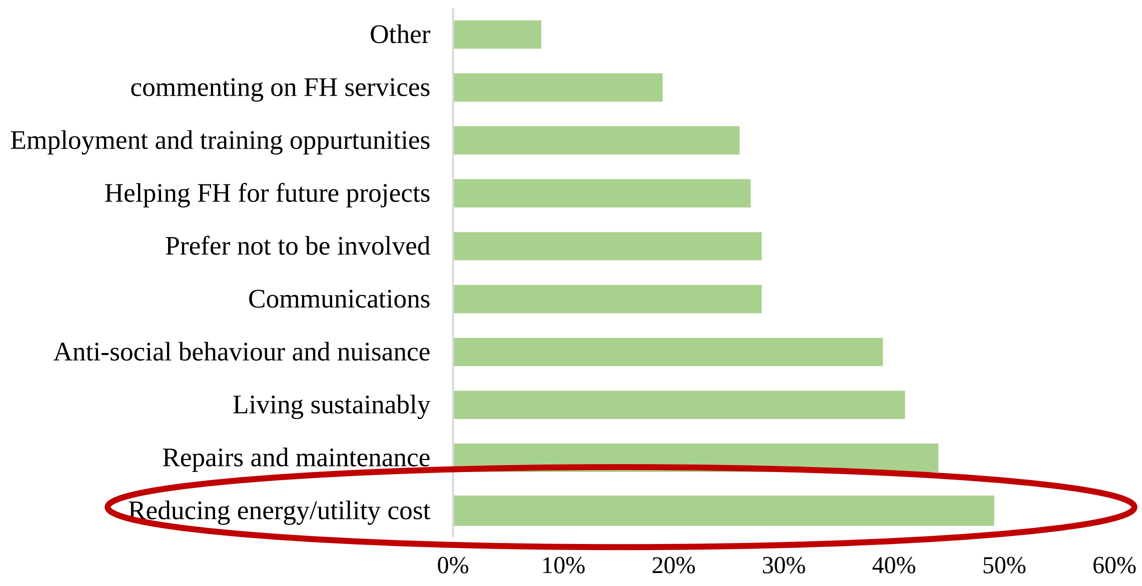

Figure 4.1 Issues or activities participants were interested in

(Source: FH Client Satisfaction Survey, May 2014)

Similar to other social housing providers, tenants of FH properties are accountable for their utility charges (Esmaeilimoakher 2018). With the high cost of energy hitting these low earners and with the aim of assisting these households to overcome the high cost of energy, residents of FH properties were selected as the target group for this study. Except for the adversities that FH (as the housing provider) had to tackle about high utility bills in some households, the tendency of the tenants to take part in activities that target their energy/utility costs was one of the main reasons this organisation agreed to take part in this study. Upon receiving the formal consent from FHL, approval was obtained from the "Human Research Ethics Committee" at Murdoch University before commencing the field study. Further information about Murdoch ethics process is explained in Chapter 3. The households were shortlisted based on the construction type, the year of construction and location of dwellings and an expression of interest to participate in the survey were sent by FHL. The interested households were then asked to send their consent to the FHL office, which later on, contacted by the research team.

The process of the survey was explained to the interested households and the date and time were set for the interview.

4.1.1 Foundation Housing

Foundation Housing (FH) is one of WA's largest developers and managers of affordable housing for people in need, offering long-term housing options for singles, couples and families who are on low incomes. FH was formed in 2006 following the merger of three smaller social housing associations and manages around 2186 units of accommodation with over 3500 households across WA (Foundation Housing 2018). It is an innovative and rapidly growing social enterprise, providing affordable housing to families and individuals on low incomes, and those most vulnerable to homelessness in the community. As one of the State's largest rental property managers, Foundation Housing has an ownership interest in assets of $223.3 million and manage property assets of $695.5 million (Foundation Housing 2016/17). **Figure** 4.2 shows the location of accommodations in FH domain across Western Australia.

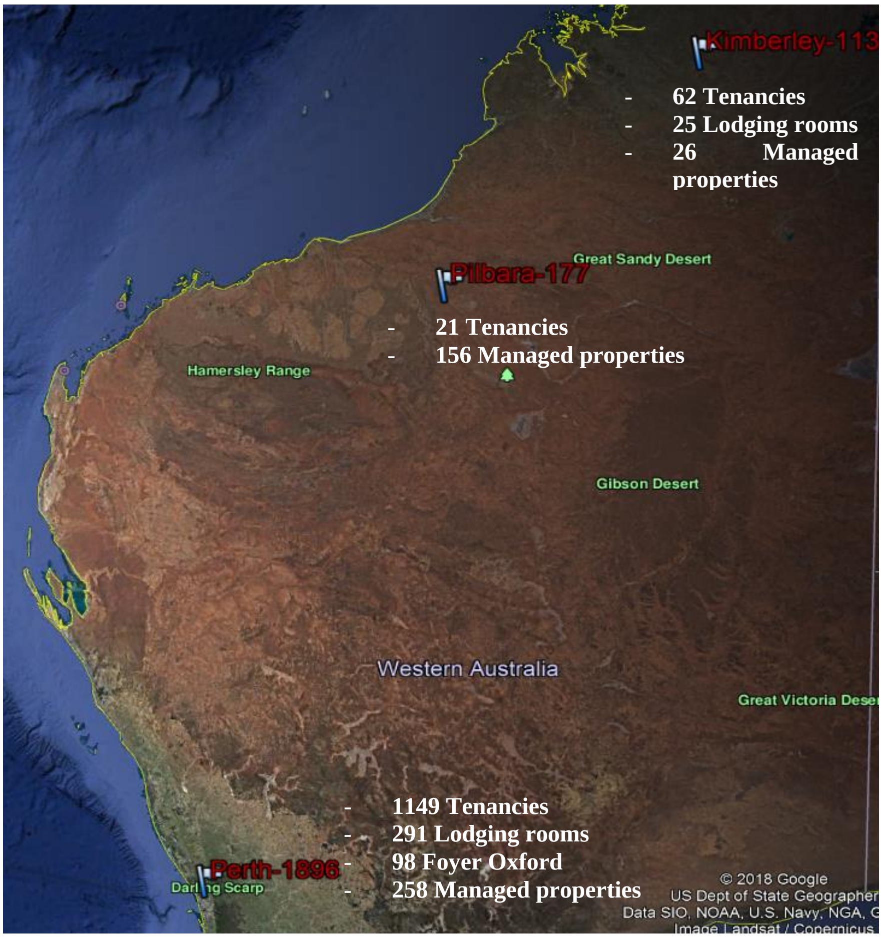

Figure 4.2 Overview of Foundation Housing domain

FH works with several not for profit agencies and commercial organisations, with the goal of impacting lives through the housing and other supports. The key partners include Cedar Woods, Nyamba Buru Yawuru (NBY), IBN Aboriginal Corporation, Anglicare WA, Central Institute of Technology and Housing Authority.

There are several options available for the applicants in the FH waiting list including Housing, Lodging, Youth and Keyworker accommodation in South Hedland. Social and Affordable houses are generally only available to those on the community housing joint waiting list. Lodging accommodation is, on the other hand, available directly through FH and provides the applicants with a single, furnished room and shared facilities. Foyer Oxford, which provides fully self-contained accommodation is allocated directly by Anglicare staff, not through

Foundation Housing. This group of accommodation has the capacity to house up to 98 young people between the ages of 16 and 25, including 24 young parents and their children. Rent levels for these properties are set according to a household's income, with the social housing rents cannot exceed 25% of household income. Upon approving an application, it will be placed in one of the following categories (Foundation Housing 2014):

Priority 1

- Severe disability or prolonged disease;
- Severe social need such as domestic violence, racial or other forms of harassment;
- Under occupation;
- Severe overcrowding

Priority 2

- Medical need
- Social need
- Overcrowded property

The applicants who fall under either of the above categories need to provide strong evidence to support their application. For example, a medical professional need to approve that the current housing status of the tenants is affecting the tenants' disability or disease. Similarly, for any form of harassment, supporting documents are required to support the application. When deciding how many bedrooms a household may need, and in assessing whether a home is over/under-occupied, factors such as sex and ages of children in the household would be also taken into account (Agency). **Table** 4.1 shows the Bedroom Entitlement Standard used by FH to match the household size with the number of bedrooms. Nevertheless, for short-term accommodation, more people may share a room (than stated in **Table** 4.1) to prevent homelessness.

Table 4.1 Bedroom Entitlement Standard used by FH for allocating accommodation

Household type	**No. of bedrooms**
Single adult	1 bedroom
Group of single adults	1 bedroom per adult
Single parent or couple with 1 child	2 bedrooms
Single parent or couple with 2 children	2/3 bedrooms depending on the sex and age of children
Single parent or couple with 3 children	3/4 bedrooms depending on the sex and age of children
Single parent or couple with 4 or more children	3/more bedrooms depending on the sex and age of children

(Source: FH transfer policy)

Despite the so-called entitlement standards, findings from the household survey revealed that discrepancy exists in reality between the number of bedrooms and the number of occupants lived in FH dwellings. For example, a single adult was living in a 2 –bedroom town-house (e.g. HH3) or, a 3-bedroom single detached dwelling was rented to a single adult (e.g. HH6).

4.2 Analysis and Discussion of Survey Data

Initially, one-third of the invited households (32%) agreed to participate in the survey. However, after giving a brief outline of the project and the possible risks involved, only 17 households (18%) decided to proceed with the further process of the survey as shown in **Figure 4.3**.

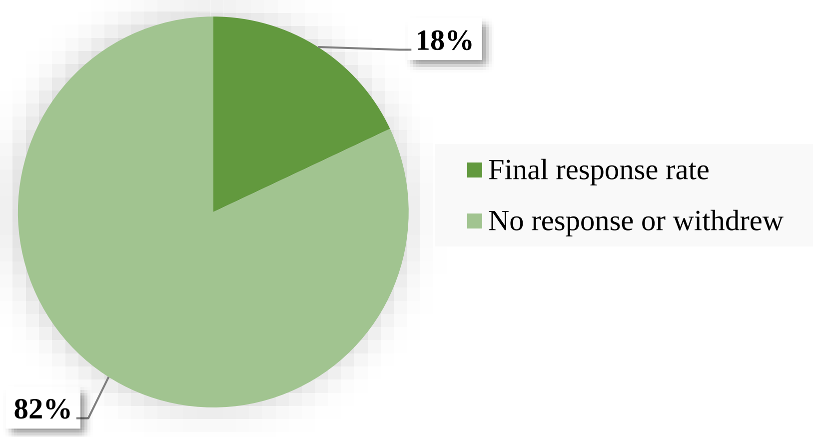

Figure 4.3 Response rate to the survey invitation

Figure 4.4 shows a snapshot of the suburbs where the surveyed dwellings are located with respect to the Perth Central Business District (CBD).

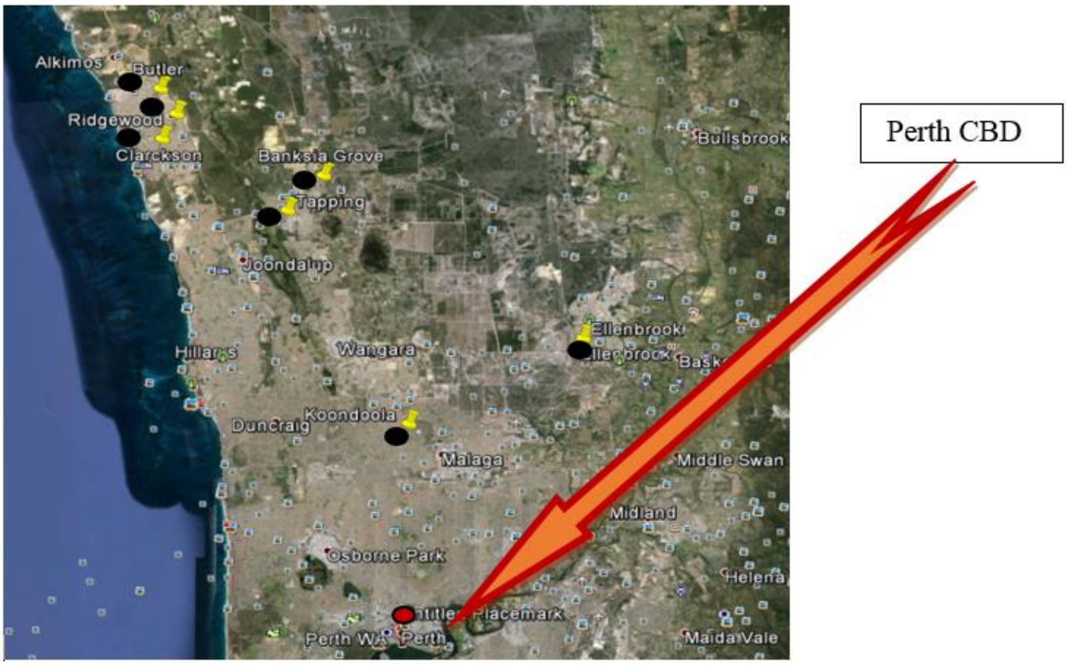

Figure 4.4 Scattering of the participated households

(Source: Google Earth)

Table 4.2 shows the breakdown of the volunteered households according to suburbs and the type of construction.

Table 4.2 Breakdown of participated households according to the suburb

Suburb	No. of Responses	Response (%)	Construction Type
Ellenbrook	5	29%	Single Detached Dwelling
Banksia Grove	3	17.5%	Single Detached Dwelling
Butler	3	17.5%	Single Detached Dwelling
Ridgewood	2	12%	Single Detached Dwelling
Clarkson	2	12%	Single Detached Dwelling
Tapping	1	6%	Single Detached Dwelling
Koondoola	1	6%	Grouped Dwelling (Villa)

Since the households joined at different points of time, completing the survey took longer than anticipated, from October 2014 to February 2015. The survey questions were designed to collect the following information:

- Historical electricity usage data
- Socio-economic characteristics
- Occupancy pattern
- Thermal sensation in winter
- Thermal sensation in summer
- Window opening behaviour

The following sections present the outcomes from the household survey.

4.2.1 Historical Electricity Usage Data

Electricity consumption data during 2013-14 was collected from Households' online bills and summarized in the form of the mid-point of the billing period and the Average Daily Electricity Consumption (ADEC) (kWh).

Households were divided into two groups based on their daily electricity consumption: extreme users (ADEC equal or above 10 kWh) and regular users (ADEC below 10 kWh). While the ADEC by regular electricity users ranged between 5 and 13.5 kWh, it varied between 7 and 33 kWh by the extreme electricity users. **Figure** 4.5 and **Figure** 4.6 presents the electricity consumption of regular users and extreme users respectively. Noted that mid-point of billing periods was calculated using the start date and the last date of each billing period as shown in the household' electricity bills:

$$\text{Mid} - \text{point of billing period} = (\text{start date} + \text{last date of billing period}) \div 2$$

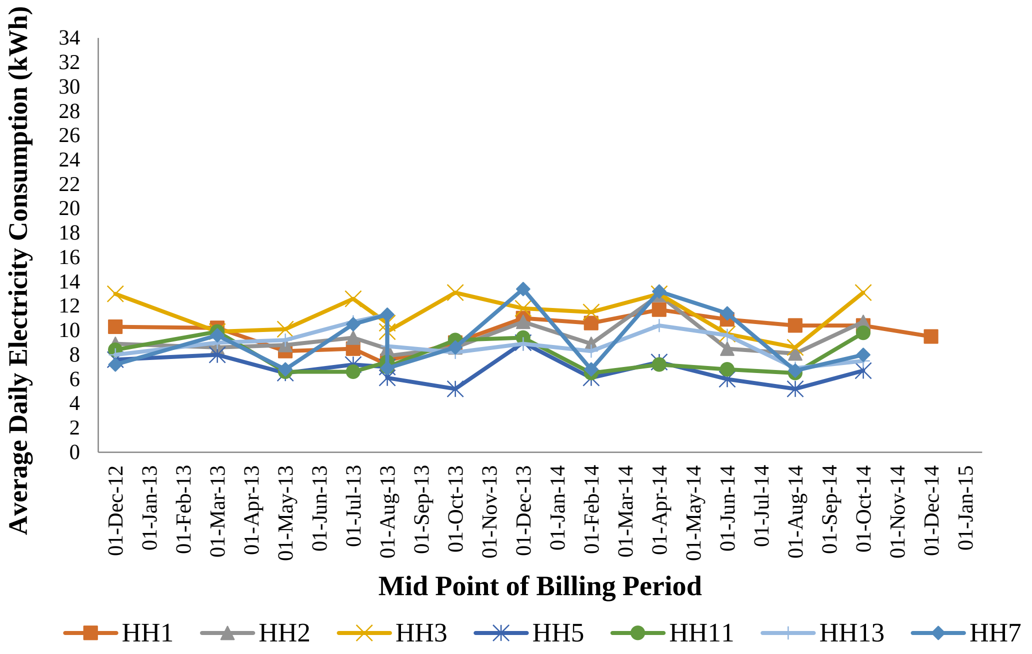

Figure 4.5 ADEC (kWh) by regular electricity users

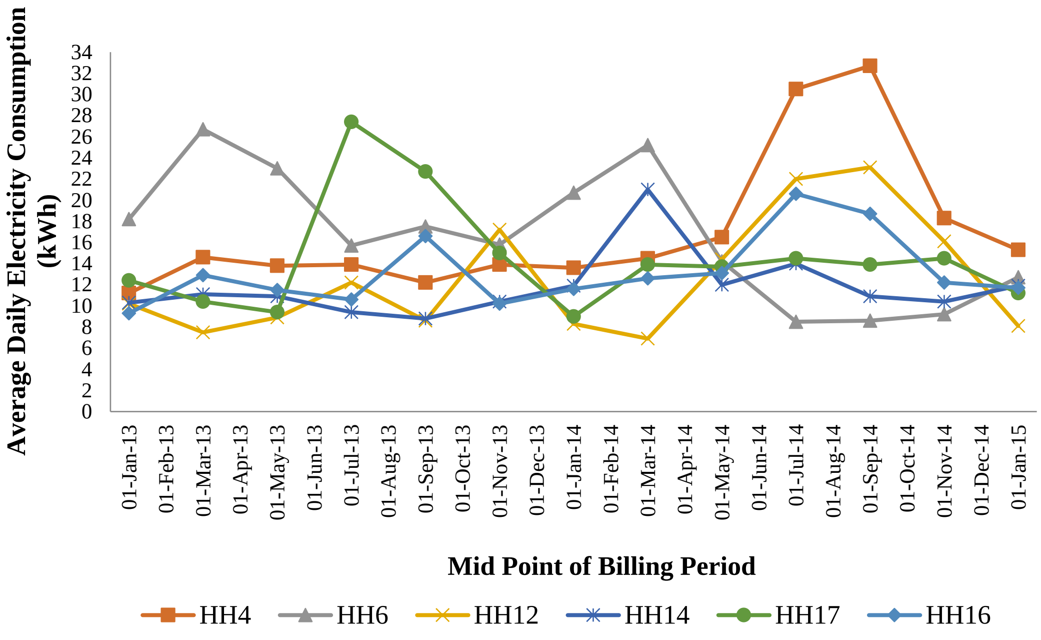

Figure 4.6 ADEC (kWh) by extreme electricity users

Electricity consumption in different households followed different trends. While some households experienced their highest consumption in summer (e.g. HH5 (9 kWh), HH6 (26.7 kWh), HH14 (21 kWh)), others used more electricity during cold winter days (e.g. HH16 (20.6 kWh), HH17 (27.5 kWh)). Additionally, electricity consumption in some households followed a steadier trend. For example, no clear peak is detected in the electricity consumption in HH1, HH3, HH11, etc. However, other households including HH4, HH17, experienced sudden changes in their consumption during the period under investigation.

4.2.2 Socio-Economic Characteristics of the Participated Households

Participants were asked about their demographic information during the survey. The questions addressing socio-economic characteristics of the households considered every individual in the households, except for income for which, the total Disposable Household Income (DHI) ($/Fortnight) was taken into account. A summary of households' socio-economic information, and the technical characteristics of the surveyed households is presented in Appendix 4A.

Except for one household, others were living in single-detached brick dwellings. The total number of bedrooms in these dwellings varies between 2 to 5, with nearly half of the households living in 3 bedroom dwellings. The household size in the survey sample varied between 1-8 persons with an average size of 4 persons per household. A small difference was established in the number of male and female occupants, with females slightly outnumbering males (51% versus 49%). In more than half of the surveyed households, HoHs were female (9 out of 17 households). **Figure** 4.7 shows the breakdown of the survey sample with respect to age of individuals in the survey sample.

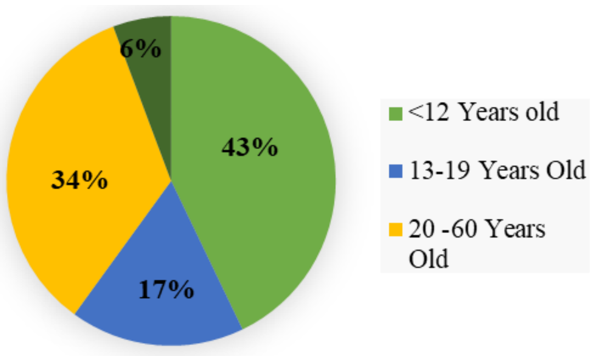

Figure 4.7 Breakdown of the households with respect to the age of individuals

Forty-three (43) per cent of the survey sample were children (below 12 years old), followed by adults (between 20-60 years old), teenagers (between 13-19 years old) and elderly (above 60 years old) that constituted 34%, 17% and 6% of the survey sample (70 people) respectively. In terms of education, most of the occupants have at least some level of education with the majority having completed primary school or secondary/high school, and a few (13 out of 70) having obtained a university degree. Seven out of the 70 occupants do not have any education, and there are either elderly or children below school age. It is worth noting that most of the HoHs are educated. They either completed secondary/high school or have a university degree. The years of residency in the dwellings varied between 4 months to 6 years with an average of 2.9 years per household. It was found that 65% (11 out of 17) of the households have lived in their current house for 2-4 years, less than one-third (29%) lived for less than 2 years and only two households have lived in their current house for more than 4 years.

Disposable Household Income (DHI) was classified based on the guidelines obtained from the Australian Bureau of Statistics (ABS). According to the ABS classifications, households with a weekly income below $581 are grouped as low-income. Households with weekly income between $689 and $904 are categorized as middle-income, while those with weekly income above $1,236 are acknowledged as high-income households (Agency). The weekly Equivalised Disposable Household Income (EDHI) values that have not fallen within the above clusters are categorised as low-to-middle income or middle-to-high income level. **Figure** 4.8 presents the percentage of the surveyed households falling in each income category.

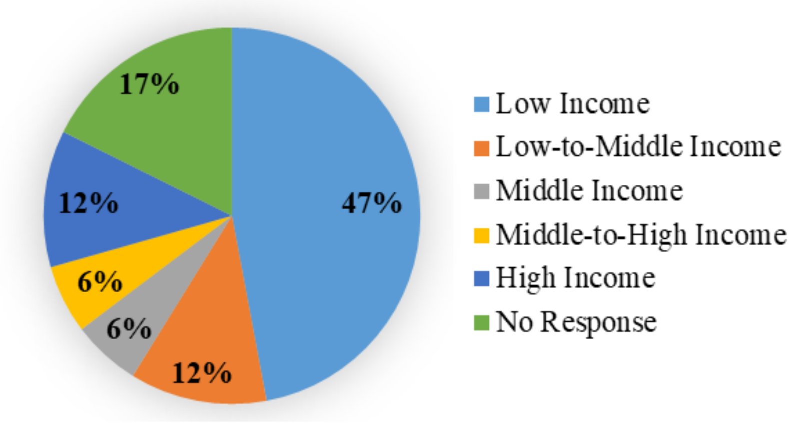

Figure 4.8 Breakdown of households with respect to DHI

Living in social dwellings, the DHI of the surveyed households was expected to vary between low and low-middle levels. However, less than half of the households fell into the low-income category, followed by 12% in both the low-to-middle income and high-income households (**Figure** 4.8).

4.2.3 Occupancy Pattern

Occupancy (presence and number of occupants) is one of the most important factors impacting the energy efficiency of buildings. Participants were asked about their presence in the house. According to the survey, occupancy hours in these dwellings ranged between 11-24 hours on a typical weekday and between 0-24 hours on weekends. On weekends, the majority of the dwellings were either vacant or occupied by the entire occupants. In most of the households, the occupancy pattern varied on weekdays. On a typical weekday, more than half of the surveyed dwellings were fully occupied in the morning (5:00 am-12:00 pm) and afternoon (12:00 pm-5:00 pm). Note that in this study, a fully occupied dwelling during a period of time is the one where at least one person is present in the dwelling during the assigned period. These dwellings were mainly those with unemployed housewives and children below school age, followed by households with elderly occupants or members with a physical disability. Towards the evening and night, the occupancy rate in almost all the dwellings increased to 100%.

4.2.4 Thermal Sensation in Winter

In order to understand the occupants' status of thermal comfort in the dwellings, ASHRAE seven-point scale was used (55-2010 2010). Unlike socio-economic information for which every individual in the household was taken into account, in response to thermal comfort and energy use behaviour related questions, the HoH (respondent to the survey questions) was considered as the household's representative and his/her perception of thermal comfort was taken as of the household. The respondents were asked to remember the situation when they entered the house on a cold winter day and no heating system was running in the dwelling.

They were then asked to describe their thermal sensation from -3 to +3 (with -3 = cold, -2 = cool, -1 = slightly cold, 0 = naturally comfortable, +1 = slightly warm, +2 = warm and +3 = hot).

It was found that in the majority of the cases, the respondents experienced an extreme level of thermal discomfort in both living areas as well as in bedrooms. One respondent (HH10) expressed her extreme dissatisfaction with indoor thermal comfort in winter:

//... In winter, inside the house is even colder than outside! Not comfortable at all ...//

On a typical winter day, more than half of the households reported that they felt uncomfortably cold (-3) in the living area. More people were even dissatisfied with their thermal comfort at night. As shown in **Figure** 4.9, the living area was not comfortable at night for any of the households. Similarly, most of the households felt extremely cold in bedrooms both during day and night if there is no heating system on (**Figure** 4.9).

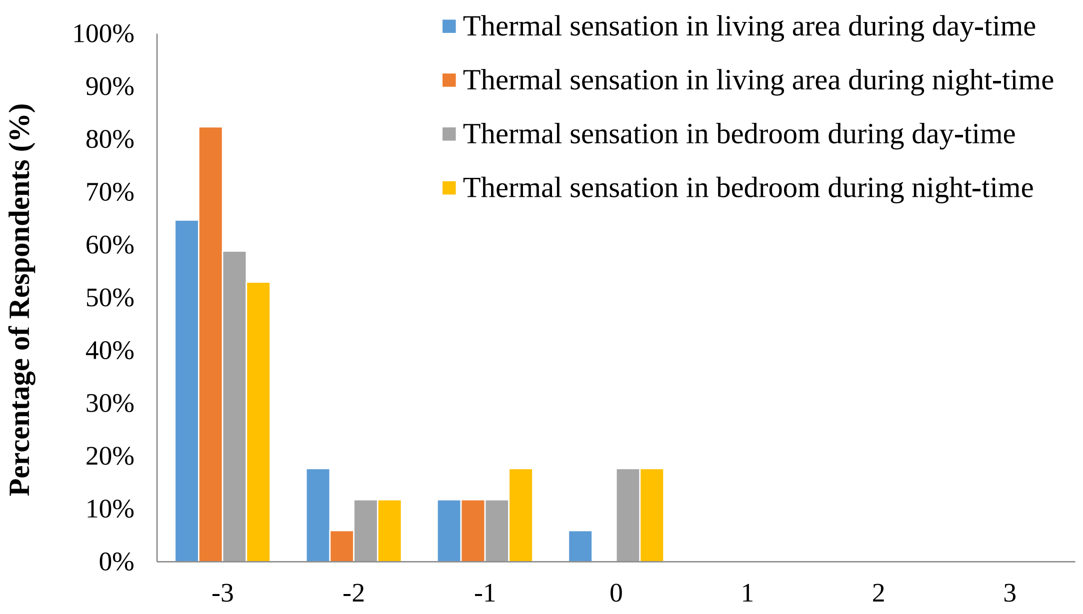

Figure 4.9 Thermal sensation in winter

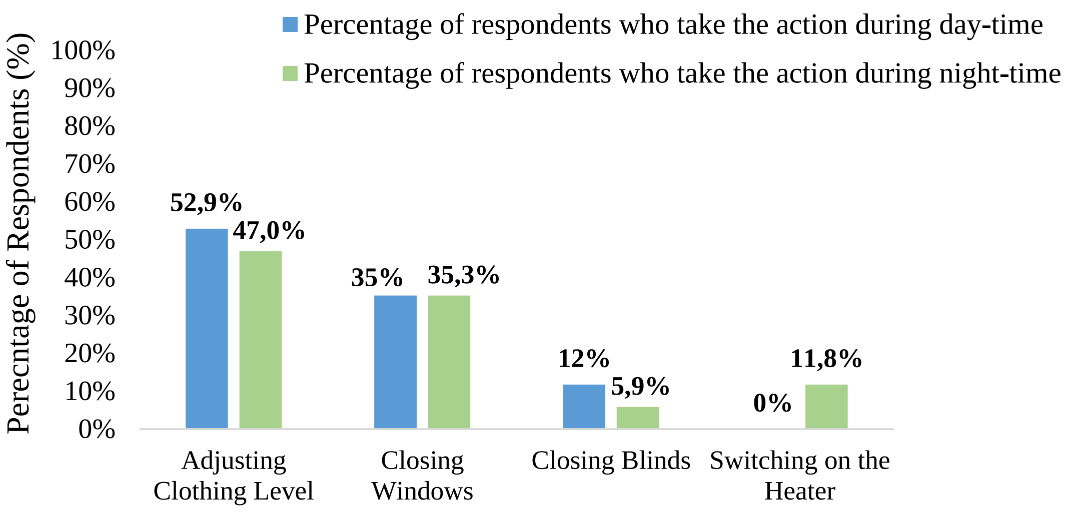

Figure 4.10 First action taken by the respondent in winter to achieve thermal comfort

Figure 4.10 shows different actions taken by the respondent (as the household's representative) while feeling uncomfortable due to the cold sensation. It was found that during the day-time, more than half of the respondents (53%) adjusted their clothing as the first response to thermal discomfort in the dwellings, followed by closing the windows (35%) and blinds (11.8%) (**Figure** 4.10). Interestingly, switching on the heater had not been ranked by any of the respondents as the first response to thermal discomfort in the dwellings on cold winter days. However, some householders (HH3) put their comfort at the forefront:

> //… I love my comfort! On cold days, I prefer to heat up the whole house rather than wearing a heavy jumper...//

During night-time, a small percentage of the households (11.8%) turned on the heater immediately after feeling uncomfortably cold (**Figure** 4.10). A comparison between occupants' thermal sensation and the heated zones in the surveyed dwellings revealed that in winter, bedrooms were likely to be more comfortable than living areas. However, this might be simply because bedrooms are mostly used during sleep hours when blankets are used to keep the occupants warm. Half of the respondent only heated up the living area.

Three out of 17 households did not have any heating system in winter. In the morning, when eight households (out of 14 remaining households) heated up the living area, only 1 household heated the bedroom. In the afternoon, the number of households heating the living area fell to 5 (mainly those with children and elderly); with no household heating the bedroom. Towards evening, the number of households who turned on the heater raised to 13 (out of 14 households) in the living area and 2 in the bedroom. Although, the duration of using the heating system on a typical winter day was reported to be between 1-13 hours in the living area and 0.5-8 hours in the bedroom (with the majority of the households use heaters in the evening, followed by morning, night and afternoon), almost all the households reported that they turned off the heater soon after they felt thermally comfortable. During night-time (9:00 pm-5:00 am), 5 households used the heater in the living area and 3 households used it in the bedroom. **Figure** 4.11 shows different types of heating systems used in the surveyed dwellings. Some households use more than one heating system (2 out of 14 households) (**Figure** 4.11). Through direct observation, it was found that some households even turn on more than one heating system at the same time. For example, in one of the surveyed dwellings, 2 reverse cycle AC units were running simultaneously in the living area. According to the tenant:

> *…//the ACs are undersized. So one of them is not enough to heat up the entire area. Sometimes, I need to turn on both the ACs at the same time//…*

Among different heating options, electric heaters were ranked as the most popular heating system used by two-fifths of the households, followed by reverse cycle AC (17%) and gas heaters (12%) (**Figure** 4.11).

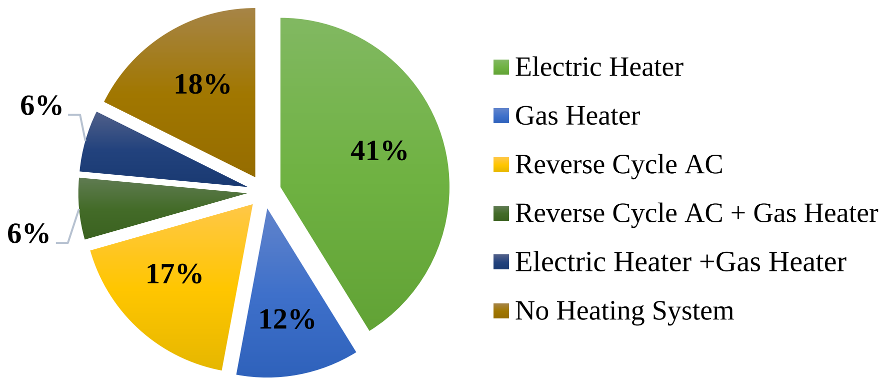

Figure 4.11 Different types of heating system in the surveyed households

4.2.5 Thermal Sensation in Summer

The respondents were asked to remember when they entered the house on a hot summer day when no cooling system was running and describe their thermal sensation on a scale from -3 to +3 (with -3 = cold, -2 = cool, -1 = slightly cold, 0 = naturally comfortable, +1 = slightly warm, +2 = warm and +3 = hot). Summary of the responses is presented in **Figure** 4.12.

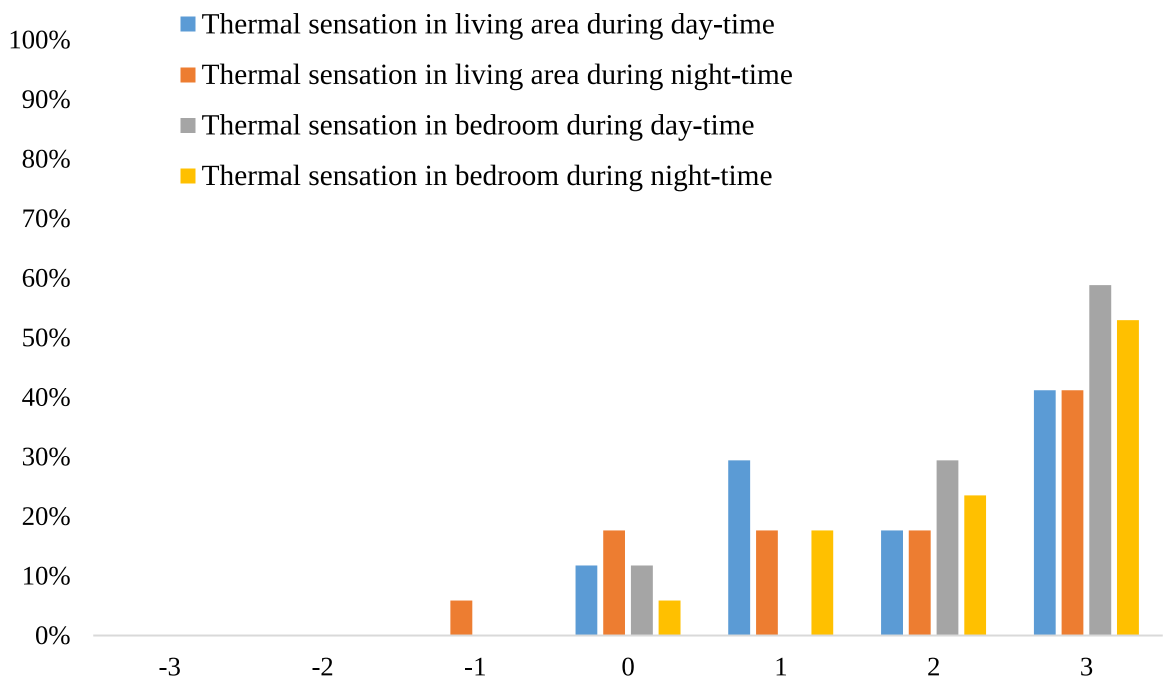

Figure 4.12 Thermal sensation in summer

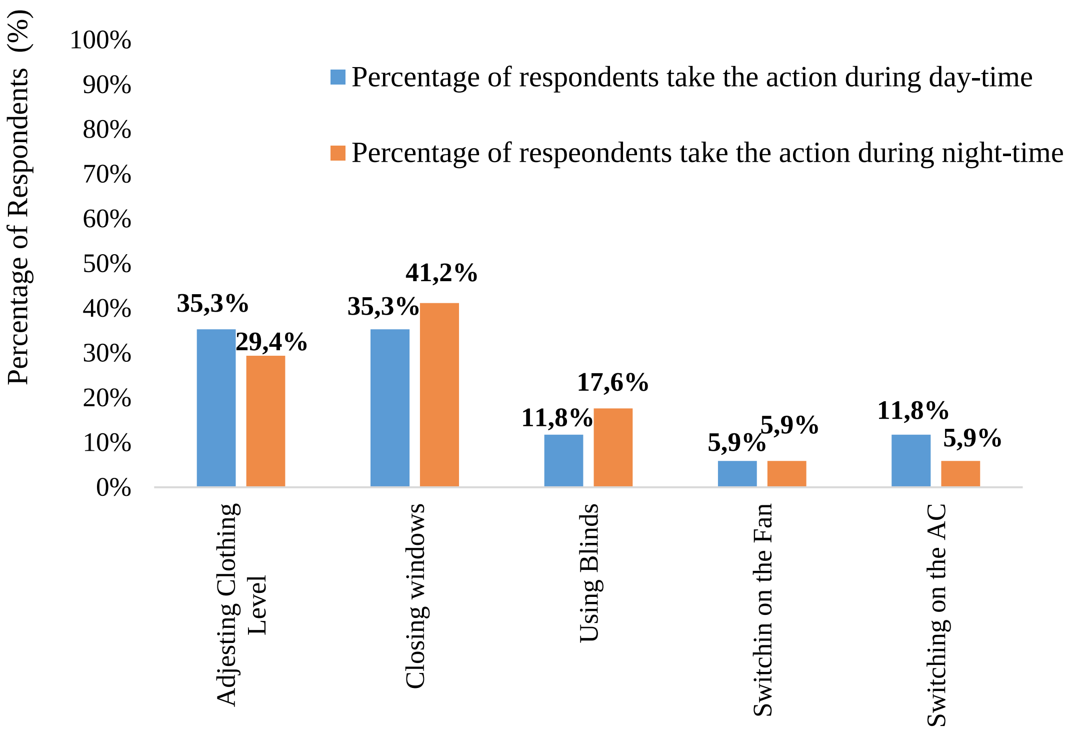

Figure 4.13 First action taken to achieve thermal comfort

Bedrooms were reported uncomfortably hot by most of the households (hotter than living areas) especially during day-time (**Figure** 4.12). With no cooling system, 40% of the households felt extremely hot (+3) in the living area against 60% in the bedroom. As shown in **Figure** 4.12, the natural comfort experienced in the living area was more than bedrooms. One individual even mentioned that she felt slightly cold in the living area during summer nights.

The respondents were then asked to rank a list of actions they might take in summer when they feel uncomfortably hot. During day-time, adjusting the clothing level and closing the windows were reported as the two common actions by more than a third of the households, followed by 12%, who turn on the AC. During summer nights, however, closing windows was reported as the first action by slightly less than half of the households, followed by adjusting the clothing level (29%), closing the blinds (18%), switching on the fan (6%) and AC (6%) (**Figure** 4.13). Two out of the seventeen households did not have any type of cooling system. Findings from the household survey revealed that the living /kitchen area was cooled in more than half of the dwellings; while nearly one-third of the households cooled both living area and bedroom. Portable fans were found to be the most common source of cooling in more than one-third of the households, followed by reverse cycle AC (29%). Only twenty-five per cent of the households used evaporative coolers (**Figure** 4.14).

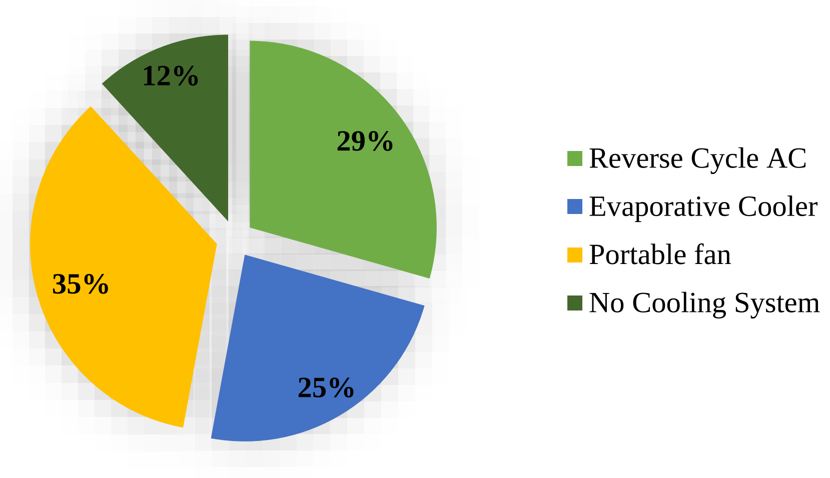

Figure 4.14 Different types of cooling systems used in the surveyed households

4.2.6 Window Opening Behaviour

In order to understand the relationship between window opening behaviour and electricity consumption in the dwellings, the respondents were asked to describe their window opening pattern on a typical summer and winter day separately. In winter, most of the households (82%) opened the windows in the living area for a few hours to get fresh air. Two out of seventeen households opened the windows only in the morning (about an hour) and closed it for the rest of the day. Eight households, however, opened the windows once again in the afternoon (12:00 pm-5:00 pm) and let the natural heat of the sun enter the house. Towards evening, only five households opened the windows for 1-4 hours. Finally, all the respondents reported that they closed all the openings at night. When respondents were asked about their window opening behaviour in their bedrooms, it was found that 33% of the households kept a small portion of the window in their bedroom constantly open to allow fresh air ventilate the room. However, direct observation revealed that even this group of households shut the windows if the outside temperature was below their comfort range.

A significant difference was found between window opening behaviour in summer and winter. In summer, more than 75% of the households opened the window in the living area early in the morning and let the fresh and cool air enter into the room (on average for 2.4 hours). As air temperature rises in the afternoon, nearly 70% of the households closed the windows. Seventy-five per cent of this group, however, opened the windows once again in the evening to cool down the house.

//…in summer, when the front door and the back door are open at the same time, the breeze comes in and makes the house cold ...//

It is worth noting that in summer, less than a third of the households kept a small portion of windows in the living area constantly open.

Window opening behaviour in bedrooms was found to be similar to the living areas. Although for 65% of the households, security was the main reason for closing the windows at nights, 35% kept the windows open throughout summer nights and let the house cool down.

4.3 Findings from Walk-Through Energy Audit in the Households

As discussed in Chapter 3, two out of seventeen households participated in the survey had recently moved to their current house for which, no historical electricity information was found. Furthermore, two more households did not authorise the research team to have access to their utility information. By removing these four households, a walk-through energy audit was conducted in the 13 remaining households. **Table** 4.3 presents a summary of building as well as occupancy related information of the sample dwellings.

Table 4.3 Building details, occupancy and heating and cooling systems in participated households

HH	Orientation /Dwelling Type	Ext. Wall Insulation	Ceiling Insulation	Star Rating	Hot Water System	No. of Occupants	Heating System	Cooling System
1	North-East/SD	No	R.4	6.5	Gas boosted Solar	8	✗	Fan
2	South /SD	No	_	_	Gas HWS	2	RAC[1]	RAC + Fan
3	East /TH	No	R2.5	5	Gas HWS	1	2* RAC + GH[2] + ERH	2* RAC
4	South-West /SD	No	R3.0	5	Gas HWS	4	ERH [3]	Fan
5	North /SD	No	R4.0	6.5	Electric Heat Pump	2	GH	EC + 2* Fan
6	North	R 1.3	R4.0	6	Gas boosted SWH	2	✗	EC+ 2*Fan
7	South	R 1	R4.0	6	Electric boosted SWH	3	RAC + 2* ERH	RAC + 2* EC + 5*Fan
11	South-East	No	_	_	Gas HWS	2	GH	EC[4] + Fan
12	North-East	No	R4.0	7	Gas HWS	5	ERH	2* Fan
13	North-West	No	_	_	Gas HWS	6	ERH	4* Fan
14	North-West	No	-	7	Gas HWS	4	RAC	RAC
16	West	No	R4.0	6	Gas HWS	6	✗	Fan
17	South-West	No	_	_	Gas HWS	6	ERH	✗

In the walk-through audit conducted in the dwellings, appliances such as refrigerators, fridge-freezers and freezers were classified as “Refrigeration”. Fans, heaters, reverse cycle air-conditioners and evaporative coolers, on the other hand; fell into the “Heating and Cooling” classification. “Entertainment” included iPads, laptops, personal computers, radios, DVD players, VCRs, video games, stereos, TVs, Foxtel and set-top boxes, etc. Laundry included washing machines, dryers and irons. Lastly, dishwashers, microwaves, electric ovens, rice cookers, electric kettles, slow cookers, coffee makers, toasters, sandwich makers, mixers, vacuum cleaners, garage door openers and other small appliances used in some dwellings, were grouped as other appliances. **Figure** 4.15 presents various appliances used in sample households.

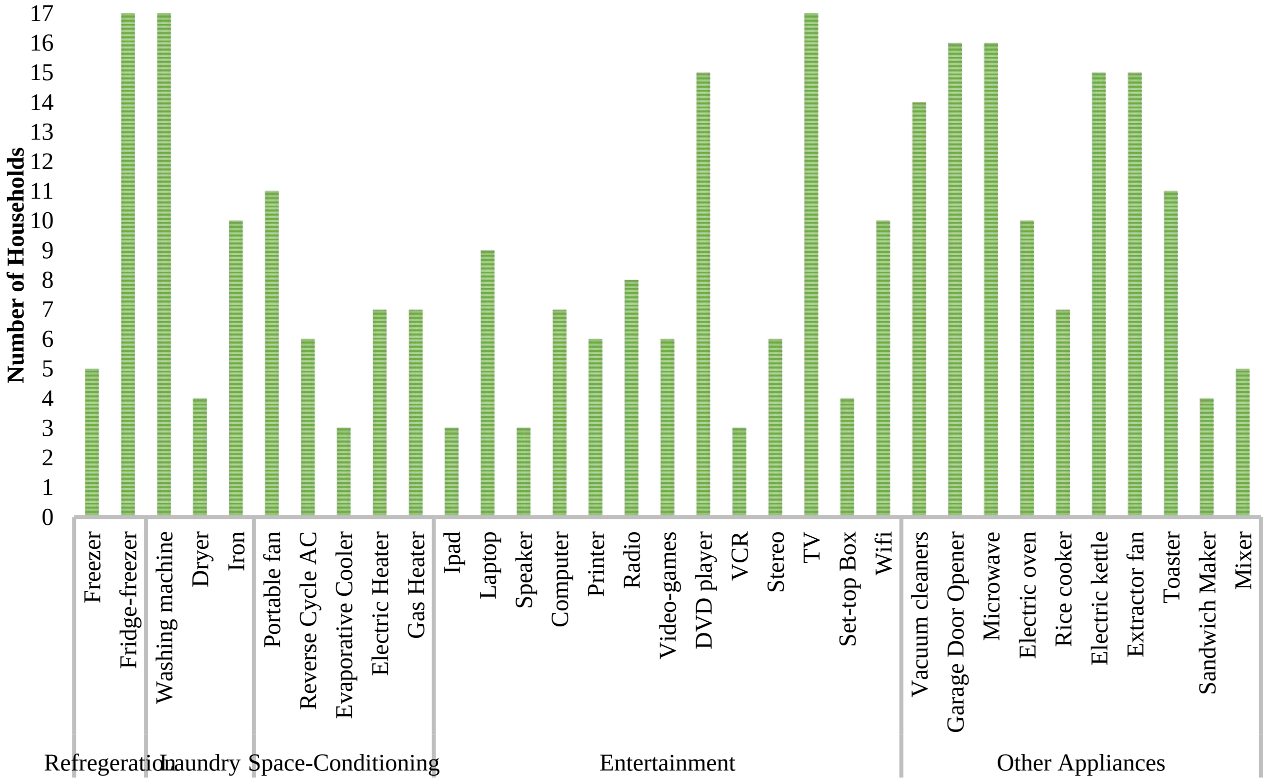

Figure 4.15 Different appliances used in the sample dwellings

Appliances such as fridge-freezers, washing machines and TVs were used in almost all households. However, the number, model, their efficiency, and how they were used (in terms of the time of use) were significantly different in each household. For example, some households had an extra fridge (6%) and freezer (29%). These extra appliances were found to be constantly on in some dwellings (e.g. HH1). However, a few households only plugged them in when they are truly needed (e.g. HH2, HH16). It was also found that most of the households had more than one television (76% of the households owned more than 1 TV and 23% have more than 2 TVs). Noted that some appliances such as mup, Telstra PVR, Foxtel, slow cookers, etc. that were only used in a few dwellings and therefore, these appliances have not been included in **Figure** 4.15.

4.3.1 Standby Power in the Surveyed Dwellings

Appliances can be on four power modes: in-use, active standby, passive standby and off (**Figure** 4.16).

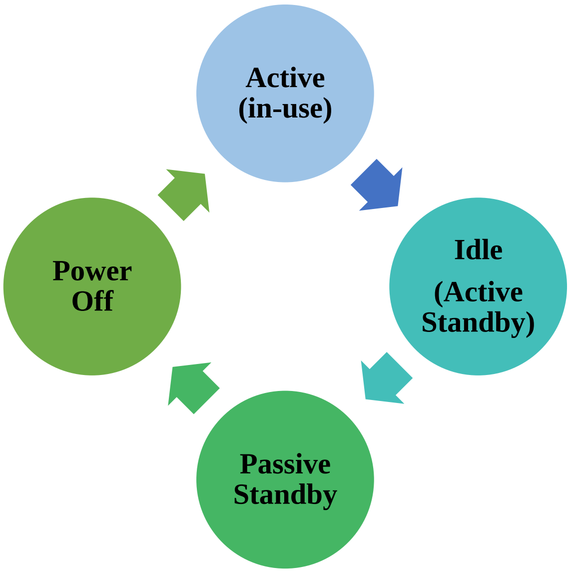

Figure 4.16 Power Modes of Appliances

The government of South Australia defined standby power as "the energy used by an appliance when it is not performing its main function" (Government of South Australia-Department of State Development). The active standby mode is when the appliance is on waiting to be used. For example, when a DVD player is turned on but no DVD is being played. Passive standby mode, on the other hand, is when the appliance is turned off, but can still be activated by remote control, internal sensor or timer. In other words, appliances performing a secondary function such as displaying the time are called to be on passive standby mode. A surprisingly large number of electronic appliances- ranging from microwave ovens to TVs and air-conditioners cannot be switched off completely unless being unplugged from the source. Many of these appliances use standby power to show the internal clock or to receive the remote control signals and sometimes there is no noticeable sign of continuous power consumption without a meter. Without the knowledge of consumers, appliances left in standby mode drew power 24 hours a day and seven days a week, resulting in high electricity bills.

Assumptions for Calculating Appliances' Standby Power

Over 10% of the electricity consumption in Australian households is attributed to standby power consumption by the appliances (Australia. Bureau of Statistics 2010). In order to incorporate the standby power usage into the energy audit of the sample dwellings, where applicable (as found from direct observations in the households), standby power consumption for appliances was collected online using the model number of appliances. When the information was not available, the assumptions from Berkeley Lab (Laboratory 2018) were used for the purpose of analysis (**Table** 4.4).

Table 4.4 Standby power consumption by some electronics

Product	**Mode**	**Average Standby Power (W)**
Charger, mobile phone	On, charged	2.24
Clock, radio	On	2.01
Computer Display, LCD	Sleep	1.38
Computer Display, desktop	Sleep	21.13
Set-top Box, DVR	On, not recording	37.64
Stereo, portable	CD, not playing	4.11
DVD Player	On, not playing	7.54
DVD/VCR	On, not playing	13.51
DVD	On, not playing	7.54
Garage Door Opener	Ready	4.48
Microwave Ovens	Ready, door closed	3.08

(Source: Lawrence Berkeley National Laboratory)

The main appliances e.g. microwaves, entertainment appliances (TVs, DVD players), and PCs were found to be often left on standby in the surveyed households. Note that the standby power incorporated into the walk-through energy audit in the sample households is the energy used by the appliances when they are on passive standby mode.

4.3.2 Distribution of Electricity Consumption According to Orientation

In order to justify the distribution of electricity consumption in the sample dwellings, the result of the walk-through audit was evaluated concurrently in the dwellings having a similar orientation. Dwellings in each group were similarly exposed to solar radiation and the prevailing wind. By eliminating the influence of orientation (especially on the use of heating and cooling appliances in the dwellings), therefore, the influence of other factors on households' electricity consumption such as the type and number of the appliances, as well as the occupants' behaviour with respect to the use of appliances were better justified.

South-Facing Dwellings: Households 2 and 7

Analysis of historical electricity consumption data during 2013-14 revealed that the average daily electricity consumption in these two dwellings followed an approximately similar trend, with both households experienced the maximum consumption in extreme seasons. The average daily electricity consumption in these two households, which were clustered as regular electricity users (**Figure** 4.5) ranged between 7.9 and 12.9 kWh / day in household 2 and between 6.8 and 13.4 kWh / day in household 7.

In order to find out the extreme electricity users that significantly affect the households' electricity bills, findings from the energy audit was used and combined with the detailed information provided by the households' representatives, on the frequency and the time of use of the appliances backed up with direct observation on a typical summer and winter day. **Table** 4.5 presents the breakdown of electricity consumption in extreme seasons in household 2 and 7.

Table 4.5 Breakdown of electricity consumption in HHs 2 and 7

Appliances	**Electricity Consumption (%)**			
	Summer		**Winter**	
	HH2	HH7	HH2	HH7
Refrigeration	14	19	28	16
Heating/Cooling	57	36	16	48
Lighting	2	2	3	2
Entertainment	23	9	45	7
Laundry	1	20	1	16
Standby	1	9	3	7
Other Appliances	2	5	4	4

Distribution of electricity consumption in each household varied significantly throughout the year (see **Table** 4.5). In summer, more than half of the electricity (57%) in HH2 was spent on space cooling, which was significantly higher than in HH7, which spent 36% of its total electricity on space cooling. On the other hand, with HH2 owning a variety of entertainment devices (e.g. Telstra-tab, 2 laptops, blue-ray disk, media player computer, 2 stereo and amplifier, 3 TVs, etc.), these appliances stood out as the second intensive electricity users in this household (23% and 45% in summer and winter respectively). Laundry appliances (i.e. washing mashing and iron), however, was the second-highest electricity users in HH7 (about one-fifth of the electricity in summer and 16% in winter in HH7 was attributed to the appliances grouped as laundry). According to the survey, HH7 used washing machine 3 times a week and ironed once a week (10 min on average). The result of energy audit further revealed that although HH2 has more electronic devices that could potentially leave on standby (e.g. entertainment appliances), HH7 spent significantly higher on standby power consumption (9% and 7% against 1% and 3% in HH2 during summer and winter respectively).

South-West Facing Dwellings, Households 4 and 17

HH4 and HH17 both experienced sudden changes in their electricity consumption during 2013-14 (see **Figure** 4.6). In HH4, this change started in May 2014 and reached its maximum in September 2014. The peak consumption in HH17, however, occurred in June 2013. According to the HoH in HH4, a portable swimming pool was used in the dwelling for some time during the period under investigation, which might have been the main cause of the increased electricity consumption in the household. However, no exact dates were specified by the HoH for using the pool.

Table 4.6 summarises the breakdown of electricity consumption in HH4 and HH17 based on the results of the walk-through energy audit, the information provided by the households' representatives and direct observations.

Table 4.6 Breakdown of Electricity Consumption in HH 4 and 17

Appliances	**Electricity Consumption (%)**			
	Summer		**Winter**	
	HH4	HH17	HH4	HH17
Refrigeration	12	49	5	45
Heating/Cooling	4	0	50	8
Lighting	2	4	1	5
Entertainment	52	20	23	18
Laundry	3	14	8	12
Standby	6	5	3	5
Other Appliances	21	8	10	7

HH4 spent more than half of its electricity consumption in summer and less than a fourth in winter on entertainment (mainly personal computers used by children, TVs, VCR, etc.) (**Table** 4.6). Household 17, however, spent significantly less on this group of appliances (20% and 18% in summer and winter respectively). In summer, HH4 used only 1 standing fan, which constituted to only 4% of electricity consumption. However, no cooling system was used in HH17. In winter, on the other hand, HH4 spent half of its electricity on space heating using two identical 1800-2000 watt electric heaters running on an average 10h/day. This was significantly higher compared to HH17 that spent only 8% on space heating.

In HH17, refrigeration was the primary electricity consumer (49%), followed by entertainment (20% and 18% in summer and winter) and laundry (14% and 12%).

North-East Facing Dwellings, Households 1 and 12

Except for a sudden drop in August 2013 (to 7.2 kWh/day), electricity consumption in HH1 was almost stable during 2013-14. However, HH12 experienced two sudden rises in its electricity consumption during the same period. The average daily electricity consumption in this household rose from 8.6 kWh/day in August to 17.2 kWh/day in October 2013. After a quick fall in March 2014 (6.9 kWh/day), the household’s ADEC raised again to 23.1 kWh/day in September 2014. **Table** 4.7 shows the breakdown of electricity consumption in these two north-east facing dwellings.

Table 4.7 Breakdown of electricity consumption in HHs 1 and 12

Appliances	**(Electricity Consumption %)**			
	Summer		**Winter**	
	HH1	HH12	HH1	HH12
Refrigeration	36	20	45	6
Heating/Cooling	12	na	0	62
Lighting	5	3	8	1
Entertainment	16	62	21	23
Laundry	15	1	5	1
Standby	5	2	6	1
Other Appliances	11	12	15	4

Major differences existed between the distributions of electricity consumption in these two households. With two fridge-freezers (348 watts and 130 watts) running simultaneously in HH1, a significant proportion of electricity in this household was spent on refrigeration (36% and 45% in summer and winter respectively). This was, higher than the electricity spent on refrigeration in HH12 with a 235 watts' fridge-freezer (20% and 6% of the total household electricity consumption in summer and winter).

HH1 and HH12 both used fans to cool down the house in summer. Since no information was provided by the respondent in HH12 about how the fan was used in this household, no approximation could be made for its electricity consumption. In winter, on the other hand, no heating system was used in HH1. However, 62% of electricity in HH12 was spent on space heating with a 1500-Watt ceramic fan heater for an average 10hrs/day). The results further revealed that entertainment devices including TVs, laptops, DVD players, etc. were among the major electricity consumers in both households, which contributed to 16% and 21% of the electricity consumption in HH1 and 62% and 23% of the electricity consumption in HH12 in summer and winter respectively.

North-West Facing Dwellings: Households 13 and 14

HH14 experienced a peak in its ADEC in February 2014. As shown in **Figure** 4.6, the ADEC in this household raised from 11.9 kWh/day in December 2013 to 21 kWh/day in February 2014. During the same period, however, electricity consumption in HH13 had a steadier trend (**Figure** 4.5). The average daily electricity consumption in this household ranged between 7-11.3 kWh/day during 2013-14, while the household experienced its highest electricity consumption in winter. **Table** 4.8 presents the breakdown of electricity consumption in these two households.

Table 4.8 Breakdown of electricity consumption in HHs 13 and 14

Appliances	**(Electricity Consumption %)**			
	Summer		**Winter**	
	HH13	HH14	HH13	HH14
Refrigeration	21	40	16	54
Heating/Cooling	14	37	33	16
Lighting	4	3	4	5
Entertainment	23	11	18	14
Laundry	10	1	8	1
Standby	4	1	3	1
Other Appliances	24	7	18	9

It was found that only a small portion (14%) of summer electricity consumption in HH13 was attributed to space cooling. In winter, however, the household spent nearly a third of its electricity on space heating (**Table** 4.8). Household 14, On the other hand, spent more on space cooling (37% on space cooling in summer against 16% on space heating in winter). It was also found that HH14 owned two fridge-freezers (500 Watts and 348 Watts) that were mostly running at the same time. Therefore, the household spent a significantly high proportion of its electricity on "refrigeration". However, due to owning diverse electric devices, HH13, spent more on appliances such as a rice cooker, microwave, toaster, mixer, etc. (24% and 18% in summer and winter) followed by entertainment (23% and 18% in summer and winter). The proportion of electricity consumption on these appliances was notably lower in HH14 (only 7% and 9% on other appliances and 11% and 14% on entertainment).

From the household interview (verified by direct observations) it was found that that HH14 was highly concerned about the standby power consumption by different appliances and the energy used by lightings in the dwelling. As shown in **Table** 4.8, only 1% of the electricity used in this household was attributed to the standby power, which was lower than the standby power consumption in HH13. According to the household's representative:

…// We turn off all the lights when we are watching TV in the living area//…

North-Facing Dwellings: Households 5 and 6

Electricity consumption in HH5 and HH6 varied within a certain range. While the average daily minimum and the average daily maximum electricity usage in HH5 ranged between 5.2 and 9 kWh/day, it was significantly higher in HH6, ranged between 8.5 and 26.7 kWh/day, with both of these households experienced their highest consumption in summer. HH5 used an evaporative cooling system to cool down the house in summer, while a gas heater was used in winter (no electricity was used for heating in this household). Similarly, in HH6 which was using an evaporative cooling system in summer, no heating system was used during winter. **Table** 4.9 summarizes the distribution of electricity consumption in each of these households.

Table 4.9 Breakdown of electricity consumption in HHs 5 and 6

Appliances	**Electricity Consumption (%)**			
	Summer		**Winter**	
	HH5	**HH6**	**HH5**	**HH6**
Refrigeration	20	16	39	40
Heating/Cooling	49	59	0	0
Lighting	2	1	5	3
Entertainment	8	9	15	19
Laundry	8	4	16	11
Standby	1	1	2	2
Other Appliances	12	10	23	25

In summer, a significant proportion of electricity in both households was spent on space cooling (49% in HH5 and 59% in HH6), followed by refrigeration (20% and 16% in HH5 and HH6), other appliances (12% and 10% in HH5 and HH6) and Entertainment (8% and 9% in HH5 and HH6). The cooling systems used in these households included a portable air conditioning system (evaporative) together with 2 fans in HH5 and a 1330-watt portable air conditioning system (evaporative)in HH6.

During winter, no heating system was used in HH6. With HH5 used a gas heater, refrigeration was found to be the major electricity consumer in both of the households, contributed to 39% of electricity consumption in HH5 and 40% of electricity consumption in HH6 r. As shown in **Table** 4.9, nearly one-fourth of electricity in both of the households spent on other appliances including grinder, sandwich maker, microwave, toaster etc. in HH5 and halogen convection oven, slow cooker, coffee maker, etc. in HH6.

East-Facing Dwelling: Household 3

From the historical electricity consumption data in HH3, it was found that the average daily electricity consumption in this dwelling ranged between 8.6 kWh/day and 13.1 kWh/day (see **Figure** 4.5). It was also found that no significant difference existed between electricity consumption trends in 2013 and 2014. While the minimum electricity was used in mid-seasons, the maximum consumption occurred in summer during both 2013 and 2014 (13 kWh/day and 13.1 kWh/day in summer 2013 and 2014) and winter (12.6 kWh/day and 13 kWh/day in 2013 and 2014 respectively). The breakdown of electricity consumption in HH3 is shown in **Table** 4.10.

Table 4.10 Breakdown of electricity consumption in Household 3

Appliances	**(Electricity Consumption %)**	
	HH3	
	Summer	**Winter**
Refrigeration	3	2
Heating/Cooling	79	83
Lighting	1	2
Entertainment	4	4
Laundry	3	1
Standby	2	2
Other Appliances	8	6

Using two reverse cycle air-conditioning systems (Cooling Capacity = 3.5/4.8 kW and Heating Capacity = 5.2/6.25 kW), mostly running at the same time during summer and winter, a large proportion of electricity in HH3 was spent on space heating and cooling (79% on space cooling in summer and 83% on space heating in winter). This finding is in line with the household's historical electricity consumption data (**Figure** 4.5), which confirmed that the maximum electricity was used during extreme seasons. Appliances such as microwave, electric kettle, toaster and vacuum cleaner constituted about 8% of the electricity consumption in summer and 6% in winter, followed by entertainment appliances (4%). Only 1% of the ADEC in summer and 2% in winter was found to be attributed to lighting.

West-Facing Dwelling: Household 16

Analysis of historical electricity consumption data revealed that the average daily electricity consumption in this dwelling ranged between 9.3 kWh/day and 16.6 kWh/day in 2013 and between 11.6 kWh/day and 20.6 kWh/day in 2014 (**Figure** 4.6). **Table** 4.11 presents the breakdown of electricity consumption in HH16 during summer and winter.

Table 4.11 Breakdown of electricity consumption in HH16

Appliances	**(Electricity Consumption %)**	
	HH16	
	Summer	**Winter**
Refrigeration	41	46
Heating/Cooling	11	0
Lighting	4	5
Entertainment	25	28
Laundry	4	5
Standby	2	1
Other Appliances	13	15

Refrigeration was found to be the most intensive electricity consuming appliances in this household. Running a 122-Watt freezer, a refrigerator and a 200-watt fridge-freezer at the same time, 41% of the electricity consumption in summer and 46% of the consumption in winter was attributed to this group of appliances.

In summer, 2 standing fans were used in this household. Although no heating system was reported by the HoH during the energy audit, from the historical electricity consumption data, it was discovered that the average electricity consumption in this household was significantly higher in winter. As shown in **Figure** 4.6, the ADEC in 2013 raised from 12.9 kWh/day in summer to 16.6 kWh/day in Winter. In 2014, the ADEC increased from 12.6 kWh/day in summer to 20.6 kWh/day in winter. The existing discrepancy might have been caused by using a heating system(s), which was not reported by the HoH at the time of interview. Lighting constitutes 4% and 5% of the average daily electricity consumption in summer and winter respectively.

South-East Facing Dwelling, Household 11

Electricity consumption in HH11, which has been grouped as a regular electricity user (see **Figure** 4.5) followed a steady trend, ranged between 6.6 and 9.9 kWh/day, with the household experienced its maximum electricity consumption in summer during both 2013 and 2014 (9.9

kWh/day and 9.4 kWh/day in 2013 and 2014 respectively). **Table** 4.12 presents the breakdown of electricity consumption on a typical summer and winter day in this household.

Table 4.12 Breakdown of electricity consumption in Household 11

Appliances	**(Electricity Consumption %)**	
	HH11	
	Summer	**Winter**
Refrigeration	29	36
Heating/Cooling	32	0
Lighting	3	4
Entertainment	30	37
Laundry	1	16
Standby	2	2
Other Appliances	4	5

As shown in **Table** 4.12, the major proportion of electricity in summer was spent on space cooling, using a portable evaporative cooler (32%). However, with the household used a gas heater in winter, no electricity was spent on space heating. Entertainment appliances including 2 laptops, video game, 2 TVs, DVD player, etc. were the second-highest electricity consumers in summer, and the first one in winter (30% and 37% in summer and winter respectively).

It was found that a 413-Watt fridge-freezer was running in this household together with a freezer, which made the refrigeration to stand as one of the major electricity consuming appliances in this household. These appliances together contributed to 29% and 36% of the household electricity consumption in summer and winter respectively.

As shown in **Table** 4.12, a significant difference existed between the electricity consumption by the appliances grouped as "Laundry" during summer and winter. According to the HoH, the existing difference is mainly caused by using the dryer for an average of 2 hours/day in winter.

4.4 Developing Guidelines for Improving the Energy Performance of Occupants in the Sample Dwellings

Findings from the household survey and walk-through energy audit revealed that electricity consumption- as the main source of energy in the surveyed household- significantly varied in the sample dwellings. From long-term direct observations, it was found that except the diversity of appliances used in the households and their efficiency, different socio-economic characteristics of occupants and their energy use behaviour to a great extent affect the variation in the households' electricity consumption. Indeed, households with different socio-economic characteristics used diverse electronic appliances in different ways, resulted in different energy consumption patterns. However, since most of these households were on low income, enhancing the efficiency of electronics including heating/cooling systems used in these households by replacing them with more efficient appliances could not be simply achieved.

In order to assist the sample households with their everyday energy usage, mostly the portion spent on space heating/cooling during extreme seasons, guidelines were developed to address the areas of inefficacy observed in the sample households at minimum cost. These guidelines were then tailored based on the specific requirements of each household and communicated with the occupants during a face-to-face meeting with all the occupants were present. **Table** 4.13 presents a summary of these general guidelines. The detailed guidelines are presented in Appendix 4B.

Table 4.13 Guidelines for reducing energy consumption in social housing dwellings

DOs and DON'Ts in Winter	***DOs and DON'Ts in Summer***	***Generic Guidelines***
Open all the curtains and blinds in the Morning	Close all the doors, windows and blinds in the morning before it is getting too hot!	Test the windows or door for leaks by burning an incense stick or a candle; If the smoke flickers, you have an air leak: Tighten up around the windows and doors by adding new weather-stripping
Close them all in the evening	Open the windows and curtains again in the evening and night	Use washing machine with a full load
Close all the windows and curtains before turning on the heater	Cool the house by shading the East and West windows	Say NO to cloth dryers! Hang the clothes outside
Set the heater on: 20 °C in the kitchen/living area 15 – 18 °C in bedrooms	Set the temperature at around 25 °C	Switch off the appliances at the wall or power strips
If applicable, adjust the heaters louvres down towards the floor	Install the air conditioner on the shady side of the house	Avoid opening the oven door when cooking
Only heat up the rooms in use and close the openings to the cooler rooms. It saves up to 75% of the heat loss!	Only cool down the rooms in use and close the openings to other rooms.	Unplug the charger when your mobile phone is fully charged.
Use heavy curtains to reduce heat loss through the window	Close all curtains to prevent heat gain through the window	Set fridge temperature to 4 °C or 5 °C and freezer temperature on 15-18 °C. Every degree lower that uses around 5% more energy
Choose the heater carefully! Unlike the purchase price that is less in case of portable heaters (compare to gas heater and reverse- cycle ACs), the running cost of these heaters is significantly high!	Economical cooling appliances are: fan, evaporative cooler, reverse-cycle AC	Use Energy Efficient lamps (CFL or LED)

4.5 Influence of Building and Occupant-Related Factors on Domestic Electricity Consumption

In order to create an insight into how different factors affect electricity consumption in the sample dwellings, a number of factors including the floor area, household size, disposable household income, HoH gender, occupancy patterns, presence of children and window opening behaviour are plotted against the Average Annual Electricity Consumption (AAEC) in the dwellings. Out of the total 17 households participated in the survey, 4 households did not provide their historical energy information. Four more households also used different sources of energy other than electricity for heating and hot water system respectively (dwellings with electric heaters and gas hot water systems were assigned for electricity analysis). By removing these 8 households, the number of households for analysing electricity consumption in the dwellings stood at only 9 households. All of these households used electricity for heating and cooling and gas hot water system. Using information extracted from the household's online electricity bills (collected upon obtaining the HoHs' consent at the time of the interview), the average annual electricity consumption during 2013-2014 was then calculated in these dwellings.

Consumption data was transformed into 3 different metrics including Average Annual Electricity Consumption per Person (AAEC/P), Average Annual Electricity Consumption per m^2 floor area (AAEC/m^2) and Average Annual Electricity Consumption per person per m^2 floor area (AAEC/P.m^2) in order to create a measure for comparing the electricity consumption in different dwellings. Out of the three measures, however, AAEC/p.m^2, which takes into account both the HH size and the floor area, is used as the common metric for evaluating the electricity consumption in the eligible households.

4.5.1 Household (HH) Size

Figure 4.17 presents the AAEC/p.m^2 against the number of people living in the surveyed households.

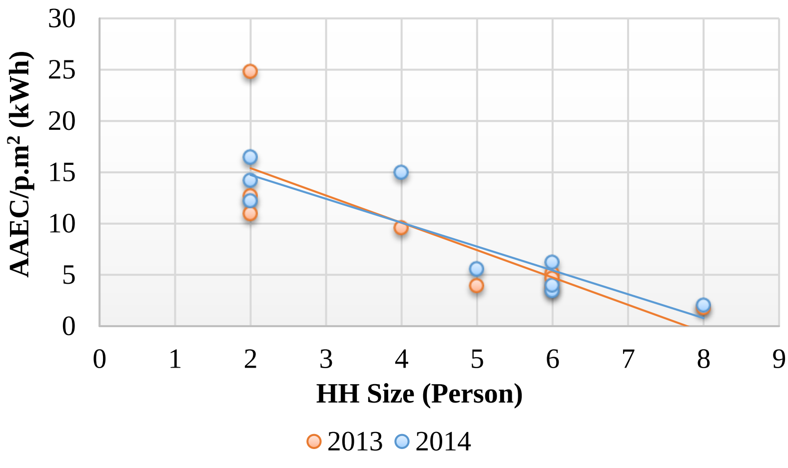

Figure 4.17 AAEC/P.m^2 (kWh) against HH size

By increasing the number of occupants in the sample households, the AAEC/p.m^2 decreased (R^2 = 0.67 and 0.82 for 2013 and 2014 respectively). A similar graph plotting AAEC/P (kWh) versus the household size also revealed that on average, less per person electricity was used in the bigger households with more occupants. Although the total annual electricity consumption in larger households was higher than in smaller households, small R^2 values confirm that household size does not strongly explain the variation in AAEC per person in the households (R^2 = 0.09 and 0.02 for 2013 and 2014 respectively). A similar outcome was reported by some other researchers. For example, Kavousian et al. (2013) used 10-min interval electricity consumption data for 1628 U.S. households over the period of 238 days (28th February – 23rd October 2010) and found that a twofold increase in the number of occupants may cause electricity consumption rise at a slower rate. In their sample, larger households had higher aggregate electricity consumption but had lower per capita consumption. Household characteristics incorporated into their model included appliances and electronics stock, demographics, and occupants' behaviour including occupancy pattern, purchasing energy efficient appliances, thermostat set-points). In another study in the UK, Yohanis, et al. (2008) used half-hour electricity consumption data in 27 households and found that per person electricity consumption decreases as the number of occupants increases. Their result was particularly significant in large dwellings as the number of occupants per dwelling gets smaller (Yohanis et al. 2008).

4.5.2 Floor Area

The variation in electricity consumption in the dwellings with respect to the dwelling size is presented in **Figure** 4.18.

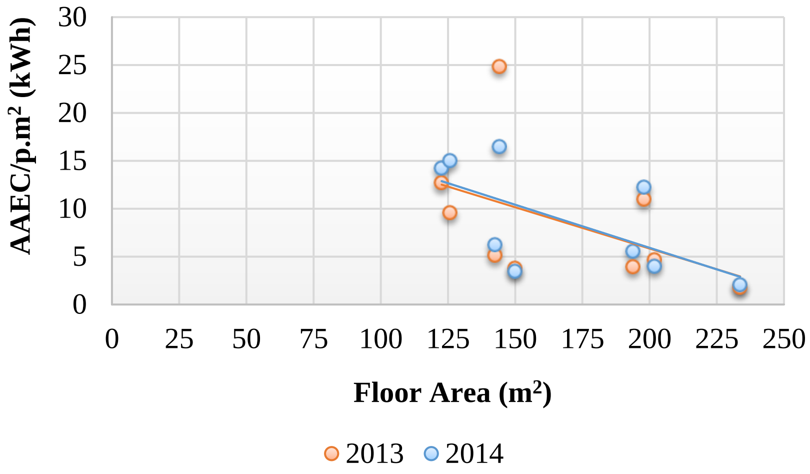

Figure 4.18 AAEC/p.m^2 against floor area (m^2)

Although larger dwellings were expected to consume more electricity caused by having more lighting fixtures and electronics and perhaps more number of rooms to be heated and/or cooled, the survey results show that less electricity per person per m^2 was used in the bigger dwellings (R^2= 0.22 and 0.39 for 2013 and 2014 respectively) (**Figure** 4.18). For example, in 2013, the AAEC/P.m^2 in a 144.19 m^2 dwelling was much higher than that in a bigger dwelling with 198 m^2 floor area (24.84 kWh/P.m^2 and 10.97 kWh/P.m^2 respectively). Similarly, the graphs plotting the AAEC per person and per m^2 against the dwelling size revealed a downward trend, suggesting that households living in bigger dwellings spent less on electricity both per person and per unit area. In India, Pachauri (2004) demonstrated that larger areas require more electrical fittings and fixtures such as fans, lights, coolers, etc. Therefore, people living in larger dwellings would have higher total per capita energy requirements (MJ/capita/year). Similarly, in the U.S., Ewing and Rong (2008) compared energy consumption by two households lived in 1,000 and 2,000 - square - foot buildings and showed that more energy was required for heating, cooling, and all other usages in the household lived in the larger house.

With the majority of our surveyed households were on low – middle income and did not have extensive electronic devices to impact their consumption, the existing discrepancy in the influence of the floor area on the households' electricity consumption can be justified.

4.5.3 Disposable Household Income ($/fortnight)

DHI per fortnight was used as a measure for evaluating the relationship between households' income and the average annual electricity consumption in the dwellings. Out of the total households that participated in the electricity analysis (9 households), two households treated income as strictly confidential information and did not share it with the research team. Therefore, they have been removed from this section of the analysis. **Figure** 4.19 shows how electricity consumption in the sample of households affected by their disposable income.

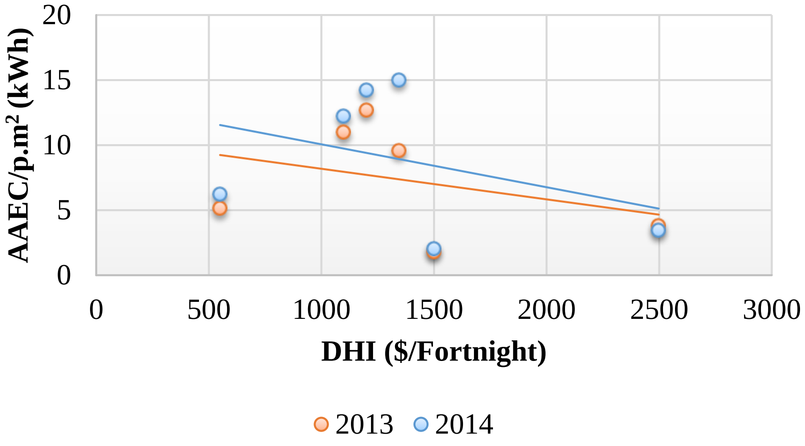

Figure 4.19 AAEC/P.m^2 against DHI excluding the high-income household

Although household income is one of the main criteria that need to be met by the successful FH applicants and despite annual income check is performed by FH to ensure the on-going eligibility of the qualified households, surprisingly only half of the sample households were on low-income, while 12% was on low-middle income and a further 12% was on high-income level. Surprisingly, despite the so-called income eligibility criteria by FH, some of these high earners were living in the FH property for more than 4 years. The presence of high-income households in the survey sample significantly affects the relationship between disposable household income and the household' electricity consumption. When this household is removed, higher-income households seem to spend less on electricity per person per square meter than their lower-income peers (See **Figure** 4.19). Nevertheless, the relatively small R^2 value (R^2 = 0.12 and 0.13 for 2013 and 2014 respectively) suggests that variation in per person per m^2 electricity consumption in the households cannot strongly be explained by their income level. .This can be to a certain extent caused by the small sample size. It is worth mentioning that a similar trend exists between the average annual electricity consumption in the households, both per person and per unit floor area, and the DHI. Similarly, through surveying 1140 households, Santamouris et al. (2007) found that the low - income households in Athens that are more likely to be living in older dwellings with inefficient envelopes and using older appliances consume more energy and pay more for both heating and electricity per person and per unit area. Nevertheless, Guerra Santin et al. (2009) found a small link between income and domestic energy consumption for space and water heating in Dutch dwellings (MJ/year).

4.5.4 Hours of Occupancy

Figure 4.20 presents the average electricity consumption in the surveyed dwellings against the number of hours the houses were occupied on a typical weekday.

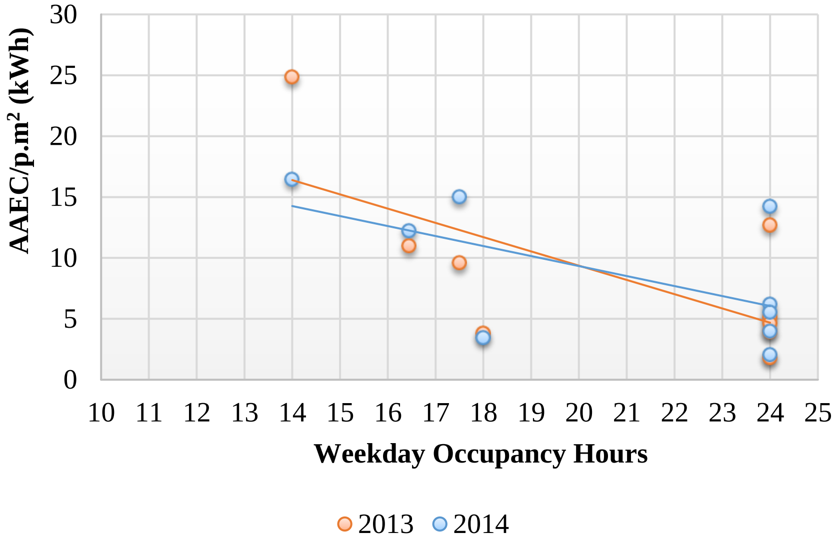

Figure 4.20 AAEC/p.m^2 against occupancy hours on a typical weekday

Electricity consumption in the surveyed dwellings with different occupancy patterns ranged between 1.8 and 24.9 kWh/p.m^2 in 2013 and between 2.0 and 16.4 kWh/p.m^2 in 2014 (**Figure** 4.20). Generally, more electricity is expected to be used in households that are always occupied compare to those in which, the occupants are never home or their presence is variable mainly because more appliances and lighting are often used in the first group of dwellings (Guerra Santin et al. 2009). However, findings from the household survey revealed that as occupancy hours in the sample households during weekdays increased, electricity consumption per person per m^2 lowered (R^2 = 0.45 and 0.36 for 2013 and 2014 respectively). A similar trend is also observed in the electricity consumption both per person and per unit of floor area (m^2), versus weekday occupancy hours in the sample households. Two possible causes may, to some extent, explain the existing discrepancy in the electricity consumption in the sample households with respect to their occupancy hours. In addition to the small sample size, inaccurate input data might have resulted in an inconsistency in the survey outcome. Occupancy pattern, which significantly affects the energy performance of a building is a highly biased independent variable. Despite this fact, however, the majority of the respondents to the survey questions could not provide a precise occupancy pattern for their households. These respondents, who were in the most cases the HoHs were spending a portion of their weekday at work had less accurate knowledge about the occupancy in the dwellings.

4.5.5 Gender

In order to understand how electricity consumption in the dwellings is affected by the HoH gender, the average annual electricity consumption was calculated separately for households with male and female HoHs. **Table** 4.14 presents a summary of findings.

Table 4.14 A comparison of average annual electricity consumption between the households with a male and a female HoH

		Male HoH	Female HoH
Year	**Number of Households**	4	5
2013	AAEC/P (kWh/2013)	619.53	1890.02
	AAEC/m^2 (kWh/2013)	21.85	32.62
	AAEC/P.m^2 (kWh/2013)	3.66	12.54
2014	AAEC/P (kWh/2014)	738.04	1846.4
	AAEC/m^2 (kWh/2014)	19.92	33.95
	AAEC/P.m^2 (kWh/2014)	4.31	12.38

In contrast with other studies that found in households with women in charge of controlling the energy consumption and expenditure, the energy consumption is the lowest (Permana et al. 2015) or those that found no indication that the HoH gender affects households' electricity expenditure (Kim 2018), average annual electricity consumption with respect to all three measures, AAEC/P, AAEC/$m^{2,}$ and AAEC/P. $m^{2,}$ in the sample households with a female HoH, was higher than those with a male HoH. As shown in **Table** 4.14, in some cases the households with a female HoH consumed up to 3.4 times more electricity than the households with a male HoH (e.g. AAEC/p.m^2 in 2013). However, small sample size prevents generalizing the findings.

4.5.6 Presence of Children/Elderly in the Households

With the elderly contributing to only 6% of the survey sample, their influence on electricity consumption in the households has been negated. At the time of the interview, seven out of the total of nine households participating in the electricity analysis had children (occupants below 12 years old). A comparison between electricity consumption by the households with and without children revealed that on average, households with children consumed less electricity (per person per m^2) than those without children. Less per person electricity consumption in these households, however, may be attributed to the higher number of occupants in these households compare to those with no children. Moreover, when the average consumption is calculated, higher consumption by some households might be, to some extent, offset by the lower consumption in other households (in the same group). Therefore, the presence of children in the surveyed households is not significant in explaining the electricity consumption trends of the surveyed dwellings. However, in other studies, the number and ages of children are established as the two significant factors in explaining the energy requirements of households (Brounen et al. 2012). For example, Deng et al. (2018) found that the child dependency ratio significantly and negatively influences the Urban Residential Energy Consumption per Capita (URECP). The presence of one additional adult, however, may require more energy increase than one extra child (Longhi 2015).

4.5.7 Number of Hours Windows Were Open in the Living Area

The majority of the surveyed households heated or cooled only the main living area. Therefore, window-opening behaviour and the influence it might have on the electricity consumption in the dwellings were only investigated in the living area. The number of hours, windows were reported to be opened varied over a wide range, between 0-18 hours in summer and 0-16 hours in winter. Diverse trends were observed in the relationship between households' window opening behaviour and AAEC/P, AAEC/m^2, and AAEC/P.m^2. By increasing the number of hours, windows were open in the living area, the AAEC/P significantly decreased. AAEC/m^2, however, experienced an upward trend, while AAEC/P.m^2 was relatively constant.

Proper ventilation is known to passively affects occupants thermal comfort in the indoor environment (Ogoli 2003) by affecting the absolute temperature of the space (Aste et al. 2009). An unventilated space is significantly hotter in summer than the one constantly ventilated (Slee et al. 2013). Although adopting appropriate ventilation strategies can reduce a building's energy demand in summer, (Aste et al. 2009), occupants' window opening behaviour in this small sample is not significant enough in explaining the electricity consumption trends in the surveyed dwellings.

Summary

A survey followed by a walk-through energy audit was undertaken to provide an indication of the determinants of electricity consumption in Perth Social Housing in Western Australia. The household survey provided a range of information about a number of building and occupant-related factors, including floor area, household size, disposable household income, occupancy hours, Head of Household (HoH) gender, presence of children in the households and occupants' window opening behaviour that may influence the consumption in the dwellings in some way. Annual electricity consumption was also calculated for the sample households during 2013-14 using the information provided in their online electricity bills. It was found that the floor area, household size, disposable household income and HoH gender may, to a certain extent, explain the variation in electricity consumption of the sample households. Other factors such as the presence of children in the household and window opening behaviour of the building users, however, did not precisely explain the changes in the households' electricity usage mainly due to the small sample size. Occupants in the sample households were then, educated with a series of practical guidelines, which were proposed based on the information collected through the survey and energy audit and aiming at improving their energy performance mainly with respect to the use of heating/cooling systems and performing natural ventilation in the dwellings. In the next chapter, findings from temperature monitoring in the selected household are presented and variations in indoor temperatures that might have been caused by occupants' behavioural activities are discussed in detail.

CHAPTER 5

TEMPERATURE MONITORING IN THE SAMPLE DWELLINGS AND INVESTIGATING OCCUPANTS' BEHAVIOUR

Overview of Chapter

The sudden divergence of air and wall surface temperatures in a building may be an indicator for running some source of heating/cooling or performing natural ventilation in the building. Space heating/cooling is a significant component of electricity consumption and increases in electricity usage, often in extreme weather, can also be a sign of increased use of heating or cooling systems. Based on two-year diurnal indoor temperature monitoring in a number of sample households and using information collected from household interviews together with informal discussions with the occupants during data collection, the variations in indoor temperatures and electricity consumption in the sample households are analysed and the possible causes of trends are discussed in the following subsections. The aim is to gain some insight into different occupant behaviour with respect to operating heating/cooling appliances or using natural ventilation in the sample households.

5.1 Temperature Monitoring in the Sample Households

In order to evaluate occupants' behaviour with respect to the use of heating/cooling appliances and ventilation of the dwellings, indoor and outdoor diurnal temperature changes were monitored for a number of sample dwellings over the period January 2015 to December 2016. Five out of the seventeen households that participated in the survey agreed to have temperature loggers installed in their houses and share electricity consumption information with the research team. For the sake of brevity, the in-depth analysis of temperature in this chapter focuses on three households. The selection of the 3 households incorporated into this section of analysis was performed based on the different types of heating/cooling appliances used in these households as well as occupants' behaviour with regard to the use of these systems and how they ventilated the house. while HH1 used no heating/cooling all year round, HH2 used a reverse cycle air-conditioning system (mostly cooling) and HH4 used 2 electric heaters in winter, but no cooling system in summer.

Note that the HoH of HH1 did not agree to share the 2015-16 electricity information and thus no investigation could be carried out on possible links between household electricity consumption and diurnal temperature changes during the period under investigation for this household. The inclusion of HH1 was mainly for 2 reasons: firstly, HH1 was the only sample household that used no heating/cooling all year round, despite experiencing thermal discomfort in the dwelling. Evaluating how the indoor temperature and the wall surface temperature followed each other in a household with no heating or cooling, was useful as a benchmark comparison with households with heating/cooling systems i.e. comparing the divergence of the air temperature from that of the wall surface temperature with and without a source of heating/cooling in a dwelling. Secondly, from direct observations, it was found that, except in extreme weather conditions, HH1 was actively naturally ventilated through opening doors and windows, and curtains were adjusted to take the most out of the solar radiation (solar heat gains from north and east-facing windows). Therefore, the influence of natural ventilation was intended to be evaluated as a way of maintaining occupants' thermal comfort in the dwelling.

From the household interviews, it was found that heating/cooling systems (if any) were mostly used in extreme seasons, i.e. winter and summer in the main living area to maintain a certain level of thermal comfort for all occupants. Only a few HoHs reported that they sometimes heated or cooled the bedrooms (e.g. HH4) or ventilated this zone by opening windows (e.g. HH2). To that end, only temperature changes in the living area in summer and winter are examined. During these periods, the heating and cooling appliances were likely to be the major energy consuming appliances in the sample households.

As discussed in Chapter 3, Thermochrons DS1922L were used to record temperature changes in the sample dwellings (**Figure** 5.1).

Figure 5.1 Temperature logger Thermochrons DS1922L (Maxim Integrated 2019)

Thermochrons were programmed to record spot readings of temperature in the dwellings every 15 minutes. Since the DS1922L records a maximum of 4,096 high-resolution temperature values, data had to be downloaded and the loggers reprogrammed every 42 days. In order to save the recorded data in the memory, the loggers were programmed in such a way that if a household could not be visited within 42 days for any reason, the loggers automatically stopped recording to avoid overwriting the data recorded earlier. During the data collection, households' energy use behaviour was monitored, and occupants were asked about any changes in their energy performance since the last visits. These informal discussions significantly assisted data analysis by creating better insight into the households' daily energy use behaviour.

Temperature monitoring started in October 2014 and proceeded until December 2016. For analysis purposes, data has been selected for the two-year period of 2015-16 i.e. from January 1st 2015 to December 31st 2016. In assessing temperature changes in the sample dwellings, 3 types of variables were taken into account including:

- **External factors:** Including ambient temperature (average day-time and average night-time temperature) and Daily Global Solar Exposure (DGSE) (kWh/m^2);

- **Internal factors**: Including average values of day-time and night-time indoor air temperature, wall surface temperature, and the difference between the indoor air and wall surface temperature ((air-mass) temperature); and
- **System-related factors:** Including use of heating/cooling appliances, thermostat set-points of the air-conditioning systems and their time of use, and household electricity consumption.

DGSE is the total amount of solar energy for a day on a horizontal surface (Australia. Bureau of Meteorology 2018), which is higher on a clear sunny day in summer compared to a cloudy day in winter. Note that the value of DGSE is measured from midnight to midnight to provide daily readings. Information about DGSE was publicly available for each household on the Bureau of Meteorology (BOM) website (Australia. Bureau of Meteorology 2019), which was downloaded by entering the postcode/suburb of dwellings. The ambient temperature was recorded at the location of each dwelling with a DS1922L logger installed outside of each building, under the eaves to protect it from direct solar radiation or prevailing wind. In order to create a broader insight into the possible changes in households' energy usage pattern during the period under investigation, households' electricity consumption data were obtained from their online bills and assessed as a system-related factor. Each household's electricity consumption was estimated at the mid-point of the billing period, which was calculated using the end date of the billing period and the number of billing days, and represented by average daily electricity use for the period.

Reasons for changes in electricity usage in 2016 compared to the previous year are suggested on the basis of knowledge gained from direct observations, household surveys and energy audits, and information collected from the occupants during the data collections. Specifically, using the monthly average, daily average, and 15-minutes values of temperature data in the households, the analysis sought insight into when and how heating/cooling systems were used in the households in order to verify the information provided by the HoHs regarding the use of heating/cooling systems in the dwellings. Temperature data was grouped into day-time and night-time, based on the typical monthly sunrise and sunset times in Perth (timeanddate.com 2015) (see **Table** 5.1). Given that the loggers were programmed to record the temperature at 15-minute intervals, monthly sunrise and sunset were rounded up or down for the ease of classification.

Table 5.1 Typical sunrise and sunset times in Perth (rounded)

Month	Sunrise	Sunset
January	5:30	19:15
February	5:45	19:00
March	6:15	18:30
April	6:45	18:00
May	7:00	17:30
June	7:15	17:30
July	7:15	17:30
August	7:00	17:45
September	6:15	18:15
October	5:30	18:30
November	5:15	19:00
December	5:00	19:15

Source: (Time and Date Australia 2019)

Buildings orientation, as well as household composition (number of occupants in each household), was different in sample households. Furthermore, from direct observations, it was found that the pattern of energy use was significantly different in each household. Therefore, outcomes from temperature monitoring are discussed on a case by case basis for the sample households. In the following subsections, these scenarios have been discussed together with changes in the households' electricity consumption during 2015-16, where electricity consumption data was available. Direct observations, HoHs responses to the survey questions and informal discussions with the occupants during the 2-year data collection was then used to suggest possible reasons for differences in a household's indoor temperature profiles and electricity consumption over the period of consideration.

5.2 External Factors in Sample Households

Figure 5.2 shows the summary of external factors in one of the sample households during 2015-16.

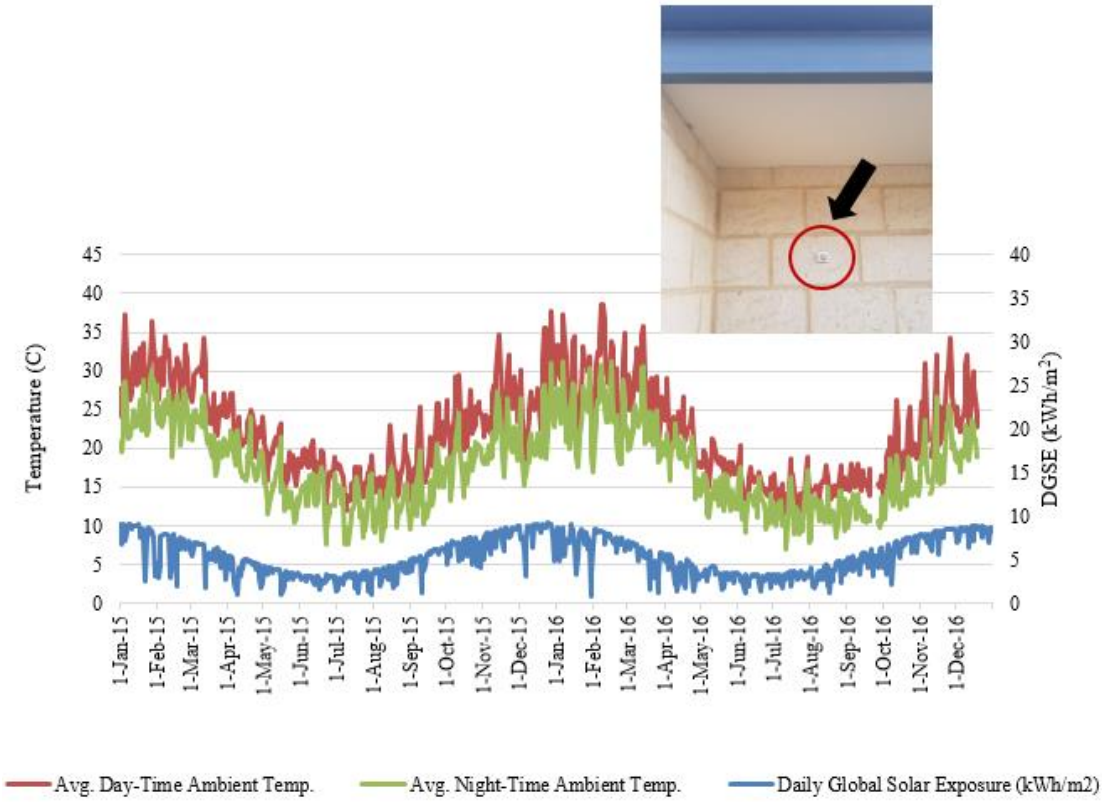

Figure 5.2 External factors in one of the sample households (HH1)

Although each household experienced unique daily ambient temperatures and DGSE (kWh/m^2), the average values were to a certain extent similar for all households, due to the relative close proximity of the households, in terms of degrees of latitude and longitude, and the consistency of the solar resource over such large areas. Appendix 5A shows the external factors in households 2 and 4. As expected, the ambient temperature and solar exposure, in both 2015 and 2016, were higher in January and lower in July for all households. In order to take the extreme weather conditions i.e. hot summer days (relatively high ambient temperature and solar exposure) and cold winter days (relatively low ambient temperature as well as solar exposure) into account, further investigation of indoor temperature fluctuations in the selected households targeted these two months of the year. For some households (e.g. HH4), temperature data was incomplete for January and July and in this case, different months were considered depending on the availability of the temperature data. A few hot/cold spells were then selected within each month and changes in the indoor air and wall surface temperature were investigated further in detail and discussed in relation to possible actions that might have been taken by the occupants in the dwellings in regard to using a heating/cooling system and/or naturally ventilating the dwelling. It is worth mentioning that throughout this chapter, days with relatively high ambient temperature and high solar exposure in summer are referred to as "peak days" and days with relatively low ambient temperature and low solar exposure in winter are referred to "trough days".

5.3 Electricity Consumption and Temperature Changes in Sample Households

5.3.1 Scenario 1: Household 1

Figure 5.3 shows the position of loggers, dominant ventilation and solar heat gain pathways through the north and east-facing windows in HH1. Note that four children lived in this household and, as discussed in Chapter 3, loggers were installed approximately 60 cm below the ceiling to minimise the chance of recording inaccurate temperature by children touching the loggers.

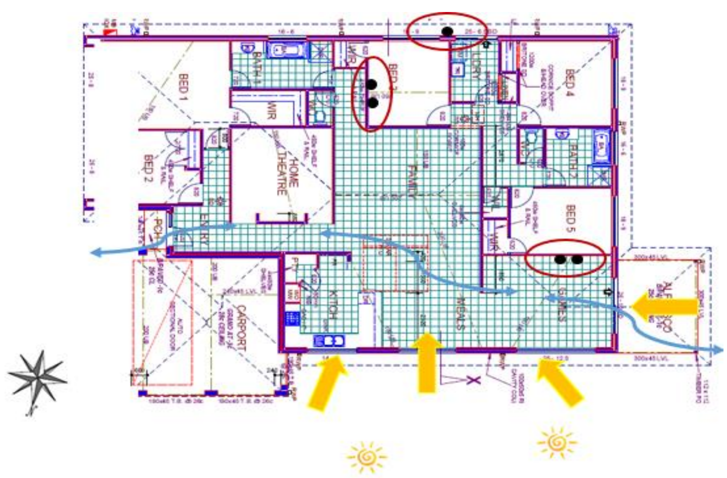

Figure 5.3 Logger positions, prevailing natural ventilation and solar heat gains in HH1

* Black dots represent loggers, yellow arrows represent solar heat gain through north-facing windows and blue arrows represent natural ventilation in the dwelling

The building envelope consisted of the typical building components in Western Australia: cavity brick external walls with no insulation and colorbond roof. The internal walls were brick plaster and the ceiling is plasterboard with R4.0 insulation. All the windows in this 6.5-star dwelling were single clear aluminium (U-value: 6.46 W/m^2 K), shaded by 480 mm eaves all-around the building.

From the energy audit of the dwelling (confirmed by direct observations), it was found that a 40 cm misting fan was the only conditioning system in HH1, which was said to be hardly turned on. No other heating/cooling system was reported in this household, in neither summer nor winter. On an average day, the dwelling was observed to be actively ventilated through opening the front door and the back sliding door. However, if the ambient temperature was beyond the occupants' comfort limit, all the openings, as well as the curtains, were kept shut both in summer and winter, preventing the excess heat or coolth entering the dwelling. In order to create a better insight into the occupants' behaviour with respect to natural ventilation in this household, indoor temperature fluctuations in the dwelling are analysed and discussed in the following sub-sections.

Temperature Changes and Occupants' Behaviour in Summer

Figure 5.4 presents the average ambient temperature recorded by the logger installed outside of the building and the total daily global solar exposure from BOM in HH1 in January 2015 and 2016.

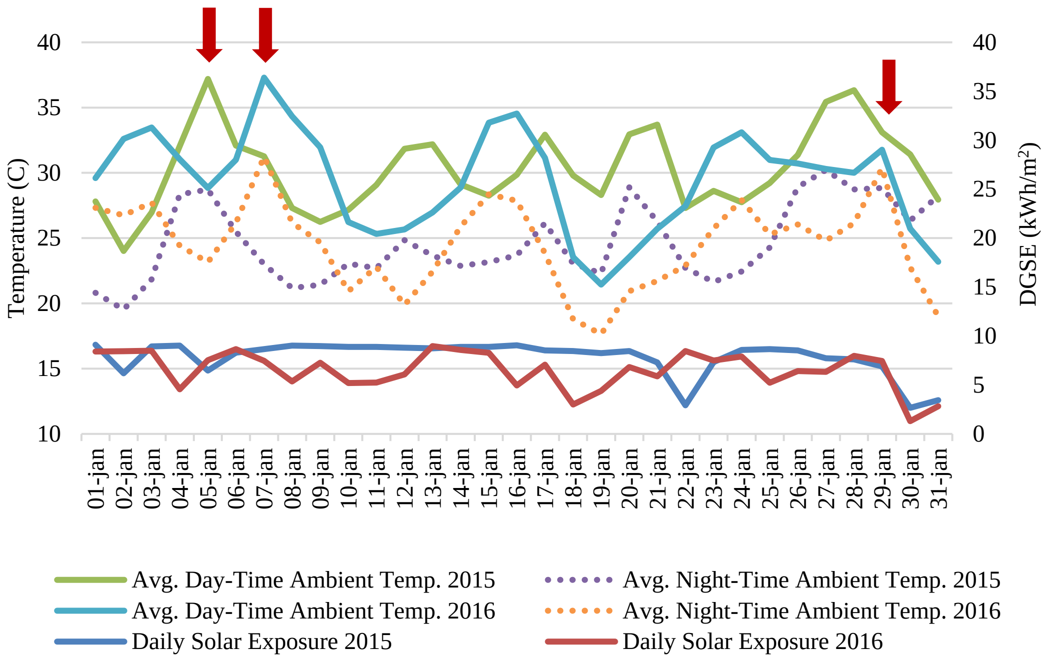

Figure 5.4 Average ambient temperature and DGSE (kWh/m^2) in January 2015-16

As shown in **Figure 5.3**, DGSE was more consistent across the month in 2015 than 2016 – particularly from the 6th to the 20th of January, 2015. In contrast, DGSE values had greater fluctuations in January 2016. Due to the greater fluctuations in solar radiation, there were more fluctuations in the outdoor temperature in 2016 and this resulted in greater fluctuations in indoor temperature in 2016 compared to 2015. The range of day-time ambient temperatures in January 2015 and January 2016 are similar although 2015 has 3 days over 35 °C compared to just one day for 2016. The ambient temperatures on January 5th, 2015 and January 7th, 2016 were close in value and were the maximum temperatures recorded for the respective months (see arrows on left in **Figure** 5.4). **Figure** 5.5 and **Figure** 5.6 plot the indoor air and wall surface temperature recorded by the loggers in the main living area in HH1 during a few days surrounding these days in 2015 and 2016, to investigate the correlation between the variation of indoor temperature and occupants' ventilation behaviour in the dwelling. These are period 1 (3rd - 7th January 2015) and period 2 (5th - 9th January 2016), respectively.

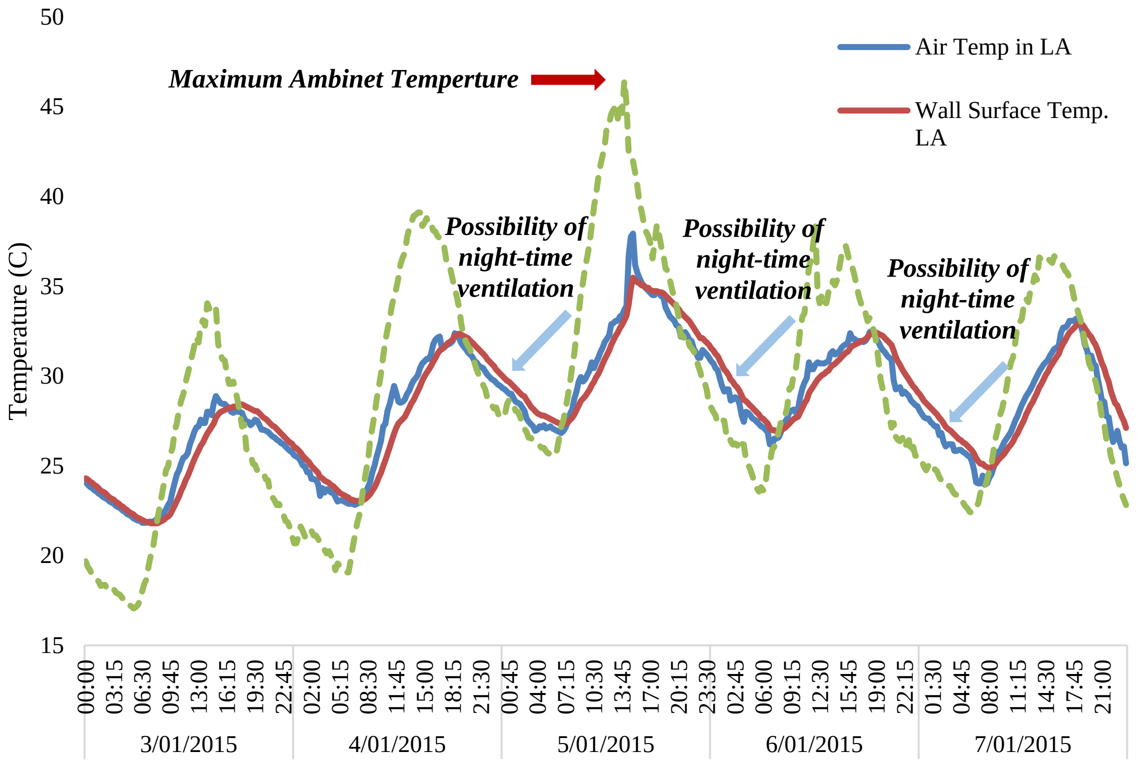

Figure 5.5 Indoor air and wall surface temperature in the main living area – Period 1

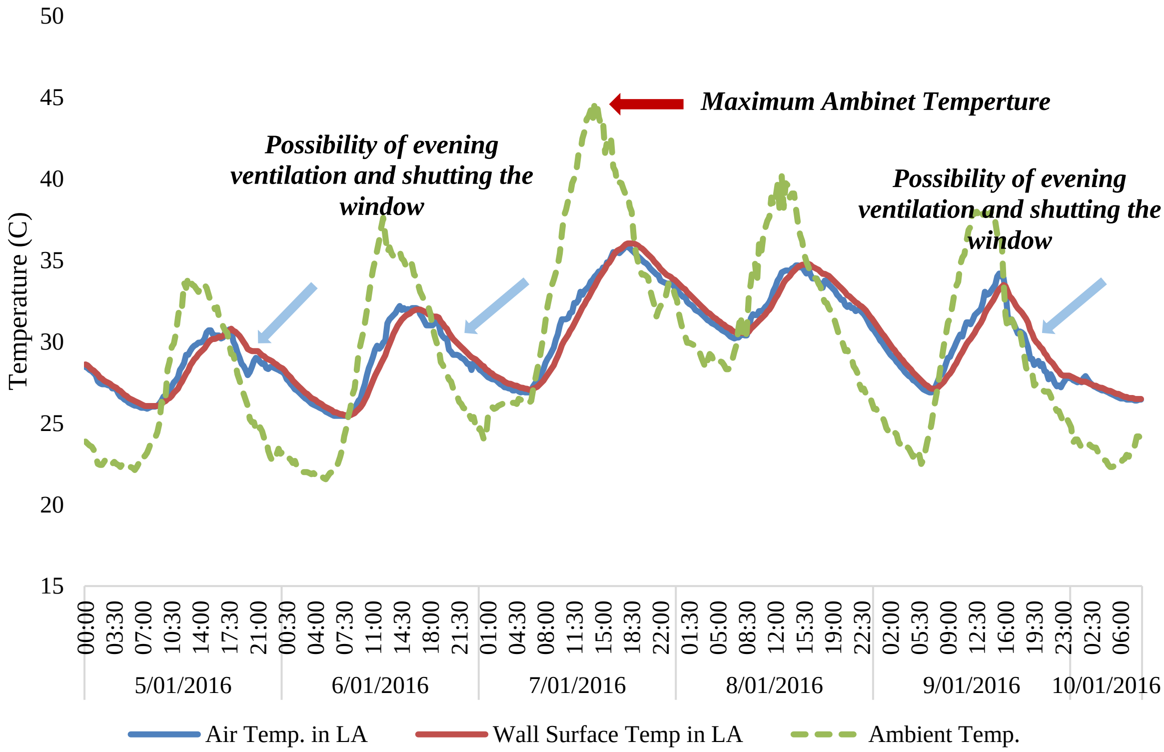

Figure 5.6 Indoor air and wall surface temperature in the main living area – Period 2

For two similar outdoor temperature peaks (January 5, 2015, versus January 7, 2016) (see **Figure** 5.4 for outdoor peaks), the indoor peak temperature was a few degrees higher for 2015. Although the solar exposure was lower on the peak day in 2015 (DGSE was 6.5 kWh/m^2 on 5th January 2015 and 7.5 kWh/m^2 on 7th January 2016), it was higher on the two days prior to the peak i.e. 3rd and 4th January 2015 (8.9 and 9 kWh/m^2 in 2015 compared to 7.5 and 8.7 kWh/m^2 in 2016). The indoor temperature on the peak day is likely to have been affected by the solar energy stored in the building mass during these days. Note that the maximum outdoor temperature was higher on the peak day in 2015 compared to 2016 (46.4 °C on 5th January 2015 and 44.7 °C on 7th January 2016).

When outdoor temperature raised during day-time, the indoor air temperature also raised in this free-running building, which used no cooling system in summer. Similarly, when the ambient temperature dropped in the evening, the indoor temperature was lowered. However, in both cases, the variation of indoor temperature was significantly less than the outdoor temperature, and hence, there was evidence of a damping effect with a DF of around 0.4 for the peak day in period 1 and 0.5 for the peak day in period 2. The difference between the fluctuations of indoor and outdoor temperature can be explained by the influence of building thermal mass providing thermal inertia for the indoor temperature to dampen the outdoor temperature fluctuations and provide a more comfortable indoor environment for the occupants.

As shown in **Figure** 5.5 and **Figure** 5.6, both indoor air and wall surface temperature during period 1 and period 2 followed a similar trend to the outdoor temperature. However, there was a time lag between the changes in outdoor temperature and indoor air and wall surface temperature due to the impact of insulation and building thermal mass. The average time lag in period 1 was around 3 hrs, and in period 2 was around 2.5 hrs.

Both **Figure** 5.5 and **Figure** 5.6 show that air temperature in the living area was slightly greater than the wall surface temperature during day-time when the outdoor temperature raised. This was expected due to the increased solar exposure and the relatively lower heat capacity of the indoor air compared to the wall discussed in Chapter 2. As the ambient temperature dropped at night, the indoor temperature fell below the wall surface temperature, which again is caused by quicker changes in air temperature compared to the wall surface temperature due to the greater thermal inertia of the surface.

The air and wall temperature profiles generally follow each other reasonably closely. Nevertheless, there are points in **Figure** 5.5 and **Figure** 5.6 that indicate a sudden rise/drop in the indoor temperature (see blue arrows). Although there are many factors that dictate the trend in indoor temperature, these points may suggest some behavioural activity in the dwelling that caused a sudden variation in the indoor temperature, resulting in its divergence from that of the wall surface temperature. For example, on 5th January 2015, the indoor temperature suddenly raised at 02:15 pm, which lasted for a relatively short period of time. This could have been caused by opening a door/window in this zone and/or by opening the curtains, which resulted in either hot outdoor air entering into the dwelling and/or increasing the solar heat gains from the windows in the living area. Another example of sudden changes in the indoor temperature occurred on 5th January 2016 at 04:00 pm, when the indoor temperature dropped for a few hours in the evening, reaching a minimum of 26.8 °C at 7:15 pm. This change, which might have been caused by opening a door/window and the cool outdoor air entering into the dwelling, lasted only a few hours and the openings seemed to be closed after that.

A comparison between indoor air and wall surface temperature during night-time in period 1 (**Figure** 5.5) and period 2 (**Figure** 5.6) suggests that there were some changes in occupants' ventilation behaviour, with more ventilation from the afternoon right through the night performed in 2015 than in 2016. In other words, whereas the dwellings seemed to be mostly ventilated overnight during period 1, possibly by leaving a portion of a window/door open in the living area, less overnight ventilation was performed in period 2. As shown in **Figure** 5.6, there are some indications that in period 2 (on peak 1, peak 5 and to a lesser extent peaks 2 and 4), the dwelling was ventilated for a few hours in the evenings. However, with no evidence of significant heat loss as a result of opening a door/window, the openings seemed to be closed in the living area sometime during the period 7: 00 pm – 12:00 pm, perhaps before the occupants went to bed.

Figure 5.7 further illustrates the type of overnight ventilation that appears to be happening in January 2015 by presenting a close snapshot of temperature profiles for January 30th and January 31st during another hot spell. This figure plots the variation of indoor temperature in relation to ambient temperature and its divergence from that of the wall surface temperature in the living area during these two days. Comparison of the night-time indoor temperature values for January 30th and January 31st shows a marked difference in the graph for a section of the plot from around 10:00 pm on the night of the 30th to around 6:00 am the following day. There is a drop in temperature between 10:00 pm and 01:00 am, a period where the temperature stayed relatively constant between 01:00 am and 2:45 am followed by a period where there is a marked drop in temperature until around 05:45 am, where the indoor air temperature reaches the same value as the outdoor temperature. One explanation could be some opening and closing of the window in the living area, with the window fully open at 02:45 am on January 31st so that the indoor and outdoor temperature reached equilibrium.

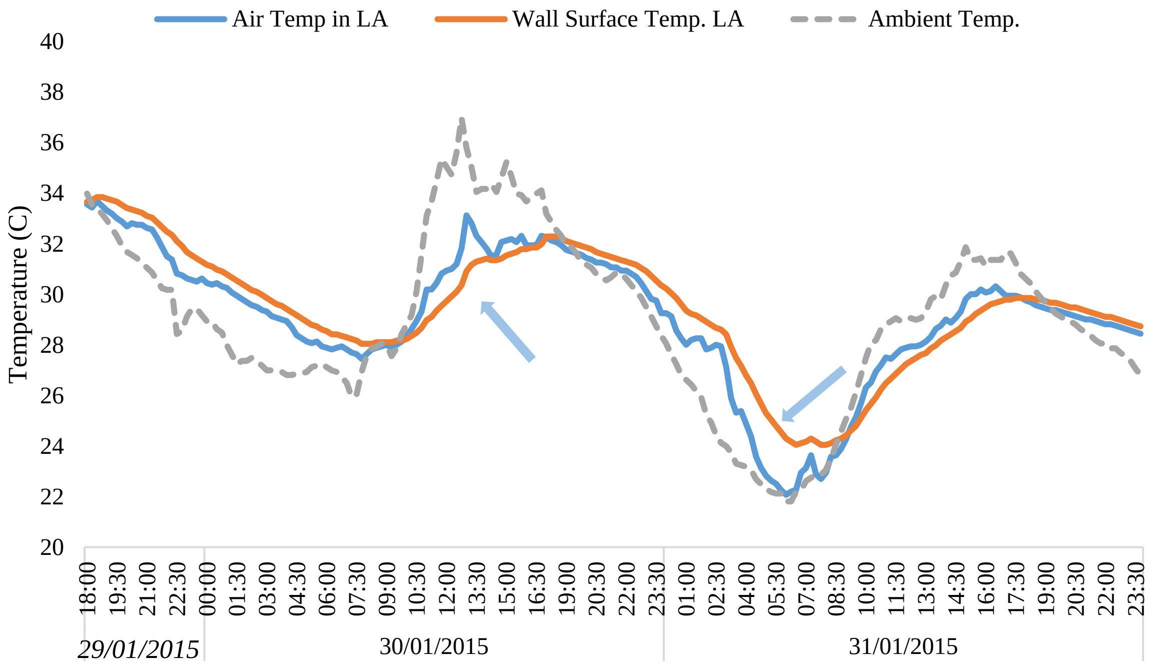

Figure 5.7 Indoor air and wall surface temperature in the main living area – January 30th and 31st

Findings from the household interview during temperature monitoring revealed that an incident happened in the dwelling in late 2015 and one of the east-facing windows was broken by an unknown person. This might, to a certain extent, explain why less night-time ventilation was performed through opening doors/windows in 2016:

…//After the incident, we don't feel safe to leave any door/window open when everyone is going to bed or when the house is vacant. We know leaving a window partly open throughout the night will cool down the house, but we are not doing that due to security issues//…

Temperature Changes and Occupants' Behaviour in Winter

Figure 5.8 presents a summary of average day-time and night-time ambient temperature together with DGSE (kWh/m^2) for HH1 during July 2015 and July 2016.

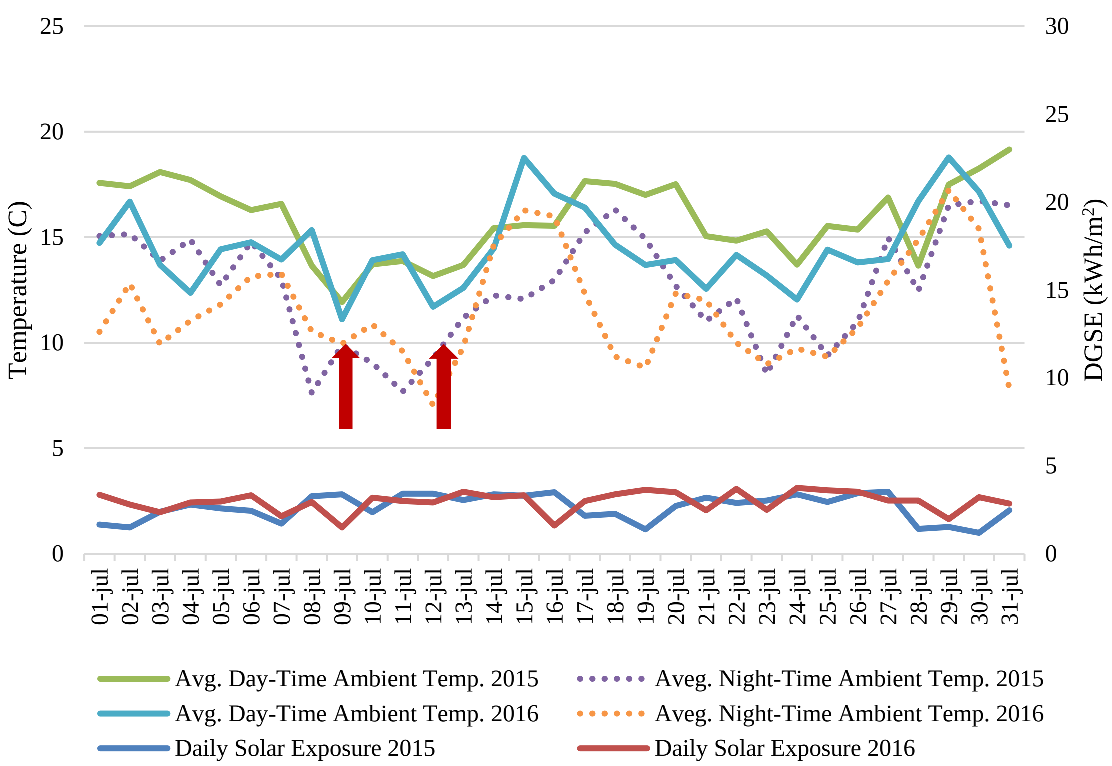

Figure 5.8 Average ambient temperature and DGSE (kWh/m^2) in July 2015-16

Although the average solar exposure was higher in July 2016, the ambient temperatures in July 2016 were lower than in July 2015. As shown in **Figure** 5.8, day-time ambient temperatures were a bit peakier in their fluctuations in July 2016 than July 15, with 2016 having a couple of peaks around July 15th and July 29th and then some troughs around July 9th and July 24th. This greater fluctuation in ambient temperature in 2016 seems to correlate with greater variations in DGSE, which is slightly less consistent in 2016 than in 2015.

No heating system was reported in this household (later confirmed by direct observations) and, as stated by the HoH, no door/window was left open during cold winter days and nights (no natural ventilation) to prevent excess heat loss and maintain an acceptable level of thermal comfort for the occupants in the dwelling. Periods of sustained coolth (relatively lower ambient temperature and solar exposure) were selected in July 2015 and July 2016 to compare occupants' behaviour mostly with respect to performing natural ventilation and opening/closing curtains on the north-facing windows in the dwelling to take full advantage of the solar heat gains from these windows to heat up the indoor environment. These periods are referred to as period 3 (08th – 12th July 2015) and period 4 (08th – 12th July 2016), and include minimum outdoor temperatures for both July 2015 and July 2016. **Figure** 5.9 and **Figure** 5.10 take a closer look at daily temperature data recorded in the living area on days when the average ambient temperature and daily solar exposure were relatively low.

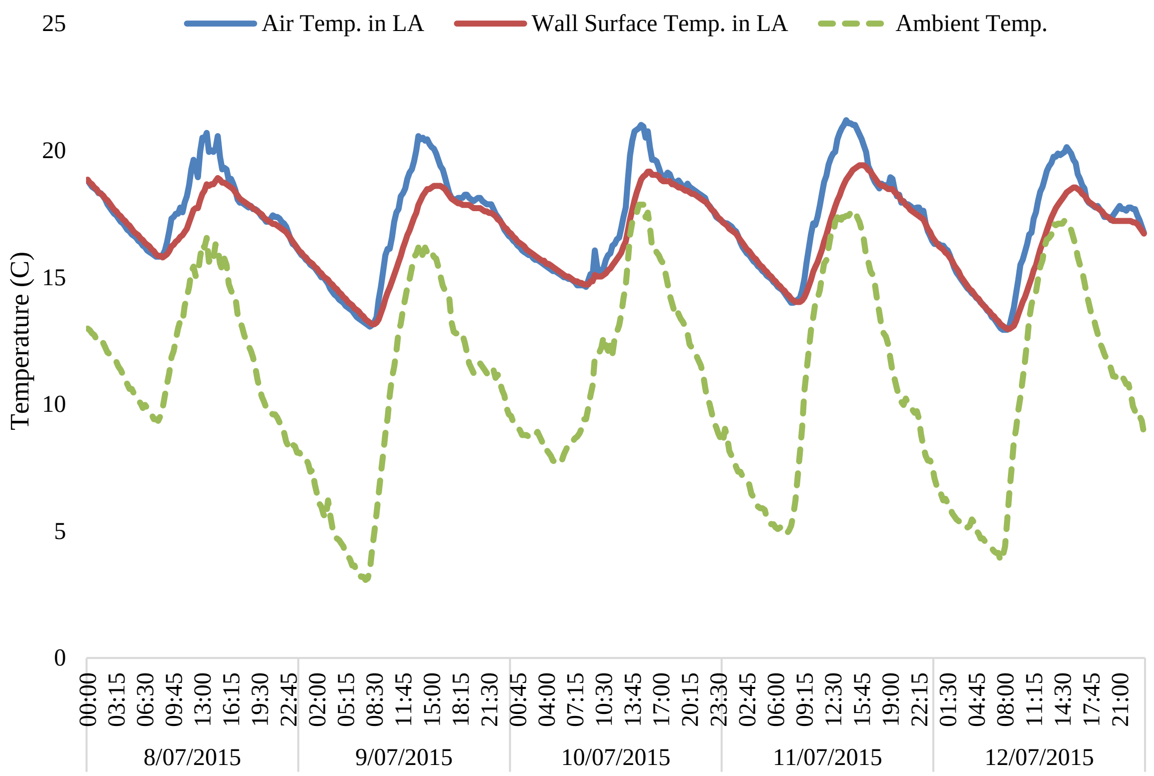

Figure 5.9 Indoor air and wall surface temperature in the main living area – Period 3

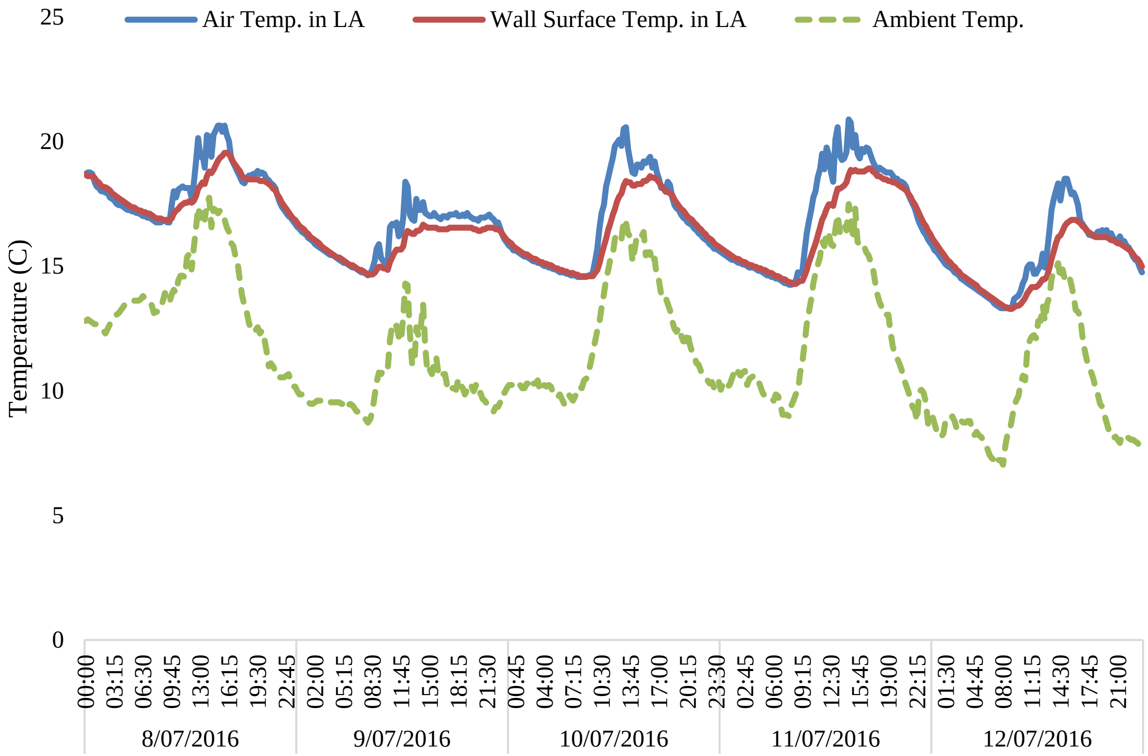

Figure 5.10 Indoor air and wall surface temperature in the main living area – Period 4

Figure 5.9 and **Figure** 5.10 show that in both period 3 and period 4, indoor temperature changes followed the variation of outdoor temperature. In other words, when the ambient temperature raised during day-time, the indoor temperature also raised and when the ambient temperature dropped in the evening, the indoor temperature also lowered. However, due to the insulation and building thermal mass providing thermal resistance and inertia against outdoor temperature fluctuations, the indoor temperature in the dwelling changed within a significantly limited range compared to the ambient temperature e.g. on 09th July 2015, when the ambient temperature dropped to around 3 °C at 07:30 am, the indoor temperature lowered to around 13 °C at 07:45 am. Unlike summer, however, there was no indication of a long time lag between outdoor and indoor temperature changes when the ambient temperature raised during the day-time (the average time lag between the indoor and outdoor temperatures was less than 1 hour in period 3 and insignificant in period 4), which might be explained by the position of the sun in the sky. In summer, the sun reaches its peak at noon and so the ambient temperature reaches a max. However, the full solar heating effect on the house only comes into effect a few hours later when the sun is low enough in the sky to produce direct beam radiation through the (north-facing) windows of the house. Nevertheless, the sun is already low in the sky in winter and producing direct beam radiation into the house.

From direct observations, it was found that occupants in HH1 often opened the curtains on the north-facing windows on sunny winter days to take the advantage of direct solar heat gains. Hence, when solar exposure was high, the indoor temperature in the living area also raised. However, as shown in **Figure** 5.9 and **Figure** 5.10, there was up to a few hours' time lags between the troughs of outdoor and indoor temperature mainly due to the influence of insulation and building thermal mass on slowing heat loss and controlling the temperature fluctuations inside the dwelling. For example, when the ambient temperature reached a minimum of 3.1 °C at 07:30 am on 09th July 2015, the indoor temperature lowered to 13.2 °C at 08:00 am. On 10th July 2016, the ambient temperature dropped to 9.5 °C at 06:15 am, a minimum of 14.6 °C was recorded in the living area 08:00 am.

The fluctuations of indoor temperature recorded in the living area during period 3 and period 4 revealed that in winter, the divergence of indoor temperature from that of the wall surface temperatures in HH1 with north/east- facing windows in the living area was affected by the value of solar exposure. For example, daily solar exposure values between 08th – 12th July 2015 (period 3) were 3.3, 3.4, 2.4, 3.4 and 3.4 kWh/m^2, respectively. As shown in **Figure 5.8**, the deviation of indoor temperatures from the wall surface temperatures in the living area during daylight hours on 10th July 2015, when DGSE was lower than the rest of the days within period 3, was noticeably different, with less difference between air and wall temperatures. However, on 09th, 11th, and 12th, July 2015 for which, a similar value of solar exposure was recorded for HH1, the divergence of the indoor air and wall surface temperature seemed similar. This could be evidence that solar heat gains from (north-facing) windows in HH1 was the main source of heat gains in winter and hence, when it was higher, resulted in the rise in the indoor temperature and its divergence from the wall surface temperature. Therefore, the occupants' appropriate behaviour with respect to opening/closing the curtains mainly during sunny days in winter can significantly assist them to heat up the living area and maintain a certain level of thermal comfort in the dwelling.

In contrast with summer, when the indoor temperature recorded in HH1 verified that the dwelling was either ventilated overnight (peak 2, 3 and 4 in period 1) or for a few hours in the evening (peak 1 and 5 in period 2), there was no clear evidence that the dwelling was ventilated either during day-time or night-time during periods 3 and 4 in winter. As shown in **Figures 5.8** and 5.9, indoor air temperatures during night-time in both period 3 and 4 closely followed the wall surface temperature and there was no evidence of heat loss as a result of opening a door/window in the dwelling. This may suggest that in winter, all the openings in HH1 were kept closed when the ambient temperature dropped in the evening to avoid the cool outdoor air entering the house.

5.3.2 Scenario 2: Household 2

Figure 5.11 shows the position of the loggers in HH2 together with the dominant ventilation through the front entrance and back door, and solar heat gains pathways as perceived from long-term direct observations during visits to the dwelling.

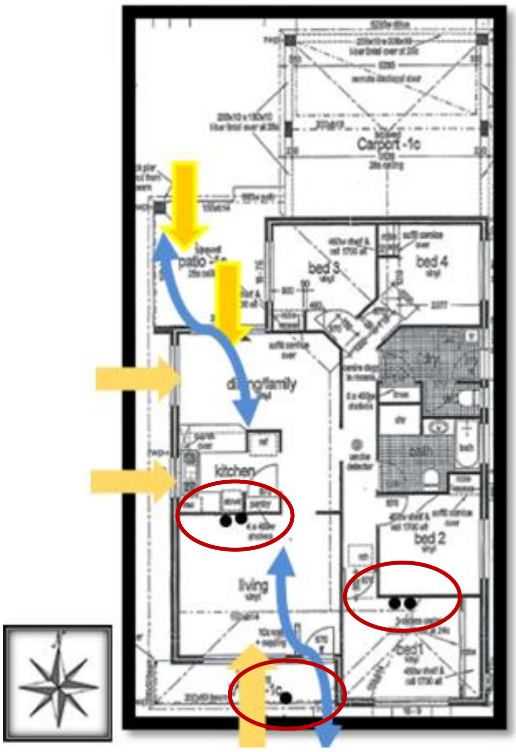

Figure 5.11 Loggers position, prevailing ventilation and solar heat gains in HH2

* Black dots represent loggers, yellow arrows represent solar heat gain through windows and blue arrows represent natural ventilation in the dwelling

This analysis focuses on data from the two loggers located in the main living area. This area was heated/cooled with a reverse cycle air-conditioning system and ventilated through opening the entrance and/or back door (north-south) when the house was occupied. To record the ambient temperature, a logger was also installed outside the dwelling under the eaves to prevent direct solar radiation and prevailing wind affecting the logger.

Findings from the household survey revealed that more cooling was required in summer than heating in winter for maintaining the occupants' thermal comfort in the dwelling. Turning on the AC was typically the first action taken by the occupants, together with closing all the openings and curtains, in response to summer thermal discomfort in the dwelling. In winter, according to the HoH:

...//Instead of turning on the AC, we prefer to put on more clothes when it is cold //...

Towards the end of spring and before the ambient temperature started to build up in summer, all the external fences in HH2 were covered with bamboo sheets to protect the building against excess solar gains (see **Figure** 5.12). According to the HoH, these bamboo sheets together with the shadings created by plants at the front and back of the building aimed to reduce the impact of excess solar heat gains in summer and result in less cooling energy requirements for maintaining occupants thermal comfort in the dwelling.

Figure 5.12 Bamboo sheets and planting surrounded the dwelling in HH2

Some proportion of electricity in HH2 was delivered by a 1.3-kW solar array installed on the rooftop. Given that no information was provided by Synergy about the amount of electricity delivered by these panels (only the amount exported to the grid is cited in the household's bills), the variation in the household's total electricity consumption between 2015 and 2016 was estimated by predicting the daily energy production from the solar array using **Equation** 5.1. **Figure** 5.13 shows the estimation of average daily electricity consumption in HH2 during 2015 and 2016.

$$\boldsymbol{E = A \times r \times H \times PR} \qquad 5.1$$

E =Energy (kWh)

A = Total solar panel Area (m^2)

r = solar panel yield or efficiency (%)

H = Average solar radiation on tilted panels

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

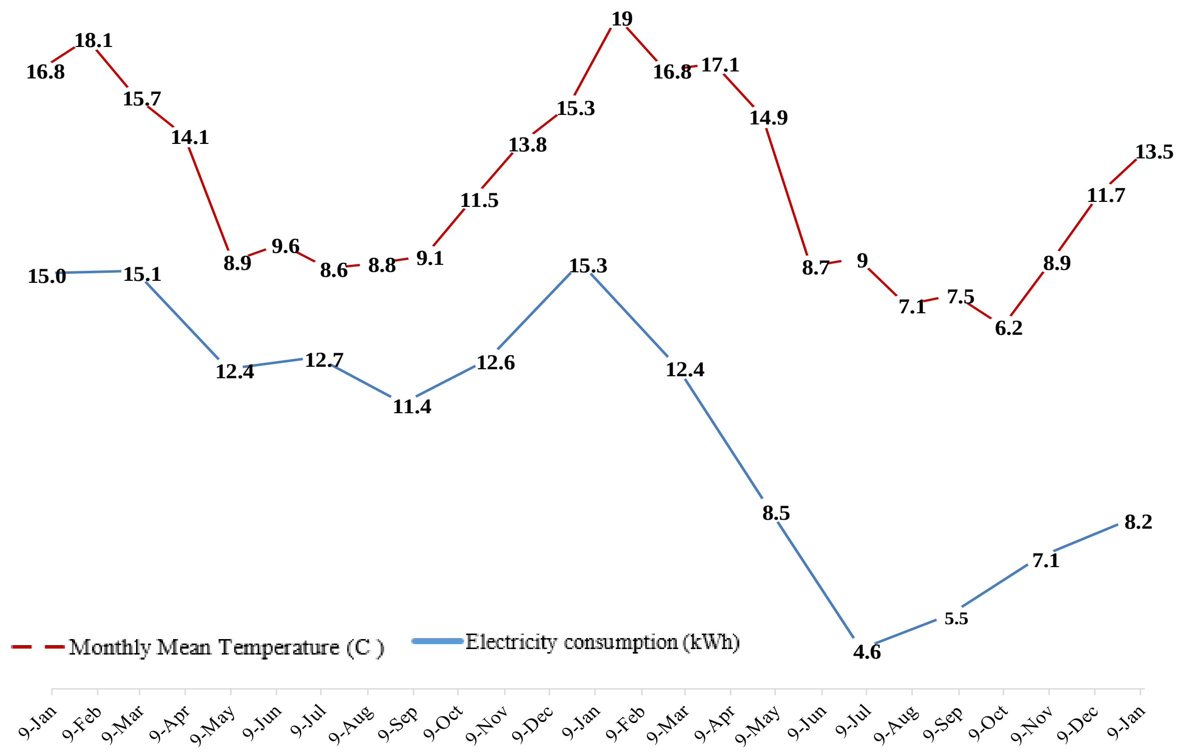

Figure 5.13 Estimation of electricity consumption in HH2

Electricity consumption in HH2 significantly reduced in 2016 compared to 2015 (**Figure** 5.13). Extended observations during temperature monitoring during 2015-16 revealed remarkable energy usage pattern and natural ventilation strategies adopted by the occupants in this household right from starting the temperature monitoring in this dwelling. The HoH was contacted to find out any possible changes that might have been happened in the households, which resulted in a significant reduction in their electricity consumption. Factors such as attentive energy use behaviour usage, changing 98% of indoor and outdoor lighting to LEDs, replacing the plasma TV units with LED TVs, growing plants and shrubs around and in the house, which could aid in lowering the ambient temperature surrounding the dwelling, and, spending more time away from home were some of the factors that the HoH was highlighted as the possible causes for lower electricity consumption in 2016. Temperature changes in this household were investigated in more detail to create a better insight into how the dwelling was conditioned and/or ventilated on extreme summer and winter days during the period under investigation in an attempt to find an indication for the changes in the household's electricity consumption.

Temperature Changes and Occupants' Behaviour in Summer

Figure 5.14 shows the variations in average ambient temperatures recorded at the location of HH2 by a logger installed outside of the dwelling together with the total daily solar exposure from the Bureau of Meteorology across the month of January 2015 and 2016.

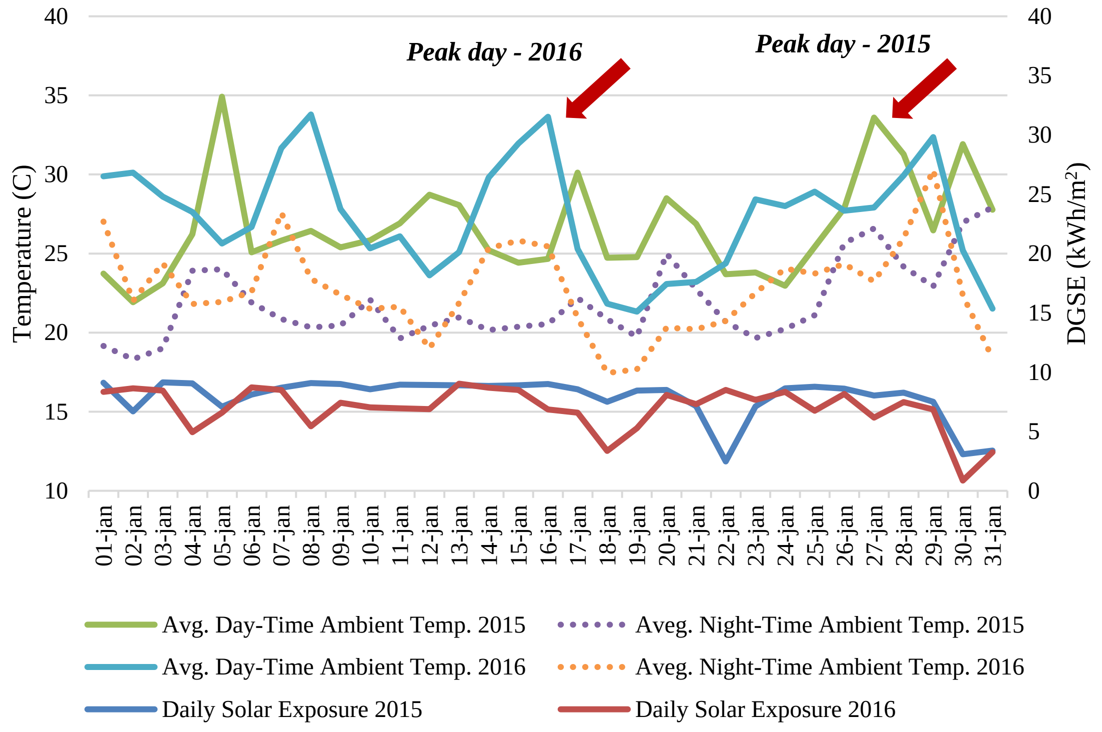

Figure 5.14 Average ambient temperature and DGSE (kWh/m^2) in January 2015-16

Solar exposure appeared to be peakier and on average, lower across the month in 2016 compared to 2015. Due to the greater fluctuations in solar radiation, there were also more variations in the day-time ambient temperature in 2016 (see **Figure** 5.14). Nevertheless, both January 2015 and January 2016 had several days with an average ambient temperature over 30 °C (05th, 17th, 27th, 30th January 2015 and 08th, 16th, 29th January 2016), while there were noticeably a number of cooler days in January 2016 when the day-time ambient temperatures fell below 25 °C and solar exposure was relatively low.

Different ambient temperatures together with diverse values of total solar exposure recorded for HH2 during hot summer days might have affected the way the dwelling was conditioned and/or naturally ventilated, especially during peak days (when ambient temperatures and solar exposure were relatively high). In order to investigate how the living area was conditioned or ventilated, two periods are selected in January 2015 and January 2016 with each period including at least one peak day. Comparing the variation in indoor temperatures (indoor air and wall surface temperature) in the living area (where the AC was installed) during these periods may create a better insight into the occupants' behavioural changes with respect to the use of AC and ventilating the dwelling in 2015 and 2016, before and after the occupants were educated with the proposed guidelines. These periods are period 1 (26th - 29th January 2015), and period 2 (13th – 16th January 2016) (see red arrows in **Figure** 5.14 for the peak days). **Figure** 5.15 and **Figure** 5.16 show the variations in the internal factors of indoor air and wall surface temperatures in the living area in HH2 during period 1 and period 2.

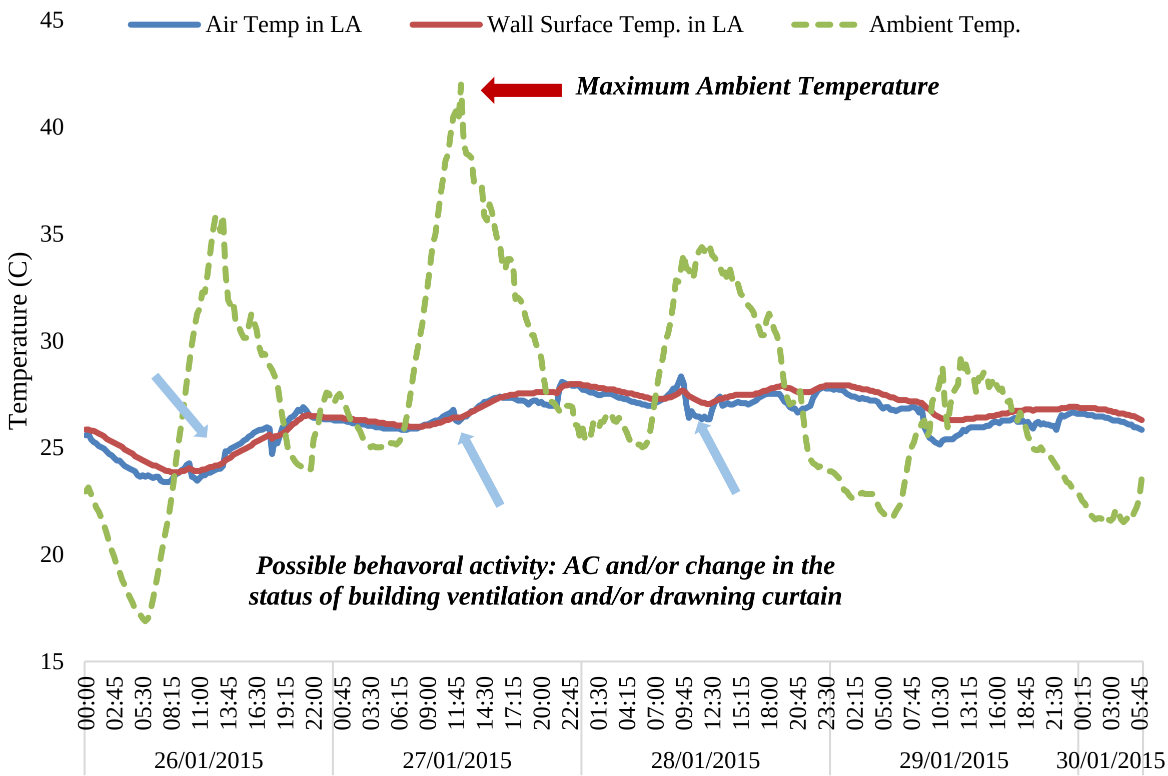

Figure 5.15 Indoor air and wall surface temperature in the main living area - Period 1

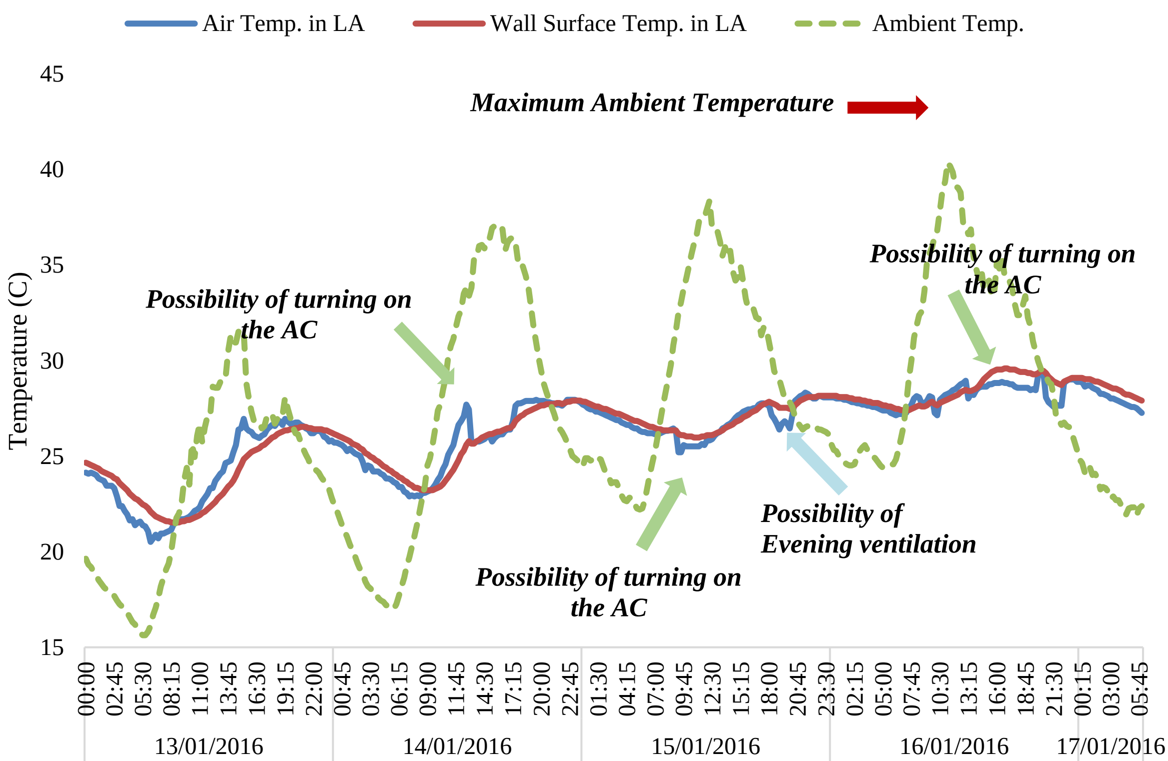

Figure 5.16 In indoor air and wall surface temperature in the living area - Period 2

The results for HH1 showed that variation in internal temperatures in free-running buildings typically follow a similar trend as the fluctuations of ambient temperature, although damped and with a certain time lag. As shown in **Figure** 5.15 and **Figure** 5.16, however, there was much greater damped behaviour of indoor and wall temperatures in HH2. In other words, although ambient temperatures during period 1 varied over a wide range, the indoor air, as well as wall surface temperatures changed within a limited range and were mostly between 24-25 °C. To quantify this change in behaviour, the damping factor on the peak day (a day with maximum ambient temperature and relatively high solar exposure) in period 1, was estimated to be 0.1, compared to a DF of 0.5 for HH1. Note that the time lag between the indoor and outdoor temperatures was around 3 hours in HH1 and 8 hours in HH2. Although greater time lag and lower damping factor in free-running buildings may suggest better insulation and higher thermal mass of the building, since HH2 used AC to cool down the house in summer, it is difficult to draw firm conclusions about the physical characteristics of the two dwellings based on the difference in these parameters (time lag and damping factor) between HH1 and HH2.

As shown in **Figure** 5.15, there are a few occasions in period 1 when a sudden drop in indoor air temperatures may suggest some behavioural activity performed in the living area. It may be that the AC was switched on or curtains were drawn to reduce solar gain or there may have been a change in the status of ventilation in the dwelling i.e. closing doors when the ambient temperature was high or opening doors when the ambient temperature was dropping. However, since the divergence of the indoor air from the wall surface temperature (indoor air-wall surface temperature) during the day-time was within the accuracy range of loggers (±0.5 °C), it is difficult to draw firm conclusions. For example, on 26th January 2015, the air temperature in the living area suddenly dropped around 10:15 am and raised again at 01:15 pm before it dropped again at 05:45 pm. These changes, which happened either in the morning or in the evening might have been caused by e.g. closing or opening a door in the dwelling, which slightly lowered the indoor air temperature. The raising of the internal temperature between 12:30 pm and 05:30 pm may suggest that the openings might have been all closed while no AC was running in the living area (the indoor air was above the wall surface temperature during this period). On 27th January 2015 (peak day), it seems that the openings in HH2 were closed before 12:00 pm and were opened again around 05:45 pm when ambient temperature lowered. Based on direct observations in the dwelling, the AC might have been turned on around mid-day for a few hours so that the indoor temperature during the peak hours of the day was around 26 °C. Although during the interview, the HoH in HH2 mentioned that the average thermostat set-point in this household was often between 22-24 °C, temperature data recorded in this household suggests that during period 1 and period 2, the set-point was slightly higher, around 25-26 °C.

Despite lower ambient temperatures on 28th January, the AC might have been running started from 09:30 am (openings seemed to be closed) since the indoor temperature drops 1.5 °C and is held at a constant 26.5 °C for around 90 minutes. Temperature data recorded on this day may further suggest that doors/windows might have been opened around 07:00 pm with the indoor air and ambient temperatures recorded between 08:45 pm and 09:15 pm similar in value). On the last day of period 1, when the ambient temperature and solar radiation lowered, it seems that the dwelling was ventilated in the morning, starting from 08:45 am. However, since the air temperature fell below the wall surface temperature, the windows appear to be closed for midday and afternoon.

Although there was no clear evidence that the AC was running in the living area during period 1, even on a peak day, there were a few occasions in period 2 that variation in indoor air temperatures and its divergence from the wall surface temperatures suggests that the dwelling was conditioned for a few hours. For example, on 14th January 2016, air temperatures in the living area started to rise from 08:30 am and followed the variations in ambient temperature. However, as shown in **Figure** 5.16, it suddenly dropped by 2 °C and from 01:00 pm to 05:00 pm air temperatures in the living area fell below the wall surface temperature in this zone, which might have been caused by running the AC in the dwelling. After 05:00 pm, the AC appears to be turned off and the openings remained closed until around 09:00 am the next morning when the indoor air temperature lowered. This might have been caused by closing curtains to block solar gain or by opening doors/windows and allowing a breeze to enter into the living area (see blue arrows in **Figure** 5.16). Note that air temperatures in the living area on this day, January 15th, varied over a narrower range compared to the ambient temperatures (DF = 0.2) as that of January 14th. On 16th January 2016, at 01:00 pm, the indoor temperature suddenly dropped by around 1 °C and fell below the wall surface temperature in the living area up to 07:45 pm. This may have been caused by the AC system but it is again difficult to draw firm conclusions as the difference between air and wall temperatures was around 0.8 °C, which falls within variations in the accuracy for the two loggers. Air temperatures in the living area dropped once again starting at 08:45 pm, with a difference with wall surface temperatures of over 1 °C. This variation, however, is less likely to be caused by turning on the AC in the dwelling (based on direct observations and interviews, where the HoH stated that no AC was used during evenings and overnight). Instead, opening doors/windows and allowing a cool breeze to enter might have lowered the indoor temperature. It is worth mentioning that no clear evidence was found that the dwelling was ventilated overnight either in period 1 or in period 2.

Temperature Changes and Occupants' Behaviour in Winter

Figure 5.17 shows how ambient temperature and daily solar exposure fluctuated at the location of HH2 during July 2015 and July 2016.

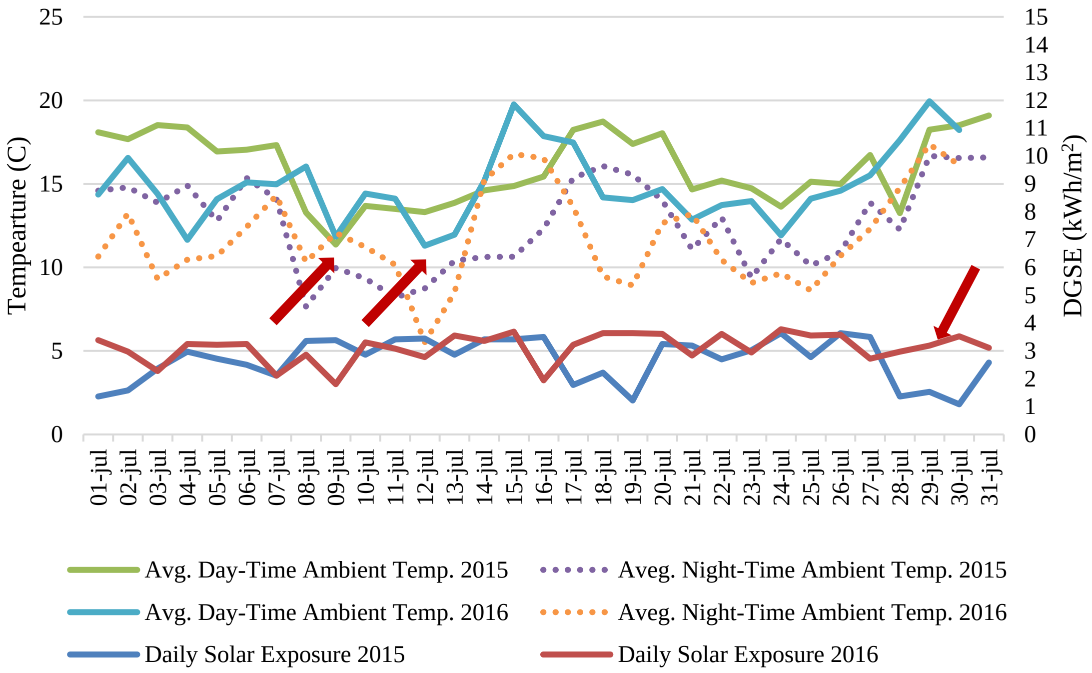

Figure 5.17 Average ambient temperature and DGSE (kWh/m^2) in July 2015-16

Although the average solar radiation was higher in July 2016, ambient temperatures were mostly below the values in July 2015. As shown in **Figure** 5.17, the peaks and troughs of solar radiation seem to vary over a wider range in 2015 than 2016 with a number of troughs around the 17th, 19th, 28th and 30th July 2015. Ambient temperatures, however, seemed a bit peakier in its fluctuations in 2016, and **Figure** 5.17 shows noticeable troughs around July 04th, July 9th, and July 12th, 2016.

As stated by the HoH, the air-conditioning system was barely used in winter, except for short periods on extremely cold days and turned off after the indoor temperature raised to the occupants' comfort level. Instead, putting on more clothes and closing doors/windows and curtains were the actions taken by the occupants to maintain their thermal comfort in winter. In order to investigate occupants' behavioural activities with respect to the use of the air-conditioning system (in the main living area) and how they ventilated the dwelling, two periods were selected when temperature data recorded by the loggers in this zone was relatively low. These are period 3 (08th – 12th July 2015) and period 4 (08th – 12th July 2016). **Figure** 5.18 and

Figure 5.19 show the variation of indoor air and wall surface temperature in the living area in HH2 during period 3 and period 4.

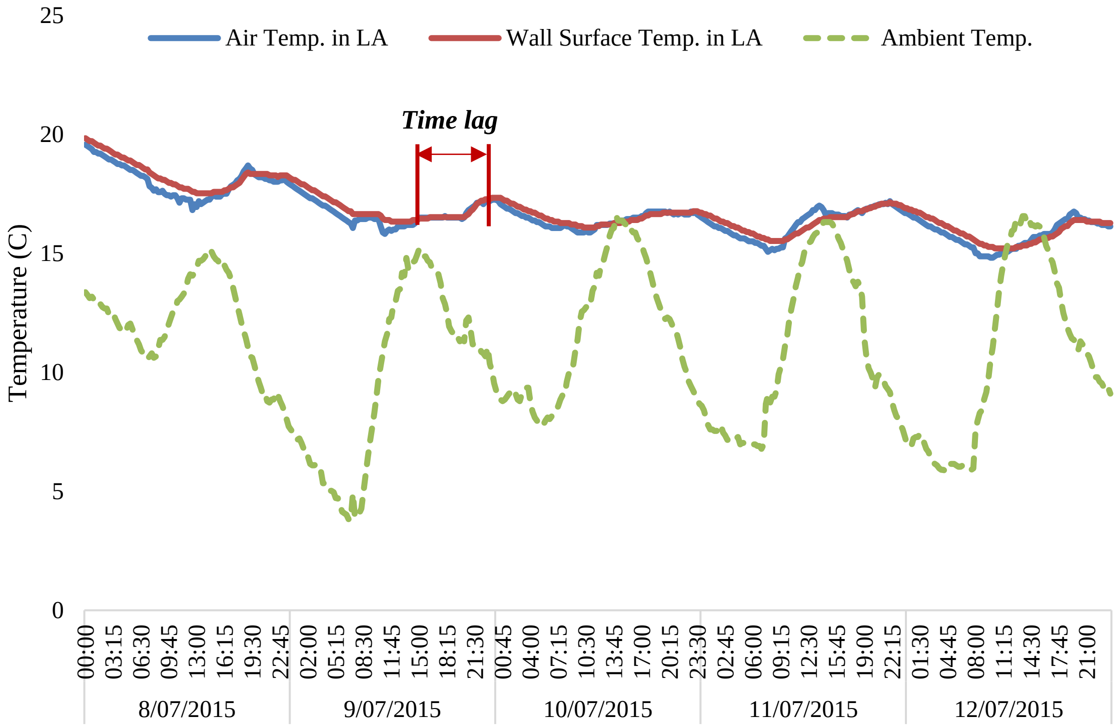

Figure 5.18 Indoor air and wall surface temperature in the main living area – Period 3

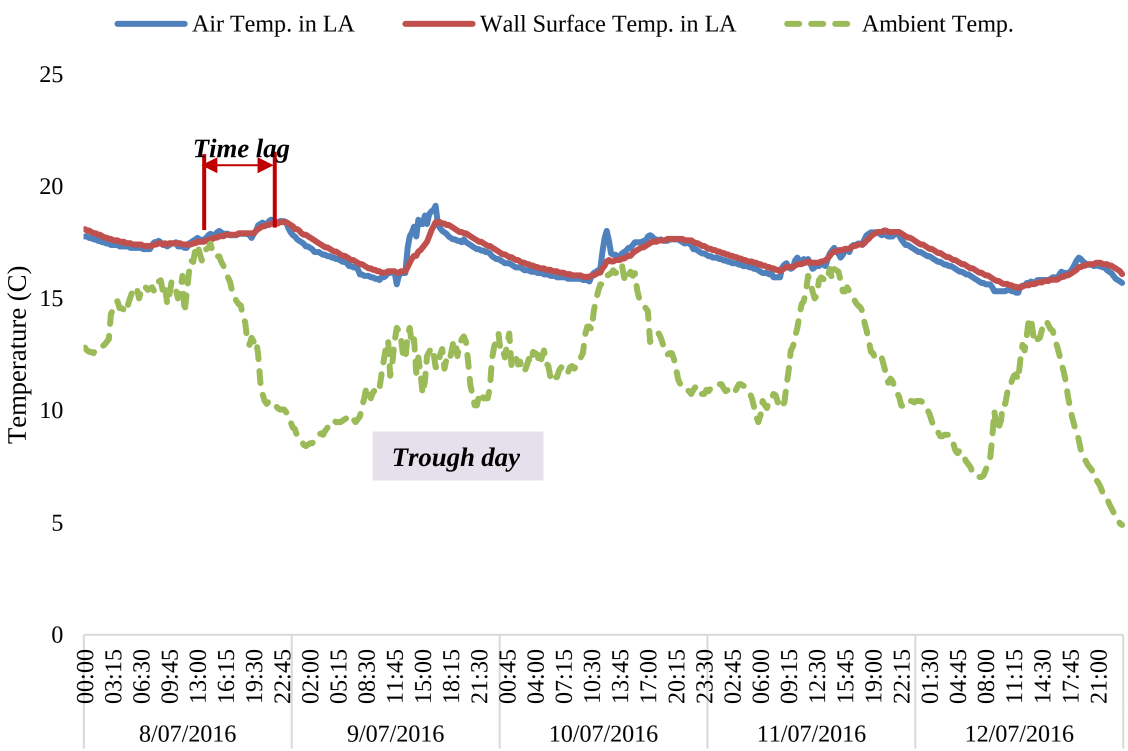

Figure 5.19 Indoor air and wall surface temperature in the main living area – Period 4

Except in a few cases, the variation in indoor air temperatures in the living area followed a similar pattern to the variation in ambient temperatures. However, as shown in **Figure** 5.18 and **Figure** 5.19, an average of 5.5 and 5-hour time lag exists between the indoor and outdoor temperatures in period 3 and period 4 respectively (an example time lag is given in **Figure** 5.18 and **Figure** 5.19). In other words, around 5 hours after the ambient temperature arrived at its highest point, the indoor temperature in the living area raised to its maximum value due to the insulation of the building slowing down heat transfer as well as the ability of the building thermal mass to absorb and store heat energy. When ambient temperature raised during the day-time, the building mass stored thermal energy and released it to the indoor environment 5 hours later when the ambient temperature lowered. In addition to moderating internal temperatures by averaging out the diurnal extremes, thermal mass significantly helped the house stay warm during cold winter nights by reradiating the heat stored in the mass during the day-time, reducing the need for conditioning the house at night-time.

As shown in **Figure** 5.18, indoor temperatures in the living area on 11th July 2015 suddenly raised and deviated from the wall surface temperature in this zone starting from 09:45 am. The air temperature raised to a maximum of 17 °C at 01:45 pm before it dropped and followed the variations in ambient temperature (7.5 hours' time lag between outdoor and indoor temperatures). Although this sudden divergence of the air temperature in the living area from the wall surface temperature might have been caused by some behavioural activity in the living area, it does not necessarily indicate that the AC was turned on. Instead, based on direct observations in the dwelling, the curtains might have been opened to increase the solar heat gains in the dwelling or internal heat gains might have been increased in the dwelling. However, there were occasions in 2016 when the variation in indoor temperatures and their divergence from the wall surface temperatures in the living area are suggesting that the AC was turned on in the dwelling, specifically on the 09th and 10th July 2016. On the 09th July, the indoor temperature in the living area started to rise from 15.6 °C at 12:00 pm and stood at a maximum of 19.1 °C at 04:30 pm. This change on a day when both ambient temperature and solar exposure were relatively low, with little difference between the minimum and maximum ambient temperatures may suggest that the AC was running in the dwelling during this period. This, however, did not verify the occupants' response to the survey question where they stated that if required, the AC was mostly used at night.

On closer examination of the temperature profiles on 10^{th} July 2016, the variations of indoor temperatures seem to be similar to what happened on 11^{th} July 2015 and are less likely to be caused by running the AC in the living area. The indoor air raised from 15.3 °C at 11:15 pm to 18 °C (the highest ambient temperature) at 12:15 pm but then has dropped again to 16.5 °C at 02:00 pm. Based on direct observations of HH2 and the interview with the HoH, it is not likely that they turned the AC on for just 1 hour at this time of day.

From the household interview, it was found that all openings in this dwelling remained shut overnight since security was the occupant's priority rather than ventilating the house overnight. However, as shown in **Figure** 5.18 and **Figure** 5.19, night-time indoor air temperatures in the living area typically fell below the wall surface temperature and in some cases deviated from the surface temperature quite significantly (unlike HH1, in which, indoor temperatures in winter closely followed the wall surface temperatures when no ventilation was performed in the dwelling overnight). There are a few possibilities, which may to some extent explain this trend. Firstly, the uncontrolled flow of air into the dwelling through gaps and cracks in the building envelope (infiltration) might have resulted in the flow of outdoor air into the dwelling, lowering the internal temperature at night when the ambient temperature lowered. Alternatively, lower insulation in HH2 might have caused the internal temperatures to drop to a lower level and deviate from the wall surface temperature when ambient temperatures dropped. Although no information was available about the original energy rating of HH2, with this dwelling constructed in 2007, it is likely that it had less insulation compared to HH1, which was built in 2009, and hence, there was more heat flow to/from the building envelope and greater fluctuations in the internal temperatures. However, the existing time lag between the indoor and outdoor temperature in winter in HH2 does not seem to support a lower level of insulation in HH2. Time lag, a measure of the slowness of heat transfer, was on average greater in HH2 compared to HH1. A greater time lag in HH2 suggests that the dwelling has better insulation compared to HH1. The lower time lag in HH1, however, might have been affected by the orientation of the dwelling. The majority of the windows in the living area in HH1 are north-facing and curtains were found to be actively opened/drawn to make the most of the incoming solar radiation. Solar heat gains from these windows resulted in raising the indoor temperature quicker than in HH2, which has no north-facing window in the living area and no direct solar heat gains from the only south-facing window in the living area due to the wide eaves and the planting surrounding the building.

As discussed earlier in this section, evergreens and bamboo sheets were used in HH2 to prevent excess solar heat gains in summer. Despite the HoH stated that the bamboo sheets were removed in winter to increase the solar heat gains of the building, it was found that they remained in place during winter 2015-16. In order to find out how internal temperatures are affected by limited solar heat gains in winter, a few days with relatively low values of solar radiation were selected and variations in ambient, indoor air and wall surface temperatures in the living area are investigated in more detail. **Figure** 5.20 shows how the internal temperature changed from 28th – 30th July 2015, when the solar exposure recorded by BOM was 1.4, 1.5, and 1.1 kWh/m^2 respectively.

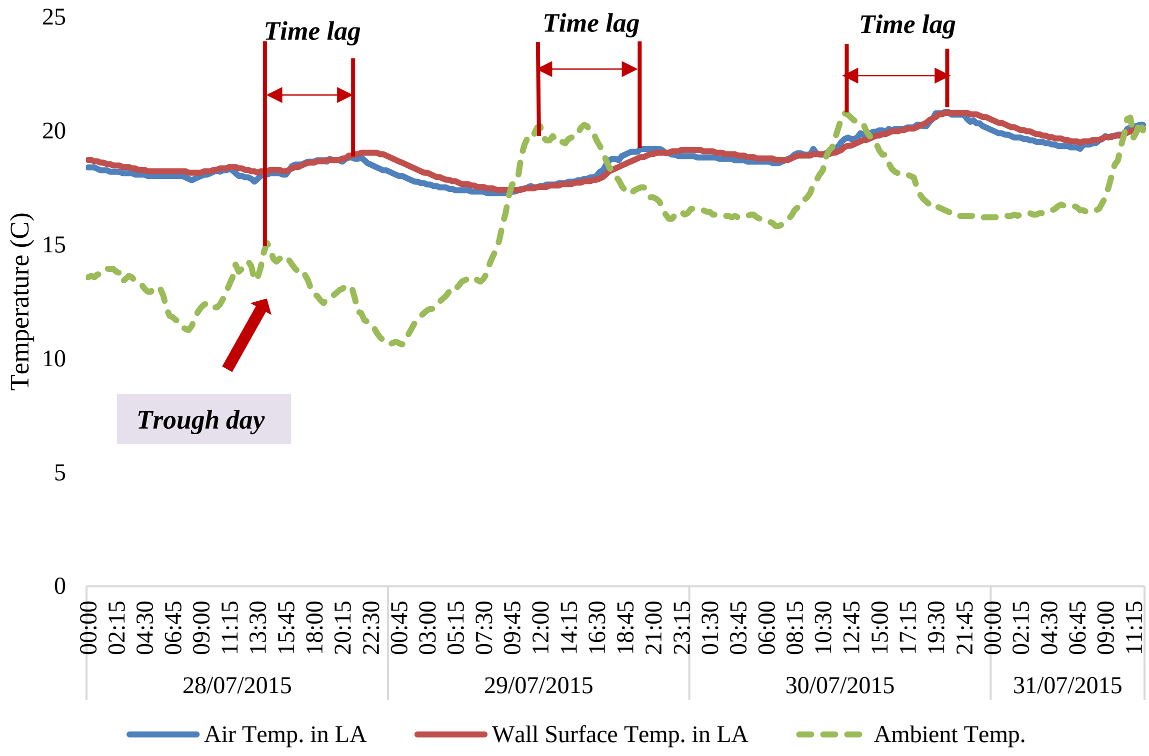

Figure 5.20 Indoor air and wall surface temperatures from 28th - 30th July 2016

Overall, the indoor temp during the day rises as the ambient temperature rises, then the indoor temperature drops overnight as the ambient temperature drops (**Figure** 5.20). Nevertheless, a noticeable divergence exists between the indoor air from wall surface temperature overnight on the evening of the 28th and 30th July and early morning of the 29th July 2015 (although at most the difference is perhaps 0.8 °C – still within the loggers' accuracy range).

On 28th July 2015, both ambient temperatures and solar exposure were significantly low (see red arrow in **Figure** 5.19). While the ambient temperature on this day ranged between 10.7 °C and 15.1 °C, indoor temperatures had a more limited range from 17.8-18.8 °C, with a time lag of around 5 hours between the outdoor air and indoor air temperature. As shown in **Figure** 5.19, the air temperature in the living area on this day dropped twice, once at 08:00 am and 12:00 pm, suggesting that a door/window might have been opened in the dwelling, resulting in a lowering of the indoor temperature.

It was found that on one day prior to the selected day (27th July 2015), both ambient temperatures and solar exposure were higher (outdoor temperature on 27th July raised to 21 °C and DGSE were 3.5 kWh/m^2). The solar energy stored in the thermal mass of the building might have facilitated moderating the internal temperatures on the following day (28th July) when ambient temperatures and solar exposure lowered and created relatively comfortable indoor temperatures for the occupants in the dwelling to the extent that no heating system seemed to be turned on in the dwelling on this day (no sudden rise and divergence of indoor air from the wall surface temperatures occurred on 28th July).

Despite lower solar exposures on 29th and 30th July, ambient temperatures on these days significantly raised compared to 28th July, which resulted in higher indoor temperatures on these days, with no indication that the AC was running in the dwelling. As shown in **Figure** 5.20, it seems that the living area was ventilated on 30th July started around 08:00 am and continued until 02:30 pm when the indoor air and ambient temperatures both stood at 20 °C. Although on this day the air temperature in the living area raised to the same level as the ambient temperature (20.8 °C), around 4 hours' time lag existed between the outdoor and indoor air in reaching this temperature. The existing time lag likely to be due to the thermal heat resistance of the building material as well as insulation, which helped slowing down of the rate of heat transfer from outdoor to indoor.

5.3.3 Scenario 3: Household 4

Figure 5.21 shows the position of the loggers in HH4 together with prevailing natural ventilation flows and solar heat gain pathways from doors/windows, perceived from long-term direct observations in the dwelling. Note that in order to prevent recording inaccurate data, the loggers in this household with two children was installed approximately 60 cm below the ceiling where they could not be easily touched.

Figure 5.21 Logger positions, natural ventilation and solar heat gain pathways in HH4

* Black dots represent loggers, yellow arrows represent solar heat gain through windows, the red arrow represents solar heat gain through the small window in the lounge, and blue arrows for natural ventilation in the dwelling

The thermal properties of the building envelope in this 5-star building included cavity brick external walls with no insulation and concrete-tile roof (Roof colour: cream). Except for a 50-watt standing fan, which was reported to be hardly used in summer, the only space conditioning appliances were two identical electric heaters (each around 1800-2000-Watt), which were used in winter. According to the HoH, one of these heaters was used in BED 2 while the other one was mostly used to heat up the lounge. However, if required, the heaters might have been moved to other spaces to maintain occupants' thermal comfort.

From direct observations, it was found that the cool breeze from opening the entrance, the small window in the lounge (see the red arrow in **Figure** 5.21), and/or the back door created effective cross ventilation in the lounge when the ambient temperature was not beyond the occupants' comfort level in summer and winter. However, on extremely hot summer days, the entrance was kept shut and all windows and curtains were closed, preventing the excess heat from entering the house. It is worth mentioning that the loggers in HH4 did not record the temperature on a few occasions due to (1) unknown errors or (2) when the dwelling was left vacant for some time with no notice to the research team, and hence, the loggers stopped recording when their memory became full. For example, on July 29th, 2016, the logger that recorded the ambient temperature at the location of HH4 stopped working due to an unknown error. Therefore, ambient temperature data was not recorded until August 9th, 2016, when the logger was reprogrammed. Similarly, indoor temperatures were not recorded during the first two weeks of January 2015. Temperature data was also missed in HH4 from 21st September to 09th November 2016, when the household went on holiday with no advanced notice to the research team. Despite missing data, temperature changes in HH4, in which occupants were found to have inattentive energy use behaviour were investigated during the selected periods in February and June in both 2015 and 2016.

Figure 5.22 gives an overview of the electricity consumption in HH4 during 2015-16, estimated using the information provided in the household's electricity bills (i.e. the average daily usage, total usage for periods, number of billing days, and the end date of billing periods). It also creates insight into the variation in ambient temperature during the same period.

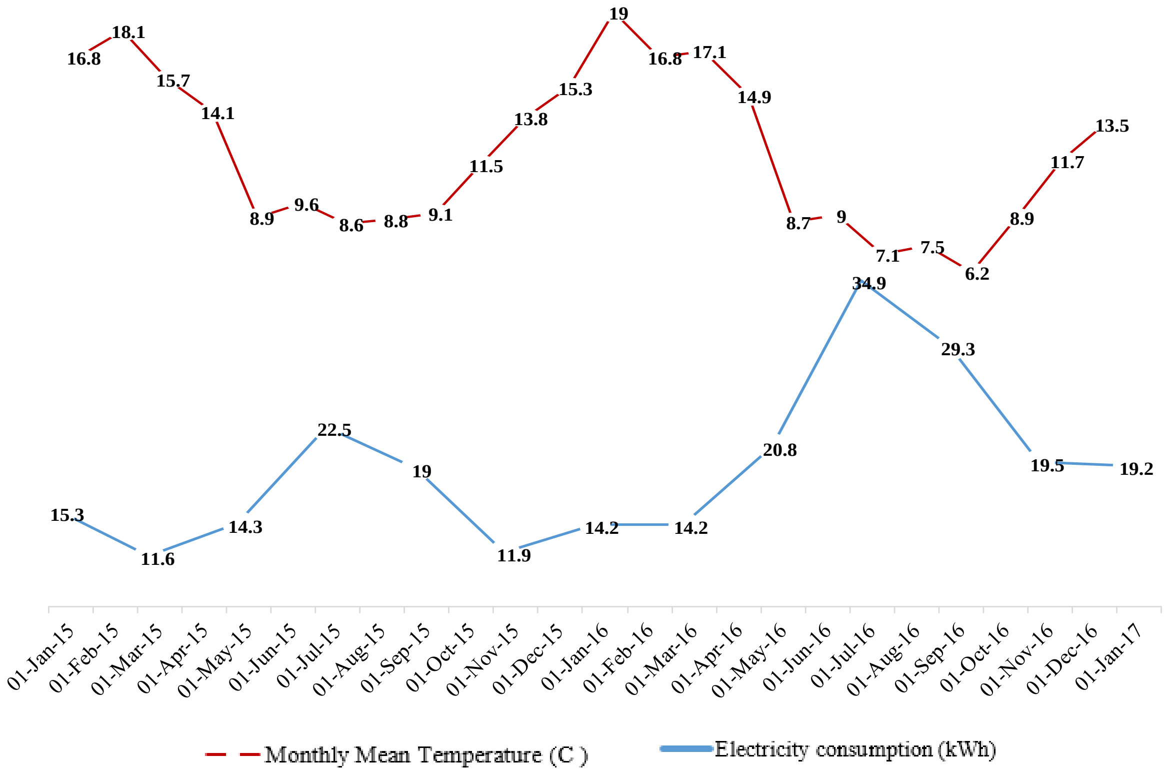

Figure 5.22 Temperature changes and estimation of electricity consumption in HH4

Overall, electricity consumption in HH4 raised in 2016. Although electricity consumption in January 2016 was slightly less than in 2015, it was significantly higher in July and August 2016 compared to the previous year (see **Figure** 5.22). In order to investigate the changes in the occupants' behaviour that might have caused a significant difference in the household's electricity usage from 2015 to 2016, such as the use of heating systems and ventilating the dwelling through opening/closing doors and windows during extreme seasons, a few periods are selected in summer and winter during the two years under investigation. Each period includes a few days with extreme weather conditions (relatively high ambient temperature and DGSE in summer and low ambient temperature and solar exposure in winter). Variations in the indoor air and wall surface temperatures in the lounge during these periods are then investigated in more detail in relation to the variation in the ambient temperature and solar exposure during the same period. The following subsections present these findings, which are discussed based on the long-term direct observations of occupants' behaviour in the dwelling and findings from interviewing the HoH during site visits.

Temperature Changes and Occupants' Behaviour in Summer

Figure 5.23 presents an overview of the variation in the average ambient temperature together with changes in total daily solar exposure across the month of February in 2015 and 2016.

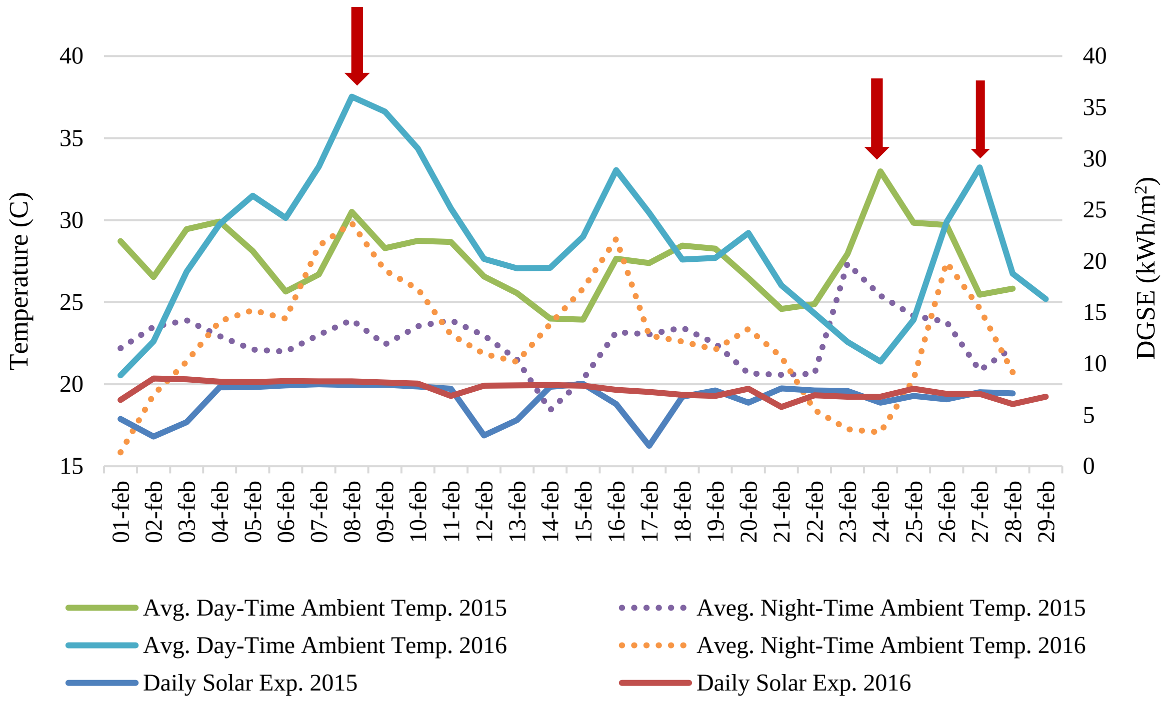

Figure 5.23 Average ambient temperature and DGSE (kWh/m^2) in February 2015-16

Solar radiation seemed to be more consistent and on average higher across the month in 2016 compared to 2015 particularly from 02nd - 10th and also from 12th - 15th February 2016. In contrast, DGSE in 2015 had three noticeable troughs, on the 2nd, 12th and 17th of February. DGSE on these three days was 2.9, 3 and 2 kWh/m^2 respectively, which was significantly lower than the average DGSE across the month (the average DGSE in February 2015 excluding these three days was 7 kWh/m^2). As shown in **Figure** 5.23, it seems that lower solar exposure on these days affected the ambient temperature on these days as well the immediate proceeding days. The average ambient temperature values had greater fluctuations in February 2016 with peaks around the 08th, 16th, and 27th February 2016 against only one peak in 2015, which was on 24th February (see **Figure** 5.23).

Two periods are selected from the data from February 2015 and 2016 to investigate in more detail the variation in internal temperatures in the lounge. These periods are period 1 (23rd – 26th Feb 2015) and period 2 (25th -28th February 2016) with peak days on 24th 2015 and 27th

February 2016 for period 1 and period 2, respectively. As shown in **Figure** 5.23, peak temperatures during these periods as well as the values of DGSE were comparable. **Figure 5.24** and **Figure 5.25** show the indoor air and wall surface temperatures during period 1 and period 2 together with the fluctuations of ambient temperature at the location of HH4.

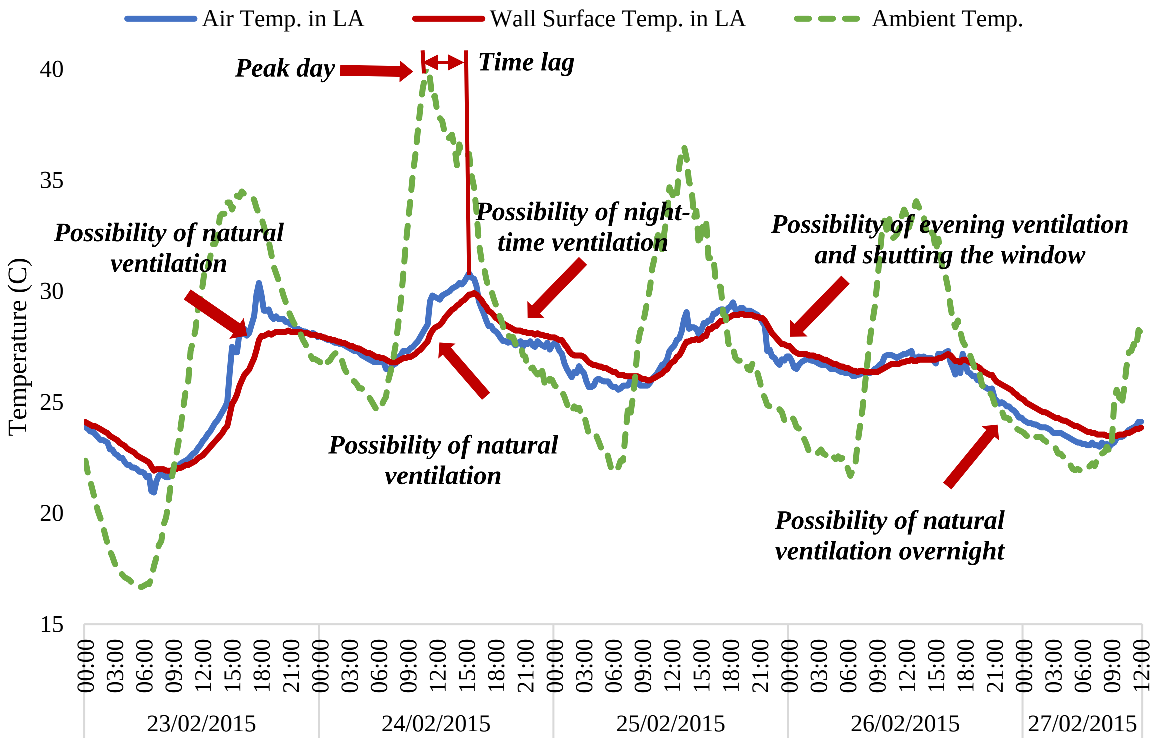

Figure 5.24 Indoor air and wall surface temperature in the main living area – Period 1

Overall, when ambient temperatures raised during the day-time in period 1, the indoor air temperatures, as well as the wall surface temperature, also raised. Findings from direct observations by the researcher in HH4 revealed that, except in extreme weather conditions, the entrance (and sometimes other doors and windows) were left open so that the lounge was constantly ventilated when the dwelling was occupied. This occupant behaviour may explain some of the trends in **Figure** 5.24 e.g. on 23rd and 24th February indoor air suddenly diverged from the wall surface temperatures starting at 03:00 pm on the 23rd and 10:45 am on the 24th February 2015. This may be due to solar heat gains through the window (just from opening the curtains) or entering the hot outdoor air into the house through opening the doors/windows (see red arrows in **Figure** 5.24).

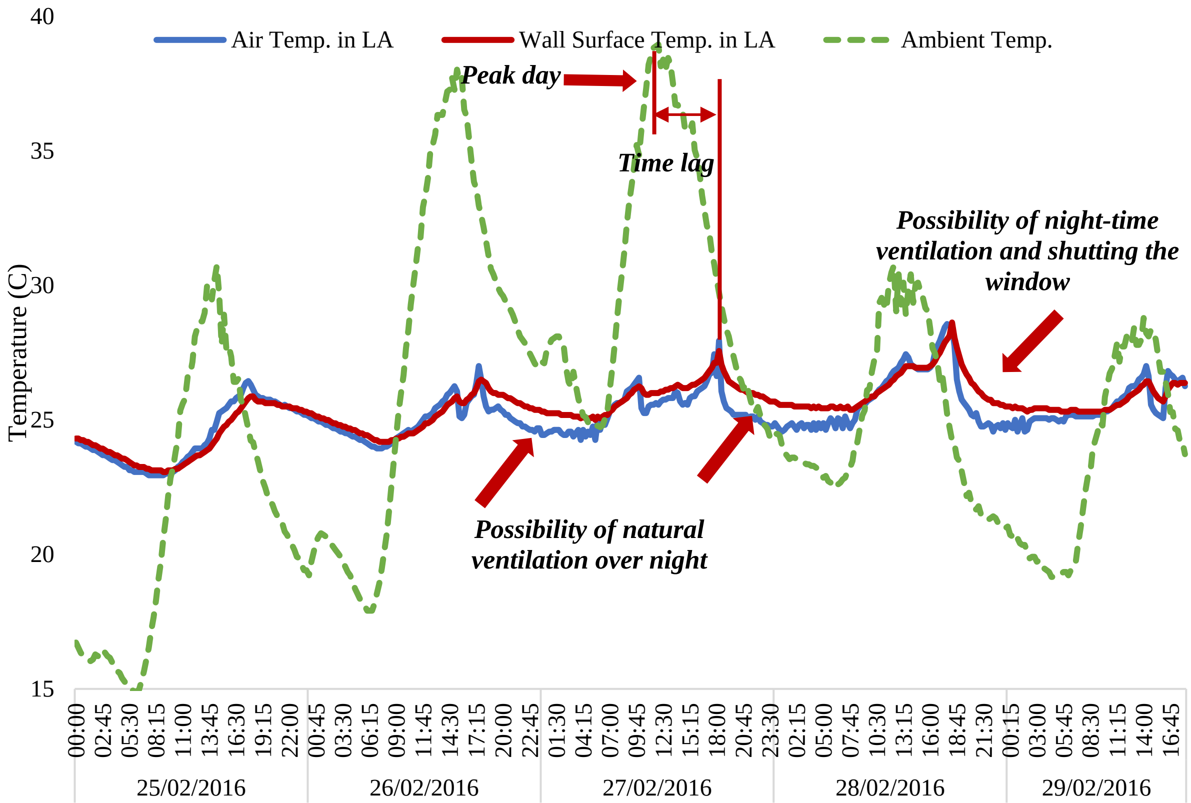

Figure 5.25 Indoor air and wall surface temperature in the main living area – Period 2

As expected, the range of temperature fluctuations indoors was smaller compared to the range of outdoor temperatures due to the influence of building thermal mass on moderating the internal temperature, with a DF on the peak day of 0.3 and a time lag of around 4 hours between indoor and outdoor temperature. As shown in **Figure** 5.24, sudden deviations of indoor air from that of the wall surface temperature may suggest that the dwelling was ventilated overnight on 24th and 26th February. and ventilated for a few hours on 25th Feb, starting from 08:30 pm with openings all closed around midnight, while no night-time ventilation was performed on 23rd February 2015.

A comparison of temperature changes during period 1(**Figure** 5.24) and period 2 (**Figure** 5.25) reveals that the variations in indoor temperature during these two periods were significantly different, especially on the peak days. Despite significant fluctuations of ambient temperature during period 2 (15-39 °C), indoor temperatures in period 2 varied over a more limited range (between 23 °C and 28 °C) than in period 1. The damping factor on the peak day in period 2 was 0.2 and more than 6 hours' time lag existed between the indoor and outdoor temperature changes. From long-term direct observations in HH4, it was found that the dwelling was often naturally ventilated through opening doors/windows and fresh outdoor air entered the house for on average a few hours a day when it was occupied. However, as shown in the profile for 25th February 2016 in **Figure** 5.25, the variations in indoor air temperature followed the same trend as the fluctuations of ambient temperatures but with no sudden rise, drop, and deviation from the wall surface temperature as a result of e.g. introducing fresh air into the dwelling (time lag between the indoor air and ambient temperatures on this day was around 3 hours). This may suggest that the dwelling was vacant on this day or the occupants did not open the doors and windows – in accordance with the suggested guidelines.

Indoor temperature changes on 26th and 27th February 2016 were, however, significantly different. Although the difference between the day-time indoor air and wall surface temperatures on these days was mostly within ± 0.5 °C, which is the accuracy range of the loggers, changes of indoor temperature on these days may suggest some behavioural activities, which resulted in sudden drops of indoor air and its divergence from the wall surface temperatures (see red arrows in **Figure** 5.24). On 26th February, the indoor temperature suddenly dropped by 1 °C at 3:00 pm. However, it raised again after about an hour, before it lowered over at 05:30 pm. Since no cooling system was used in HH4 except a standing fan, the first drop of indoor temperature might have been caused by closing all the openings and curtains and/or turning on the fan (although the HoH said the fan was rarely used). However, the second drop, which occurred in the evening and went on overnight might have been caused by naturally ventilating the lounge perhaps by leaving a window partly open. Similarly, the indoor air temperature on 27th February fell below the wall surface temperature in the lounge, starting from 10:00 am. This may also imply that no outdoor air was entered the dwelling during this period and the openings were all closed. However, the divergence of indoor air from that of the wall surface temperature at night confirms that a door/window might have been left open and the dwelling was naturally ventilated overnight.

As discussed earlier, no cooling system was used in HH4, verified through direct observations in the household. A more detailed investigation of the variations in indoor air and wall surface temperatures in the main living area, taking into account the fluctuations of ambient temperature, however, revealed significant changes in how the indoor temperatures changed on peak days during period 1 and period 2. **Figure** 5.26 plots the variation of indoor temperatures in relation to the ambient temperatures in the lounge on 08th February 2016, when the average ambient temperature and solar radiation were at their maximum (average day-time ambient temperature was 37.5 and DGSE recorded on this day was 8.3 kWh/m^2).

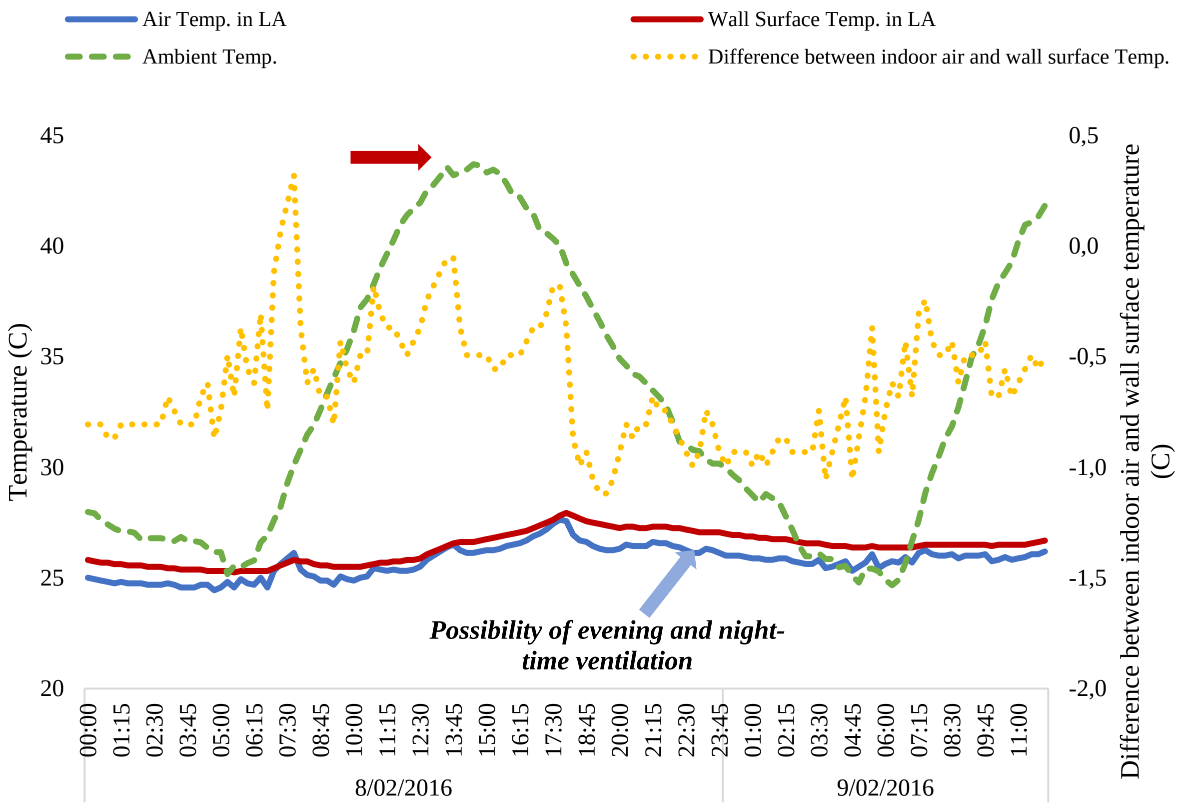

Figure 5.26 Indoor air and wall surface temperature in the lounge - 08th February 2016

It is evident that fluctuations of internal temperatures on 08th February 2016, when the ambient temperature raised to a maximum of 43.7 °C (at 02:30 pm), was noticeably less than the variations in ambient temperatures (DF=0.2). Around 3.5-hour time lag existed between the outdoor and indoor temperature, which resulted in the indoor temperature to reach its highest point (27.6 °C) at 06:00 pm, i.e. 3.5 hours after the ambient temperature stood at its highest point. As shown in **Figure** 5.26, indoor air temperatures during the day-time fell below the wall surface temperature, showing no significant rise/drop as a result of e.g. introducing hot outdoor air or running a cooling system in the dwelling (the difference between indoor air and wall surface temperature in the lounge was within the loggers' accuracy range). This indicates that closing the openings and/or curtains in the lounge were possible actions taken by the occupants to control the internal temperature on such a hot summer day. However, the indoor air temperature dropped starting at 06:00 pm, which may suggest that the doors/windows were opened in the evening when the ambient temperature lowered (see **Figure** 5.26). Comparison with ambient temperature data recorded on this day supports the idea that the dwelling was naturally ventilated overnight since indoor air temperature and ambient temperature were both around 25.5 °C at 04:00 am, 05:30 am, and 06:46 am the following day (see red arrow in **Figure** 5.26)

Temperature Changes and Occupants' Behaviour in Winter

Figure 5.27 presents the variation of average ambient temperature and total solar radiation across the month of July in 2015 and 2016.

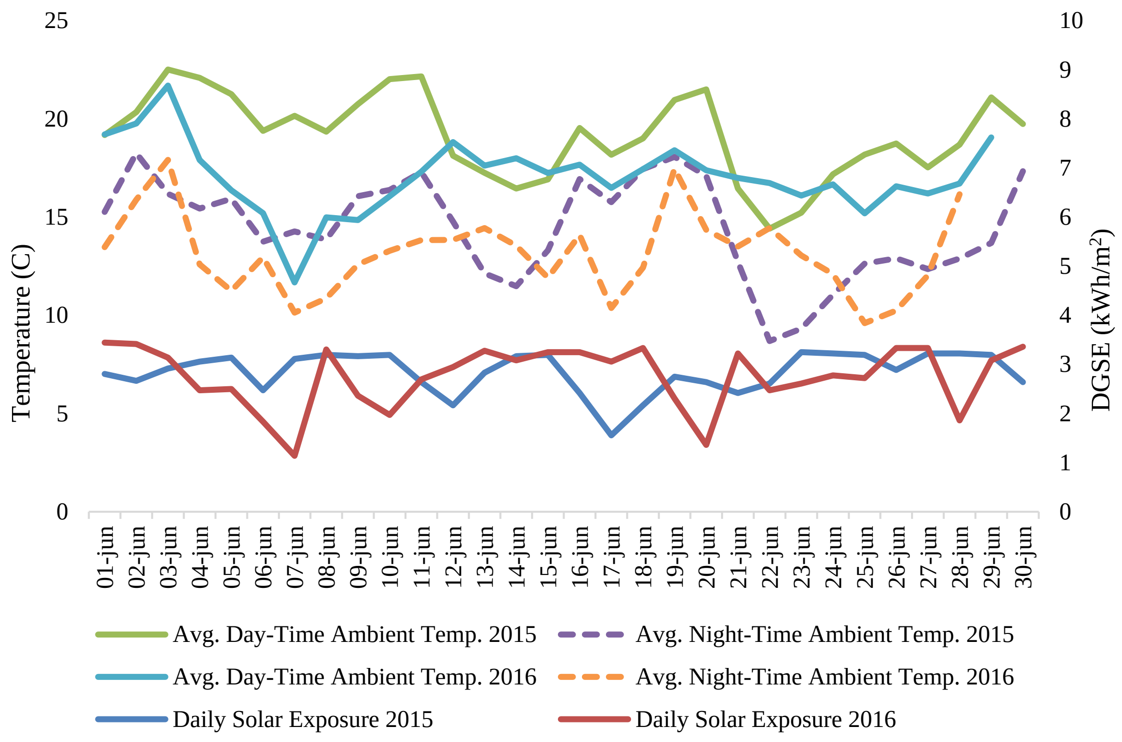

Figure 5.27 Average ambient temperature and DGSE (kWh/m^2) in June 2015-16

DGSE seemed to be peakier across the month in 2016 with quite significant troughs around 07th, 20th, and 28th June 2016 against only one trough on 17th June 2015. This greater fluctuation seems to correlate with a greater range in ambient temperatures, which are slightly more consistent and on average higher in 2015 than in 2016.

In order to investigate the changes in the occupants' behaviour with respect to heating the dwelling and ventilating the house in winter 2015 and 2016, two periods are selected from the date of June 2015 and 2016 with relatively low ambient temperature and low DGSE. These are period 3 (21st – 24th June 2015) and period 4 (06th – 09th June 2016). The variations in indoor air and the wall surface temperatures in the lounge are then discussed in more detail during these periods together with the possible actions that might have been taken by the occupants in the dwelling which might have affected the electricity consumption in 2016 compared to 2015 (see **Figure** 5.22 for the rise in the electricity consumption in winter 2016 compared to 2015 in HH4). Note that similar to the previous households, the possibility of different behavioural activities in period 3 and period 4 is informed from direct observations of the occupants' behaviour and findings from informal interviews performed during the site visits of 2015-16.

Figure 5.28 and **Figure** 5.29 show the internal temperature changes in the lounge in HH4 during period 3 and period 4 respectively.

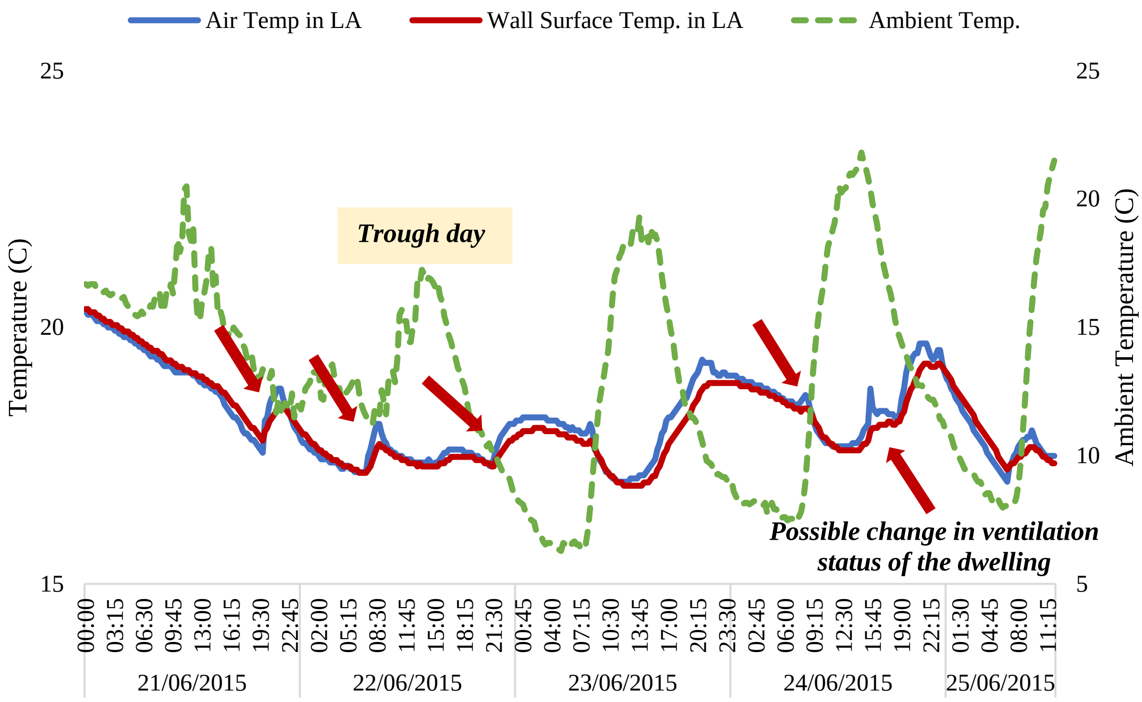

Figure 5.28 Indoor air and wall surface temperature in the main living area - Period 3

From the temperature data recorded in the lounge, it is evident that this zone was heated during both period 3 and period 4. However, a noticeable difference existed between the rise of indoor air temperature and its divergence from that of the wall surface temperatures in the two selected periods. Looking at **Figure** 5.28, there are a few occasions that the electric heater seemed to be running in the lounge during period 3, including on 21st June starting at 07:45 pm, 22nd June at 07:00 am and 09:00 pm, and 24th June at 07:30 am (red arrows in **Figure** 5.28). In each case except on 22nd June, the heater seemed to be turned off after a maximum of 2 hours. Variations in the indoor temperature on 24th June, when ambient temperature raised to around 22 °C and solar exposure for the day was relatively higher than an average (3.2 kWh/m^2), might have been caused by opening a door/window at 03:30 pm, which was then closed after 3 hours.

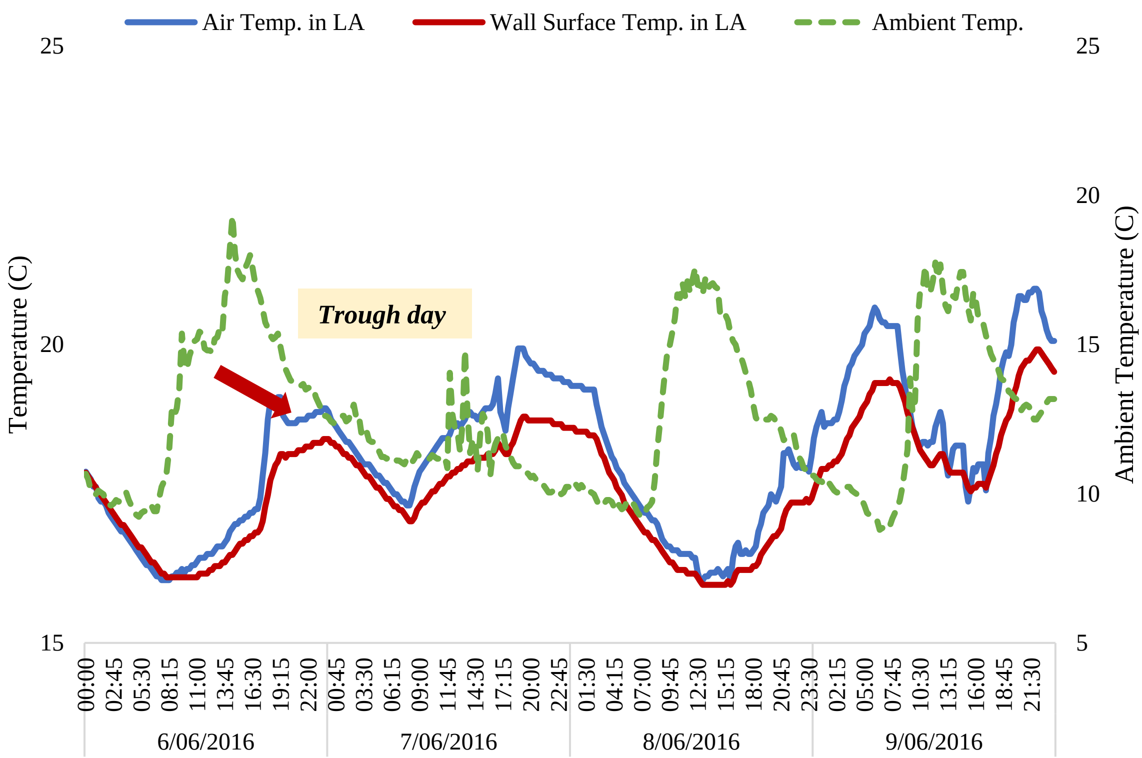

Figure 5.29 Indoor air and wall surface temperature in the main living area - Period 4

As shown in **Figure** 5.28, the rise in internal temperature to 19.7 °C at 09:00 pm on the evening of the 24th might have been as a result of solar heat transfer, with 6.5 hours' time lag, from the raised ambient temperature during the day-time.

As shown in **Figure** 5.28 and **Figure** 5.29, despite lower ambient temperatures during period 4, the internal temperature raised to higher points compared to period 3. For example, the average day-time ambient temperature and solar exposure on trough days were 14.4 °C and 2.6 kWh/m^2 in period 3 (22nd June 2015) and 11.7 °C and 1.1 kWh/m^2 in period 4 (07th June 2016). Nevertheless, the internal temperature was on average higher in period 4 than period 3 (17.5 °C and 18.5 °C in period 3 and period 4, respectively). Note that while the maximum ambient temperature was lower on the trough day in 2016, the indoor air temperature in the lounge raised to a higher value (18 °C on 22nd June 2015 compared to 20 °C on 07th June 2016).

Air temperature in the living area during period 4, however, changed quicker than in period 3 and created a significant divergence from the wall surface temperature for extended periods. On 7th June 2016, internal temperatures started to increase from 08:30 am, which lasted for 8 hours. It raised again started from 06:30 pm and went on until 02:15 am. It suggests that the heater was constantly running in the lounge significantly longer than period 3. On this day, when the ambient temperature lowered to 10 °C at 09:45 pm, the indoor air temperature was constantly between 17-19.5 °C. Another clear example of running the heater for an extended period in HH4 was on 08th and 09th June, when the indoor temperature constantly raised starting from 06:46 pm and reaching a maximum of 20.6 °C, when the ambient temperature was constantly dropping (see **Figure** 5.29).

Period 3 and period 4 were selected as the representatives of cold winter days in 2015 and 2016 and fluctuations of indoor air and wall surface temperature in the lounge during these periods supports the idea that the heating system was used more in 2016 than 2015. In order to further verify the differences between the household's heating energy use behaviour in 2015 and 2016, **Figure** 5.30 and **Figure** 5.31 plot the internal temperatures against ambient temperatures on 15th June 2015 and 15th June 2016, when the average day-time ambient temperature and solar exposure was similar (average day-time ambient temperature was 16.9 and 17.2 °C and solar exposure was 3.2 and 3.3 kWh/m^2 in 2015 and 2016, respectively).

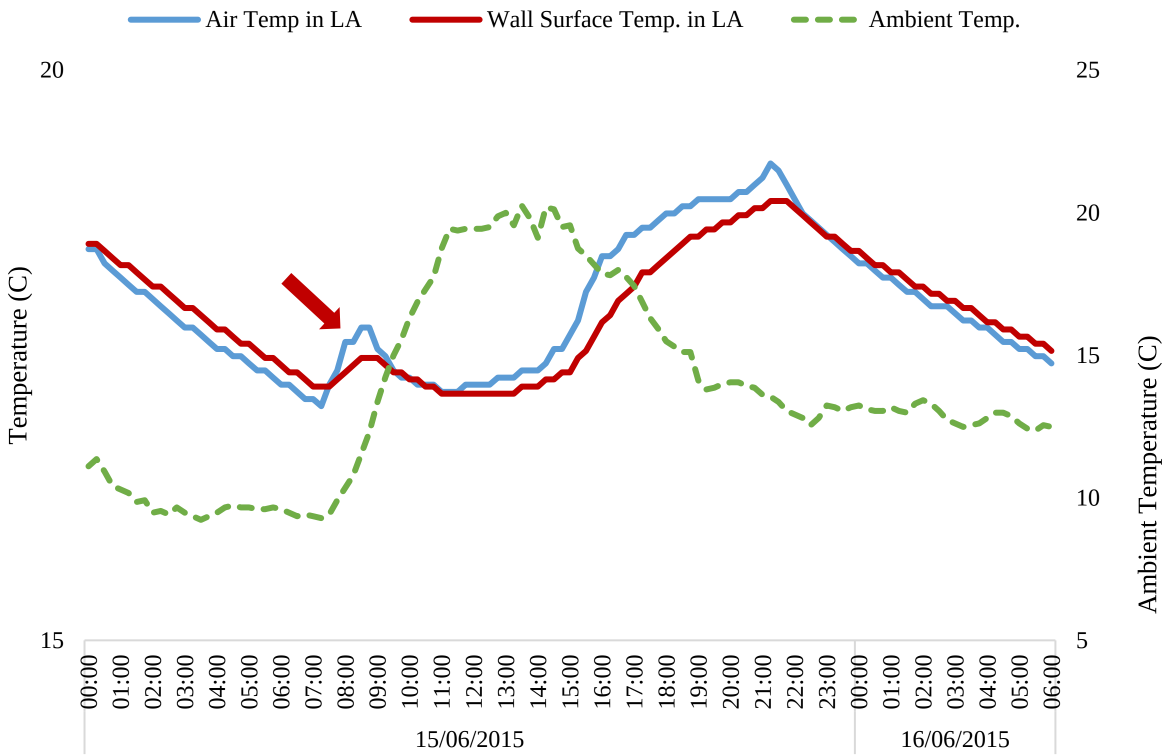

Figure 5.30 Indoor air and wall surface temperature in the lounge - 15th June 2015

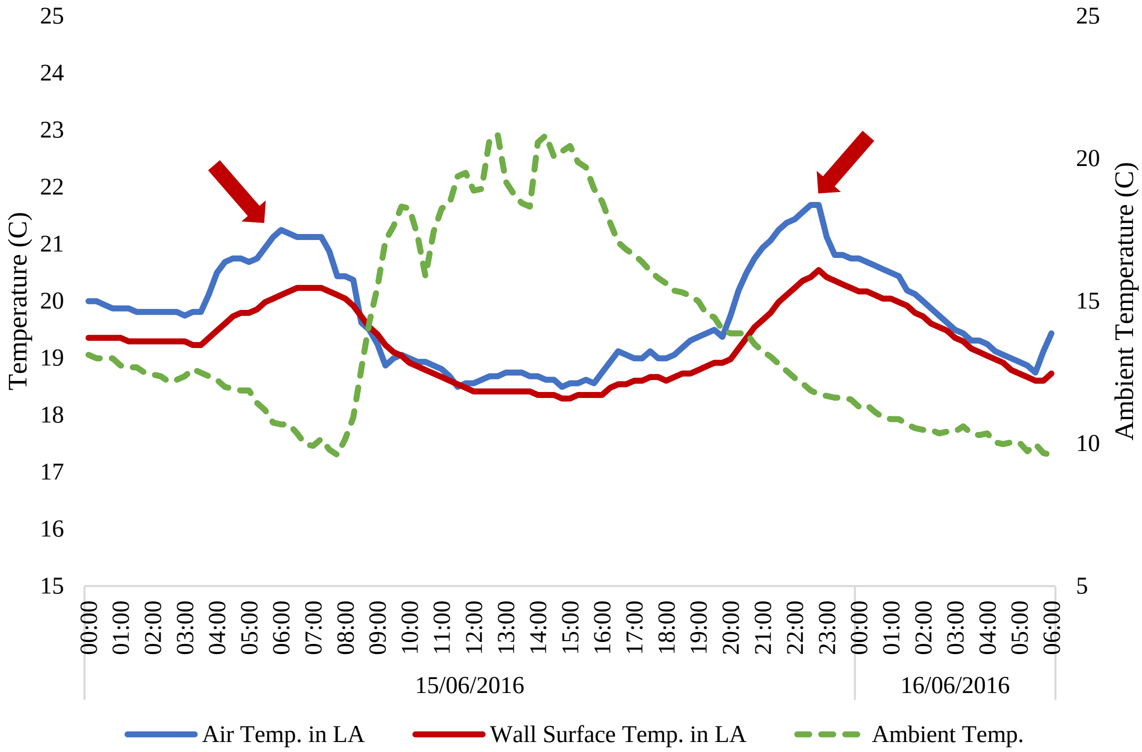

Figure 5.31 Indoor air and wall surface temperature in the lounge - 15th June 2016

The fluctuations of internal temperatures were significantly different on 15th June 2015 compared to 15th June 2016. As shown in **Figure** 5.30, indoor air and wall surface temperatures closely followed each other in 2015 and hence, no heating system seemed to be used for an extended period on 15th June 2015 except for perhaps about one hour in the morning (see the red arrow). Indoor temperatures during the day-time seemed to follow the ambient temperature with around 8 hours' time lag between the indoor and outdoor temperature. In contrast, sudden rises of indoor air temperatures and their divergence from the surface temperature in this zone recorded in the lounge on 15th June 2016 suggests that the lounge was heated for at least a few hours once in the morning (starting at 03:45 am) and once in the evening (starting at 07:45 pm) (see red arrows in **Figure** 5.31). From the above discussions, it is clearly evident that even during similar climatic conditions (similar to ambient temperature and solar exposure) more heating energy was used in 2016 compared to 2015. Despite in response to the survey questions, the HoH stated that the heater was used for a maximum of 7 hours on extremely cold winter days, temperature data recorded in the lounge in 2016 revealed that the heater run for a significantly longer period (up to 14 hours during the period under investigation). This may to a certain extent explain why electricity consumption in this household significantly raised in 2016 compared to 2015 (shown in **Figure** 5.22).

Summary

In this chapter, findings from temperature monitoring in a few sample households are presented and the possible causes of the changes are discussed based on the occupants' behaviour with respect to the use of heating/cooling appliances and natural ventilation in the dwellings obtained from the household interview and long-term direct observations. Throughout the analysis, the sudden divergence of the indoor air temperature from that of the wall surface temperature was used as an indicator for some behavioural activity in the dwellings including opening/closing doors, windows, and curtains to access or prevent solar heat gains or turning on the heating/cooling appliances where available. Evaluating how the indoor temperature and the wall surface temperature followed each other in the households created insight into occupants' energy use behaviour in these dwelling.

In all 3 households, the fluctuation in indoor temperatures was less than the ambient temperature due to the influence of building thermal mass and insulation materials used in building construction. However, this influence varied in different households depending on the occupants' behaviour with respect to ventilating the house and/or the use of heating and cooling systems in the dwellings. For example, the indoor temperature in HH1 with no heating/cooling varied over a wider range compared to HH2 with a reverse cycle AC or HH4 with the heating system.

It was found that HH1, in which, the majority of the windows in the living area are north-facing, was actively ventilated, and curtains were adjusted to make the most of solar radiation to maintain occupants thermal comfort in the dwelling. Indoor and outdoor temperature fluctuations recorded in this household confirmed that significant differences existed between occupants' behaviour with respect to ventilating the house in summer and winter. On an extremely hot summer day, indoor temperatures in HH1 raised to 38 °C (possibly due to opening a door/window or curtain), which was way beyond the occupants' thermal comfort. However, occupants' appropriate behaviour with respect to opening/closing the curtains during sunny days in winter significantly assisted them to heat up the living area and maintain a certain level of thermal comfort through maximizing the solar heat gains from the windows. Temperature monitoring in HH1 further revealed that despite the occupants were aware of the influence of night-time natural ventilation and how it can assist them to cool down the house especially during hot summer days, they performed less overnight ventilation due to the security concerns.

The fluctuation of indoor temperatures in both summer and winter was less in HH2 compared to HH1. From interviewing the household, it was found that more cooling was required in summer than heating in winter in HH2. This was further confirmed by the temperature data recorded in the dwelling. However, despite the heating system was reported to be mostly used during cold winter nights, it was found that no heating system was used at night during the periods under-investigated. Instead, a few occasions were found when both ambient temperature and solar exposure were relatively low while a little difference between the minimum and maximum indoor temperatures may suggest that the AC was running in the dwelling during the day-time. Similar to HH1, no overnight ventilation was performed in HH2 due to the occupant concerns about security.

The variation in indoor temperature during these two selected periods in summer 2015 and 2016 was significantly different in HH4, especially on the peak days with indoor temperatures varied over a more limited range in 2016. The difference between the indoor and outdoor temperature changed in the dwelling together with the time lag existed between the indoor and outdoor temperature may suggest that unlike 2015, the occupants did not open the doors and windows when the ambient temperature was high in accordance with the proposed guidelines. However, fluctuations in indoor air and wall surface temperatures in the lounge during the selected periods in winter confirms that more heating system was used in 2016 compared to 2015. Overall, less time lag existed between the indoor and outdoor temperature in HH1 compared to the other two households during the periods under investigation. Different factors including the orientation of the dwellings, how they were ventilated through opening doors/windows during extreme weather conditions, and the direct solar heat gains from windows are some of the main factors affecting the indoor temperature in a dwelling, which significantly differed in the sample households.

In the next chapter, findings from the thermal energy performance assessment of a number of sample dwellings with AccuRate Sustainability is presented and findings are discussed in detail. In this analysis, the actual occupant-related factors collected from the household survey and walk-through energy audit in the dwellings are used to estimate the impact of occupants and their energy use behaviour on the heating and cooling energy requirements of the dwellings.

CHAPTER 6

THERMAL PERFORMANCE ASSESSMENT WITH ACCURATE SUSTAINABILITY

Overview of Chapter

This chapter presents and discusses the findings from the thermal performance assessment of a number of sample dwellings using AccuRate Sustainability. As described in Chapter 2, AccuRate is the benchmark software for house energy rating in Australia for compliance with the national building code. In order to create a more realistic insight into the thermal energy performance of the sample dwellings, heating, cooling, and total energy requirements are calculated through 5 scenarios including BaseCase, BaseCase Adjust (occupancy adjust), BaseCase Adjust + Audit Survey (IHGs), BaseCase Adjust + Audit Survey (Thermostat Settings), and finally, a combination of the past two scenarios where the cumulative influence of occupants on the thermal performance of the dwellings was taken into account. In each scenario, information collected from the household survey and energy audit (discussed in Chapter 4) are incorporated into the models and the variation in thermal energy requirements calculated in each scenario was used as an indicator for the influence of occupants on the thermal performance of the dwellings.

6.1 Building Thermal Performance Assessment with AccuRate Sustainability

As discussed in Chapter 2, AccuRate Sustainability is a suite of tools for assessing the environmental sustainability of Australian residential homes and supports 2 modes: rating (regulatory) mode and non-rating (non-regulatory) mode. In the rating mode, calculation of heating and cooling energy requirements only considers the thermal performance of particular building design in terms of heat gains and losses, having no option to supply/eliminate heat or coolth in different zones of a building. Indeed, rating mode only calculates the star rating as a way of comparing the thermal performance of buildings and is valid only in the case where each building has similar appliances and hours of use. Otherwise, the effect of the design of each building on its thermal performance cannot be compared. In this mode, the active role of occupants and their behaviour in the building is limited to some fixed (non-adjustable) assumptions by the software. Using the AccuRate basic assumptions, therefore, the energy requirements calculated in the rating mode are unlikely to predict the actual thermal energy performance of a building. The non-rating mode, however, creates more flexibility as it allows providing or eliminating heat or coolth in different zones in the models through the AccuRate interface. Further adjustment, mostly with respect to Internal Heat Gains (IHG), and thermostat settings, however, can be made through the input scratch files to the AccuRate software engine.

In order to create a more realistic insight into the buildings' thermal energy performance, models of the sample dwellings were created in the non-rating mode and the heating and cooling in different zones were modelled based on real input data collected from the survey, energy audit and direct observation of each household. Upon incorporating the actual data into the models, the input files to the AccuRate engine were modified to reflect the real conditions of occupancy, thermostat set-points of the heating and cooling appliances, their time of use, etc. In the interest of this study, occupant presence is characterised by the number of occupants, times related to occupancy of zones and their choice of appliances. Energy use behaviour is also characterised by the time of use of lights and other key appliances and the choice of thermostat settings for heating and cooling appliances.

6.2 Energy Performance Assessment of the Sample Households with AccuRate Sustainability in Non-Rating Mode

The design information required for creating models of the sample dwellings in the non-rating mode was collected either from the FH database or from related councils (with the approval of

FH as the owner of the property). This information then configured as input data for the software including:

- Basic information including project name, code, building class, etc.
- Construction details
- Zones
- Shading, including vertical and horizontal shadings
- Elements
- Ventilation and building orientation

AccuRate divides the buildings into three groups: Classes 1a, 2 and 4 in accordance with the National Building Code of Australia (BCA). As stated in the BCA, Class 1a are single dwellings e.g. a detached house, or one or more attached dwellings, each being a building, separated by a fire-resisting wall. This includes a row house, terrace house, townhouse or villa unit. Class 2 includes buildings containing 2 or more sole-occupancy units, each being a separate dwelling. Finally, a building is classified as Class 4 if it is the only dwelling in non-residential building. Except for one dwelling, which was grouped as Class 2, the others are single detached dwellings, classified as “1a”. Other information including the exposure, unit number, street name, street type, suburb/town, postcode, and state was incorporated into the models, based on which, a climate zone and a weather data file was assigned by the AccuRate software for each building. Given that all the dwellings are located in low-rise built-up areas in the northern suburbs of Perth, they were all specified as suburban dwellings with a ground reflectance equal to 0.2, corresponding to a grassed surface. Subsequently, the details of different construction types were incorporated into the models, including external walls (Appendix 6A), internal walls (all 90 mm generic clay brick with 15 mm plaster (cement: sand 1:4) on both sides), doors, windows, floors/ceilings, roof, skylight, and roof windows.

Three groups of input data were incorporated into the models through the AccuRate interface including values in grey boxes, values in white boxes and those in green boxes. Unlike the input data in grey boxes that are default software values that cannot be changed by the user, values in white boxes are the input data needed to be entered by the user, including the colour and solar absorption of the external and internal surfaces of the walls. And finally, values in green boxes are the calculated fields based on the building information provided by the user such as the total resistance to heat transfer, R (heat flow up), total R (heat flow down), etc. **Figure** 6.1 visualises different input data incorporated into the models through the AccuRate interface.

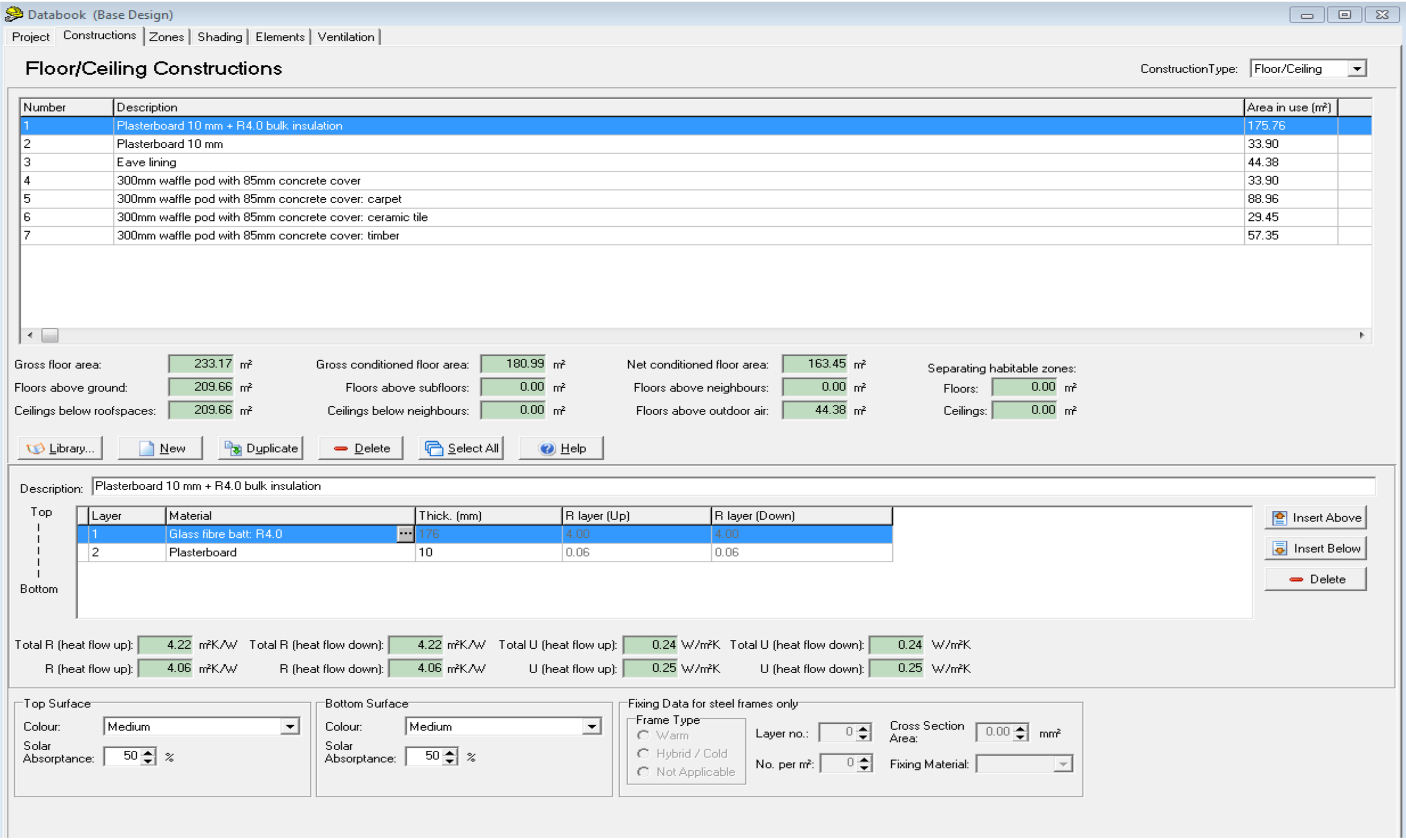

Figure 6.1 Sample of different input data in the AccuRate interface

6.2.1 Windows/Doors

Windows/doors in each dwelling were modelled based on the information provided in buildings' design documents. AccuRate Sustainability uses the classification made by the Nationwide House Energy Rating Scheme (NatHERS) for windows. According to this classification, there are two operating groups of windows. Group A consists of Awnings, Casements, Bi-folds, Tilt and Turns, and also doors comprising of Bi-fold, Entry and Hinged and French doors. Group B, on the other hand, encompasses Sliding, Fixed, Louvre and Double or Single Hung windows and also Sliding and Stacker doors. The main difference between these two groups of windows is the frame fraction, which in turn determines the system thermal transmittance (U-value) and the Solar Heat Gain Coefficient (SHGC). According to the design information, two different types of windows are installed in the sample dwellings:

- Aluminium A SG Clear: U=6.70: SHGC=0.57
- Aluminium B SG Clear: U=6.70: SHGC=0.70

6.2.2 Floor/Ceiling

The floor in all the sample dwellings is 100 mm concrete slab covered with either ceramic tiles or carpet. Ceiling, on the other hand, is plasterboard ranging between 10 - 13 mm thickness with different types of insulation. **Table** 6.1 summarizes the construction of floors and ceilings in each of the sample dwellings.

Table 6.1 Floors and ceilings in the sample dwellings

HH	Floor	Ceiling
HH1	Concrete slab 100 mm: ceramic/bare Concrete slab 100 mm: carpet/bare	Plasterboard 13 mm + R4.0 Fiberglass Batt
HH2	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic/bare	Plasterboard 13 mm + R4.0 bulk insulation
HH3	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic/bare	Plasterboard 13 mm + R2.5 bulk insulation
HH4	Concrete slab 100 mm: ceramic/bare	Plasterboard 10 mm + R 3.0 Cellulose fibre
HH5	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic/bare	Plasterboard 10 mm + R 4.0 bulk insulation

HH6	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic/bare	Plasterboard 10 mm + Cellulose fibre R 4.0
HH7	Concrete slab 100 mm: ceramic/bare	Plasterboard 10 mm + R4.0 Galss Fiber Batt
HH12	Concrete slab 100 mm: carpet/bare Concrete slab 100 mm: ceramic/bare	Plasterboard 10 mm + R4.0 Galss Fiber Batt

When incorporating building design information into the models, the thickness was constant for the following materials:

- Carpet + underlay combinations (20 mm);
- Concrete blocks (90-190 mm);
- Insulation (bulk), specified resistance: the thickness is fixed to ensure that the R-value given in the material description is obtained (7-180 mm);
- Air gaps (> 66 mm, 31-65 mm, 17-30 mm, and 13-16 mm): the thickness is fixed because the thermal resistance of air gaps depends on more than just their thickness. A selection of fixed thicknesses is available.

6.2.3 Roof

Three different types of roof are used in the construction of the sample dwellings, including metal deck, concrete tile and terracotta tiles. **Table** 6.2 summarizes the construction of the roofs in the sample dwellings.

Table 6.2 Details of the roofs in the sample dwellings

Household	Roof Construction	Roof Colour	Total Area (M^2)	Pitch (Degrees)	Exposure
HH1	Colorbond	Dune (light)	296.6	25	Normal
HH2	Tiles (Terracotta)	Brick (red pressed clay)	152.5	25	Normal
HH3	Tiles (Terracotta)	Brick (red pressed clay)	151.78	26	Normal
HH4	Tiles (Concrete)	Grey (light)	165.04	26	Normal
HH5	colorbond	Dune (light)	221.2	23	Normal
HH6	Tiles (Concrete)	Grey (light)	249.7	24	Normal
HH7	colorbond	Grey (dark)	184.24	23	Normal
HH12	colorbond	Dune (light)	279.6	24	Normal

6.2.4 Horizontal and Vertical Shadings

Two types of shadings were used in the sample dwellings: horizontal shadings and vertical shadings. A shading that was applied to each external wall was assumed to automatically shade any windows in that wall. Horizontal shadings are eaves, pergolas, etc. that create a shadow on external walls and windows. **Figure** 6.2 shows various parameters of a sample horizontal shadings.

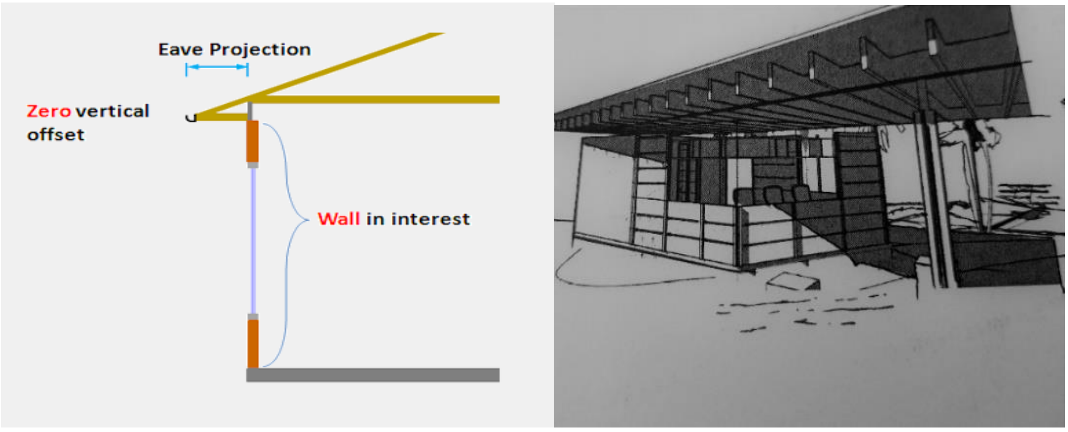

Figure 6.2 Horizontal shading

Some external walls and windows in the models were also influenced by vertical shadings or external screens including fences surrounding the building and the neighbouring structures. **Figure** 6.3 presents how neighbouring structures affect a building by creating a shadow on the building.

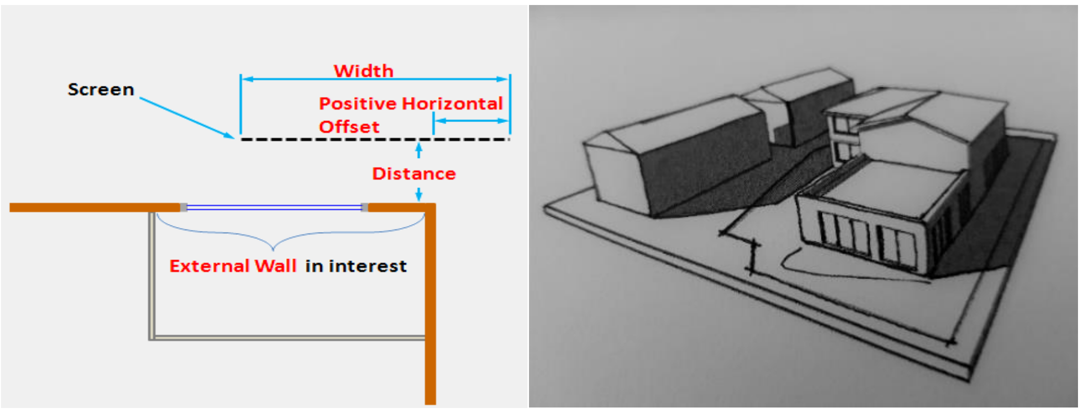

Figure 6.3 Vertical shading

6.2.5 Zones and the Assumptions Made by AccuRate Sustainability

A zone in AccuRate Sustainability is a space or group of spaces that are expected to be at a uniform temperature. Each sample dwelling was divided into different zones based on how they were used by the occupants and/or heated or cooled and ventilated (Appendix 6B). In order to calculate the thermal energy requirements of a building, AccuRate Sustainability uses a range of assumptions. **Table** 6.3 summarises some of these assumptions for heating and cooling of different zones, together with the thermostat set-points of these zones.

Table 6.3 Assumptions made by AccuRate Sustainability regarding the zones conditioned and thermostat settings

Zone type	***Assumptions and Comments***	***Thermostat Settings***		
		Heating zones of type "Living", "Living/Kitchen", "Other", "Garage"	***Heating zones of type "Bedroom"***	***Cooling for all conditioned zones***
Living	Conditioned from 07:00 – 24:00. Daytime occupancy. No cooking heat gains	20.0 C	-	25.0 C
Bedroom	Conditioned from 16:00 – 09:00. Night-time occupancy	-	15.0 C or 18.0 C	25.0 C
Living/Kitchen	Conditioned from 07:00 – 24:00. Daytime occupancy. Cooking heat gains included	20.0 C	-	25.0 C
Day time	Conditioned from 07:00 – 24:00. No occupancy heat gains	20.0 C	-	25.0 C
Night time	Conditioned from 16:00 – 09:00. No occupancy heat gains	20.0 C	-	25.0 C
Unconditioned	No heating or cooling. No occupancy heat gains	-	-	-
Garage	No heating or cooling. No occupancy heat gains	-	-	-
Garage Conditioned	Conditioned from 07:00 – 24:00. No occupancy heat gains.	20.0 C	-	25.0 C

Roof Space	Invokes special roof space model. Do not use this type for habitable spaces, e.g. attic rooms	-	-	-
Sub-floor	Invokes special sub-floor space model. Do not use this type for habitable spaces, e.g. basement rooms	-	-	-

Note: In "Bedroom", lower value applies between 01:00 – 07:00 and higher value between 08:00 – 09:00 and 16:00 – 24:00 (Source: AccuRate Sustainability Heating and Cooling Operation Help (Board 2006)*).*

Although heating and cooling are assumed to be available between these times, they are not invoked unless required. When calculating heating and cooling energy requirements in AccuRate, heating is applied if the zone temperature at the end of the hour without heating is below the heating thermostat setting for that zone. Cooling, however, is invoked in a more complicated way. If at the end of the hour, the zone temperature without cooling or ventilation is greater than a trigger temperature (0.5 °C below the cooling thermostat temperature, but with an upper limit of 26 °C) and greater than (outdoor air temperature - 4 °C), ventilation is switched on. Subsequently, the new zone condition (i.e. temperature and moisture content) is calculated and indoor air-speed is estimated. If the zone condition with natural ventilation is within the extended comfort region, cooling is not invoked. Otherwise, if the zone condition with natural ventilation remains outside the extended comfort region, and ceiling fans are available in that zone, the indoor air-speed calculated from natural ventilation is replaced by an indoor airspeed appropriate to the number of fans and zone floor area. If the zone condition with ceiling fans and natural ventilation is within the extended comfort region, cooling is not invoked. And finally, if the zone condition with ceiling fans and natural ventilation is still outside the extended comfort region, the zone openings are closed, ceiling fans (if any) are switched off, and sufficient cooling is applied so that the zone temperature at the end of the hour is the cooling thermostat setting. After incorporating all the elements of the buildings, including external walls, roofs, etc., into the models, especially with respect to their azimuths, the orientation of each building was adjusted based on the design information. A hypothetical north was first assigned based on which, external walls and roofs were oriented. The actual north was then identified, and all the elements were reoriented towards the true north.

In addition to the option of activating heating and cooling in different zones, AccuRate Sustainability in the non-rating mode calculates the energy consumption by a number of sustainability modules, including lighting, heating, cooling, and hot water. Although different types of lighting, hot water systems or heating/cooling appliances can be selected from the AccuRate library, the energy consumption calculated for each sustainability module is independent of the total energy requirements calculated and shown in the AccuRate final output file. In other words, sustainability modules are incorporated into AccuRate merely to create a better insight into the approximate energy consumption by different types of lighting, heating/cooling system, hot water system, etc., regardless of how they are used in different households in terms of their time of use and thermostat set-points of heating and cooling appliances. The assumptions made by the software for appliance time of use and thermostat set-points are still used for calculating the energy consumption by sustainability modules. AccuRate Sustainability adjusts the number of occupants based on the floor area of the building and the number of bedrooms. However, the adjusted family size used by AccuRate does not match the actual family size, for instance, small households living in buildings with large floor area (e.g. HH6) or large households living in buildings with small floor area (e.g. HH9).

In addition to the use of **Table** 6.3, there are other assumptions by which AccuRate calculates the energy requirements in a building. **Figure** 6.4 – **Figure** 6.7 show daily profiles that visualise the occupancy, heating thermostat settings, cooling thermostat settings, and the time of use of lighting in different zones as assumed by AccuRate Sustainability. The software assumes a cooling temperature set point of 25 °C for the conditioned zones at different times of the day. With respect to occupancy in **Figure** 6.4, 0 represents the zone was vacant for a given period of time and 1 means the zone was occupied (at least 1 person was present in the zone). For lighting in **Figure** 6.7, 0 and 1 represent the light was off/on, respectively.

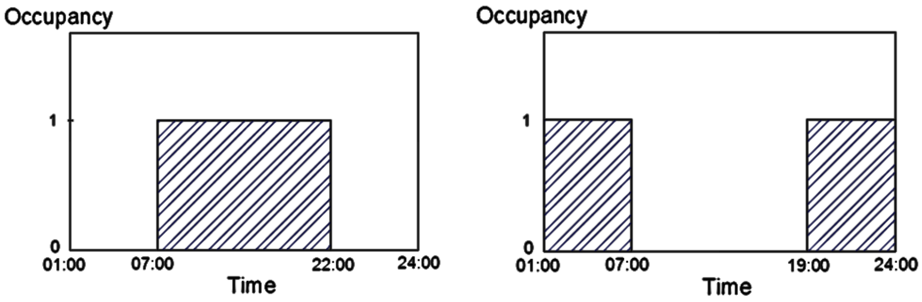

Figure 6.4 Occupancy pattern for zones of type a (left) “Living” and “Living/Kitchen”; b (right) “Bedroom”

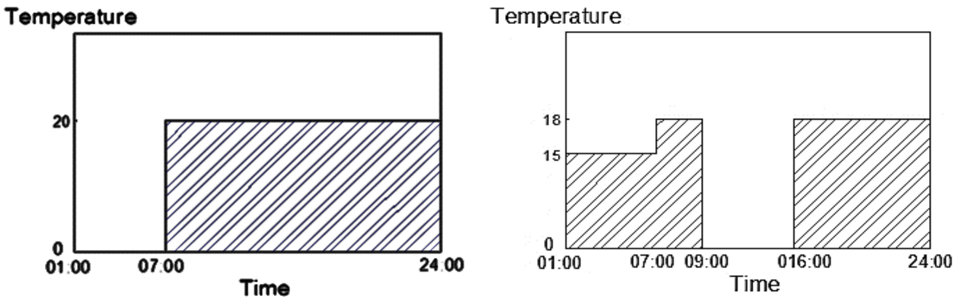

Figure 6.5 Heating thermostat settings in a (left) “Living Area” and “Living/Kitchen”; b (right) “Bedroom”

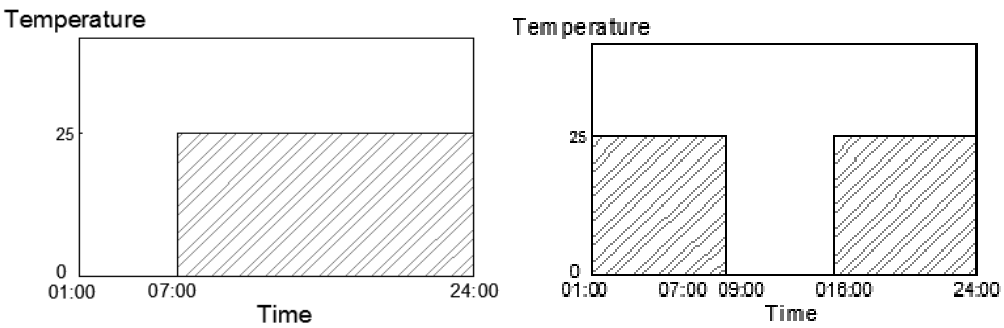

Figure 6.6 Cooling thermostat settings in a (left) “Living Area” and “Living/Kitchen”; b (right) “Bedroom”

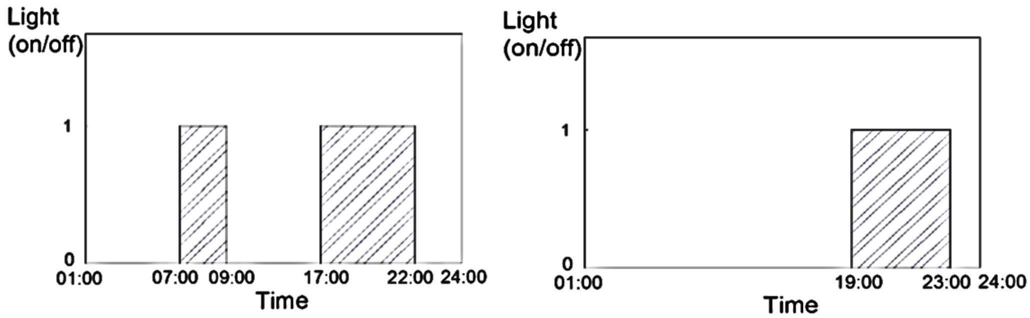

Figure 6.7 Time of use of light in a (left) Living spaces; b (right) Bedroom

According to the assumptions made by AccuRate Sustainability for calculating the heating and cooling energy requirements, all living spaces including living/kitchen are occupied between 07:00 AM – 10:00 PM (**Figure** 6.4 **(a)**). Bedrooms, on the other hand, are considered to be occupied between 7:00 PM and 07:00 AM (**Figure 6.4** (b)). In regard to the thermostat setting of heating appliances, living spaces are assumed to be heated between 07:00 AM and 12:00 AM with the thermostat fixed on 20 °C (**Figure** 6.5 **(a)**) and bedrooms are considered to be heated between 04:00 PM and 09:00 AM, with temperature set on 15-18 °C (**Figure** 6.5 **(b)**). Nevertheless, as discussed earlier in this section, heating and cooling are not invoked unless required. Lighting is assumed to be turned on between 07:00 AM and 09:00 AM and between 05:00 PM and 22:00 PM (**Figure** 6.7 **(a)**) in living spaces, and between 07:00 PM and 11:00 PM in bedrooms (**Figure** 6.7 **(b)**).

In AccuRate, only zones of type "Living/Kitchen", "Living" and "Bedroom" add to thermal loads through heat gains from lights and occupants. Equations 6.1 – 6.11 show how AccuRate Sustainability calculates sensible and latent internal heat gains.

$$\mathbf{Family} = \frac{\mathbf{Total\ Floor\ Area - 40}}{\mathbf{30}}, \mathbf{to\ the\ nearest\ integer} \qquad (6.1)$$

The total floor area excludes zones of type "Garage", "Roof space" and "Sub-floor".

Minimum value of Family = 1

Maximum value of Family = 6 (obtained with a floor area of 220 m^2)

$$\mathbf{OccupancyFactor} = \mathbf{0.33} + \mathbf{0.165} \times \mathbf{Family} \quad (6.2)$$

$$\mathbf{FamilyFactor} = {}^{\boldsymbol{Family}}/_{\mathbf{4}} \quad (6.3)$$

$$\mathbf{AreaFactor} = {}^{\boldsymbol{Zone\ floor\ area}}/_{\mathbf{80}} \quad (6.4)$$

If AreaFactor < 0.1 then AreaFactor = 0.1

If AreaFactor > 2.0 then AreaFactor = 2.0

Heat gains for zones type "Living / Kitchen":

$$\mathbf{LightingAdjust} = \mathbf{BaseLightPower} \times (\mathbf{AreaFactor} \times \mathbf{OccupancyFactor} - \mathbf{1}) \quad (6.5)$$

$$\mathbf{PeopleAdjust} = \mathbf{BasePeopleHeat} \times (\mathbf{AreaFactor} \times \mathbf{FamilyFactor} - \mathbf{1}) \quad (6.6)$$

$$\mathbf{Total\ Sensible} = \mathbf{BaseSensibleTotal} + \mathbf{LightingAdjust} + \mathbf{PeopleAdjust} \quad (6.7)$$

$$\mathbf{Total\ Latent} = \mathbf{BaseLatent} + \mathbf{0.5} \times \mathbf{PeopleAdjust} \quad (6.8)$$

Heat gains for zones of type "Living" or "Bedroom":

$$\mathbf{Total\ Sensible} = \mathbf{BaseLightPower} \times \mathbf{AreaFactor} \times \mathbf{OccupancyFactor} + \mathbf{BasePeopleHeat} \times \mathbf{AreaFactor} \times \mathbf{FamilyFactor} \quad (6.9)$$

$$\mathbf{Total\ Latent} = \mathbf{0.5} \times \mathbf{BasePeopleHeat} \times \mathbf{AreaFactor} \times \mathbf{FamilyFactor} \quad (6.10)$$

$$\mathbf{Number\ of\ Occupants} = \mathbf{max}\left(\mathbf{1} + \mathbf{0.66} \times \mathbf{NBR}, \frac{\mathbf{A}}{\mathbf{50}}\right) \quad (6.11)$$

NBR = number of bedrooms

A = floor area of the house in square metres (m^2)

The values for the above calculations were derived from the "Protocol for House Energy Rating Software" (Board 2006) and used the hour of operation as per AccuRate's inbuilt assumptions. AccuRate (developed in the 1990s) is improving on a regular basis and every so often new feature are added to earlier versions of the software, resulting in more accurate outcomes. However, it was found that the list of appliances used for calculating the heat gains in a building has not been updated for quite a while. Today, with changes in lifestyles, diverse appliances have been introduced into households, some of which significantly affect a building's energy use. These appliances, which include electronic goods such as DVD players, game consoles, etc., are not incorporated into the AccuRate assumptions, which makes the calculated energy requirements unrealistic for today's modern life. Since the 1990s, the number of some appliances such as TVs, refrigerators, etc. have also increased in most households (Esmaeilimoakher et al. 2016) and their time of use has changed with changes in lifestyle.

6.2.6 Incorporating Actual Values for Occupancy, Lighting and Home Appliances into the Models

From the household interviews as well as direct observations, it was found that each household had a unique occupancy pattern and thermostat settings. In contrast, AccuRate assumes all dwellings have similar occupancy patterns and similar thermostat set-points (shown in **Table** 6.3 and **Figure** 6.4 - **Figure** 6.7). Furthermore, it was observed that there were zones in the sample dwellings that were not conditioned or used in accordance with the assumptions made by AccuRate (e.g. a bedroom that was used as a storage room or a living area, rarely occupied and not conditioned). For example, HH12 was often occupied 24/7 (at least 1 person was present in the dwelling) and only one bedroom was heated in winter (see **Figure** 6.8 **(a)** and (b)). According to the HoH, in winter, 4 out of 5 occupants in this household used this bedroom where heated up using an electric resistive heater (25 °C). It was also found in HH12 that the zone "Living" often was unoccupied and was not conditioned throughout the year.

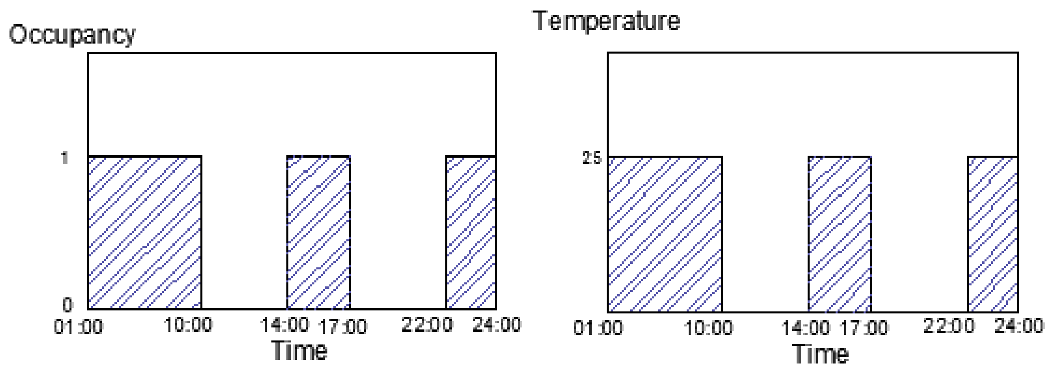

Figure 6.8 a (left) occupancy pattern of the main bedroom in HH12; b (right) Thermostat settings of the electric heater in the main bedroom in HH12

The existing discrepancy between the actual energy performance of households and the thermal energy requirements calculated by AccuRate based on its fixed assumptions were not limited to HH12. The heating and cooling energy requirements calculated by AccuRate Sustainability are, indeed, based on the internal heat gains from occupants and appliances and fixed thermostat set-points. With these assumptions significantly differed from how the households occupy and use the buildings, the thermal energy requirements calculated by the software were unlikely to represent the actual thermal energy requirements of any of the sample dwellings. To address this, the input files to the AccuRate engine were edited and modified using the data collected from household interviews, energy audits, and direct observations to better reflect the actual conditions of occupancy, thermostat settings, time of use, etc. in the sample households.

Incorporating actual values of sensible and latent heat gains (from people, lighting, appliances and cooking) as well as thermostat set-points of heating and cooling appliances and their time of use into the models was achieved by making manual changes to the 'scratch' files generated by the software. The AccuRate Simulation Engine creates these scratch files are, after incorporating the input design data via the AccuRate interface. Based on the same equations used by AccuRate (Equations 1-10), incorporating actual data into the models was performed through 5 scenarios. Each scenario represents a stepwise improvement in modelling the actual occupancy and occupant behaviour in the households as following:

Scenario 1: (BaseCase)

Models of the sample dwellings were created in the non-rating mode, with heating and cooling activated only in the zones that were heated/cooled as found from the interview and direct observations. After checking the design data, which were incorporated through the AccuRate interface, the Accurate Simulation Engine was run, and the first scratch file was generated.

Scenario 2: (BaseCase Adjust)

The occupancy factor and FamilyFactor values calculated using equations 2 and 3 in *Scenario 1* were substituted with the actual values in the sample households. the new values for heat gains were calculated for each zone using equations 5 -11 and replaced the heat gain values in the original scratch file from *Scenario 1*.

Scenario 3: (BaseCase Adjust + Audit Survey (IHGs))

Information on the key appliances, lighting and their time of use that was collected from households' interviews, walk-through energy audits and direct observations were used to calculate new IHGs. The scratch file from *Scenario 2* was then modified and the heat gains were replaced with new values.

Scenario 4: (BaseCase Adjust + Audit Survey (Thermostat Settings))

Actual thermostat settings collected from energy audits and direct observations were incorporated into the scratch file from *Scenario 2*. The energy requirements calculated in this scenario, therefore, allowed for the actual values of floor area, occupancy and thermostat settings;

Scenario 5: (Scenario 3 + Scenario 4)

This was a combination of *Scenario 3* and *Scenario 4* where an evaluation was undertaken of the cumulative influence of occupants, appliances and thermostat settings on the buildings' energy performance. This represented the most authentic scenario in terms of the actual occupancy and occupant behaviour in households.

The selection of the key appliances for calculating the IHGs was made based on how the appliances were used in the households and how much they contributed to the households' energy usage as described by the HoHs during the energy audit. The main appliances incorporated into all models included refrigerator, fridge-freezer, microwave, oven, electric kettle, and toaster. ASHRAE representative rates at which heat and moisture are given off by human beings in different states of activity was also used to calculate the sensible and latent heat gains from the occupants. According to the ASHRAE Fundamentals (ASHRAE 2013), the sensible and latent heat gains for a seated person at night are 70 W and 35 W respectively. For a seated person doing very light work, the values are 70 W and 45 W. Additionally, in order to calculate the sensible heat gains from lighting fixtures in the dwellings, the Light Use Factor and Special Allowance Factor was extracted from ASHRAE Fundamentals. IHGS calculated for the sample households using ASHRAE base heat gains and the actual time of use of the appliances in the households can be found in Appendix 6C and are discussed in more detail in Chapter 7.

Figure 6.9 presents a section of a sample scratch file created by AccuRate Sustainability for the purpose of household energy assessment.

```
C Doors
C       Height Width NArea  Azim  AbsE  AbsI EmissHShSchVShSchScSch1ScSch2ScSch3SHGFra
 3  1 88  2.14  0.93  1.99   180  0.85  0.85  1.00     4     3     0     0     0
C OpaqueLouvres
C       Height Width NArea  Azim  AbsE  AbsI EmissHShSchVShSchScSch1ScSch2ScSch3SHGFraLouvre
C Walls
C       Height Width NArea  Azim  AbsE  AbsI EmissHShSchVShSchScSch1ScSch2ScSch3SHGFra
 3  1 41  2.40  4.26 10.22   270  0.50  0.50  1.00     1     0     1     2     0
 3  1 41  2.40  4.76  5.75   180  0.50  0.50  1.00     2     1     0     0     0
C Floors, Ceilings, Partitions
C          Area  AbsI  AdjZ  SHGF
 3  1242 19.86  0.30    11
 3  1344 20.26  0.30    13
 3  1441  9.02  0.50     6
 3  1441  6.19  0.50     2
 3  1441  4.03  0.50     9
C Ventilation data
C General ventilation data
C        FlrHtCeilHtMecSupMechEx
 3  1700  0.10  2.40   0.0   0.0
C Data for each ventilation opening
C     No. Width    Cd  Perc   Low  HighCpIndx  Type ExponAdjZonConTyp MidHtContrlLouvre
 3  1701  1.55   0.6   100  0.00  1.55    -1     1   0.5     6     1  0.00     1
 3  1702  0.93   0.6   100  0.00  2.14     1     1   0.5     0     0
 3  1703  1.08   0.6    85  0.61  2.14     1     1   0.5     0     0
C
C       Sensible internal heat gain (watts), [hours 1-12]
 3  1801     0     0     0     0     0     0     0    64    64    17    17    17
C       Sensible internal heat gain (watts), [hours 13-24]
 3  1802    17    17    17    17    17    75    75    75    75    75     0     0
C       Latent internal heat gain (watts), [hours 1-12]
 3  1803     0     0     0     0     0     0     0    17    17     9     9     9
C       Latent internal heat gain (watts), [hours 13-24]
 3  1804     9     9     9     9     9    13    13    13    13    13     0     0
C
C       Heating thermostat settings [hours 1-12]
 3  1811   0.0   0.0   0.0   0.0   0.0   0.0   0.0  20.0  20.0  20.0  20.0  20.0
C       Heating thermostat settings [hours 13-24]
 3  1812  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
C       Cooling thermostat settings [hours 1-12]
 3  1813   0.0   0.0   0.0   0.0   0.0   0.0   0.0  25.0  25.0  25.0  25.0  25.0
C       Cooling thermostat settings [hours 13-24]
 3  1814  25.0  25.0  25.0  25.0  25.0  25.0  25.0  25.0  25.0  25.0  25.0  25.0
C
```

Figure 6.9 Sample ‘scratch’ file

In running the simulation through the AccuRate interface (*Scenario 1*), the entire process was accomplished by checking the input data incorporated into the models and running the simulation all at the push of a button. Running a simulation with a new scratch file, however, required a manual change of values with a high degree of accuracy. Even a minor change in the format of the new scratch file would have resulted in major errors in running the simulation. When the new scratch file was generated by incorporating the real data into the scratch file, it was saved in the AccuRate folder, where the Accurate Simulation Engine exists. The Accurate Simulation Engine was then run through a DOS command window and reads the information from the new scratch file to calculate the new thermal energy requirements of the building (Angelo Delsante 2004). Upon running the simulation with a new scratch file, a “natrep” file is generated including the following information:

- Heating energy requirements (MJ)
- Sensible cooling energy requirements (MJ)
- Latent cooling energy requirements (MJ)
- peak heating demand (kW)
- Peak sensible cooling demand (kW)
- Peak latent cooling demand (kW)
- Heating energy / m^2 of conditioned floor area (MJ/m^2)
- Sensible cooling energy/ m^2 of conditioned floor area (MJ/m^2)
- Latent cooling energy / m^2 of conditioned floor area (MJ/m^2)
- Total cooling energy / m^2 of conditioned floor area (MJ/m^2)
- Total energy / m^2 of conditioned floor area (MJ/m^2)

Thermal Energy Requirements in the Sample Households

From the analysis, it was found that in households with no heating and cooling systems (e.g. HH1), when heating and cooling was deselected through the AccuRate interface, the thermal energy requirements calculated by AccuRAte for the household was equal to 0. Due to the same reason, HH1, which used neither a heating nor a cooling system was excluded from further analysis in this section. **Table** 6.4 summarizes the heating, cooling and the total energy requirements/m2 calculated by incorporating the households' actual values into the 5 Scenarios explained earlier in this section. Furthermore, in order to create a better picture of the variation of the energy requirements calculated in Scenarios 2-5 (by using the actual input data for HH size, IHGs and thermostat settings), and the AccuRate BaseCase (Scenario 1), the Relative Percentage Difference (RPD%) was calculated separately for heating, cooling and the total energy requirements, looking at the variations as a proportion of the value of energy requirements calculated using the AccuRate inbuilt assumptions. The results are presented in

Table 6.5. **Figure** 6.10 and **Figure** 6.11 plot the variations in heating and cooling energy requirements (RPD%) in the selected households compare to the AccuRate in-built assumptions.

Table 6.4 Thermal Energy Requirements in Sample Households (MJ/m^2)

	Proposed Changes	HH2			HH3			HH4		HH5			HH6		HH7			HH12	
		H	C	T	H	C	T	H	T	H	C	T	C	T	H	C	T	H	T
1	**Non-rating (Base Case)**	200.2	16.2	216.4	64.9	48.4	113.3	126.4	126.4	51.7	43.1	94.8	16.9	16.9	63.1	36.7	99.8	5.5	5.5
2	**BaseCase Adjust (Occupancy Factor)**	200.4	16.2	216.6	69.8	44.7	114.5	112.7	112.7	51.7	43.1	94.8	16.8	16.8	59.5	39.3	98.8	5.5	5.5
3	**BaseCase Adjust + Audit Data (IHGs)**	152.0	55.2	207.2	57.5	41.6	99.1	92.6	92.6	40.8	47.7	88.5	42.0	42.0	55.3	41.6	96.9	2.4	2.4
4	**BaseCase Adjust + Thermostat settings**	179.7	73.7	253.4	356.2	148.4	504.6	512.9	512.9	20.7	126.8	147.5	490.6	490.6	261.7	104.1	365.8	550.6	550.6
5	**BaseCase Adjust + IHGs + Thermostat Settings**	145.9	147.3	293.2	320.4	140.1	460.5	484.3	484.3	17.1	131.1	148.3	686.6	686.6	247.3	118.5	365.8	424.1	424.1

H= Heating energy requirements /m^2 of conditioned floor area (MJ/m^2); C= Total cooling energy requirements/m^2 of conditioned floor area (MJ/m^2); T= Total energy requirements/m^2 of conditioned floor area (MJ/m^2)

Table 6.5 RPD (%) between each scenario and the AccuRate BaseCase (*Scenario 1*)

	Proposed Changes	HH2			HH3			HH4		HH5			HH6		HH7			HH12	
		H	C	T	H	C	T	H	T	H	C	T	C	T	H	C	T	H	T
1	**Non-rating (Base Case)**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	**BaseCase Adjust (Occupancy Factor)**	0.1	0.0	0.1	7.6	-7.6	1.1	-10.8	-10.8	0.0	0.0	0.0	-0.6	-0.6	-5.7	7.1	-1.0	0.0	0.0
3	**BaseCase Adjust + Audit Data (IHGs)**	-24.1	240.7	-4.3	-11.4	-14.0	-12.5	-26.7	-26.7	-21.1	10.7	-6.6	148.5	148.5	-12.4	13.4	-2.9	-56.4	-56.4
4	**BaseCase Adjust + Thermostat settings**	-10.2	354.9	17.1	448.8	206.6	345.4	305.7	305.7	-60.0	194.2	55.6	2803.0	2803.0	314.7	183.7	266.5	9910.9	9910.9
5	**BaseCase Adjust + IHGs + Thermostat Settings**	-27.1	809.3	35.5	393.7	189.5	306.4	283.2	283.2	-66.9	204.2	56.4	3962.7	3962.7	291.9	222.9	266.5	7610.9	7610.9

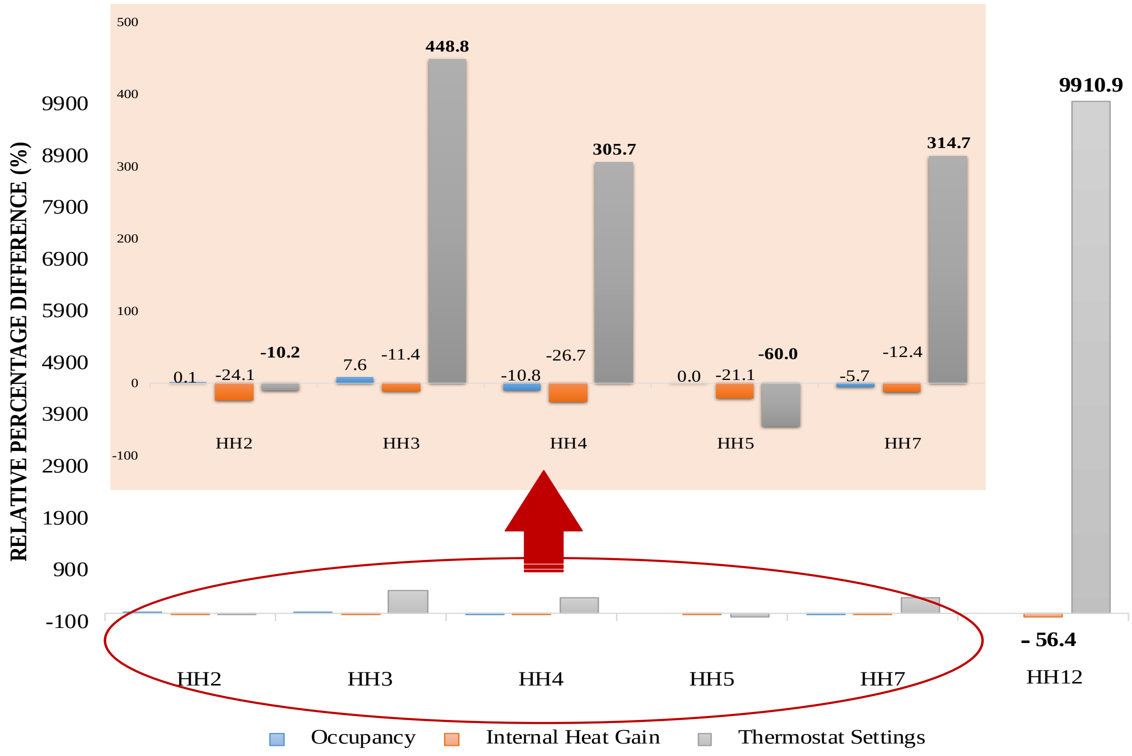

Figure 6.10 Relative change in heating energy requirements compared to Accurate's inbuilt assumptions

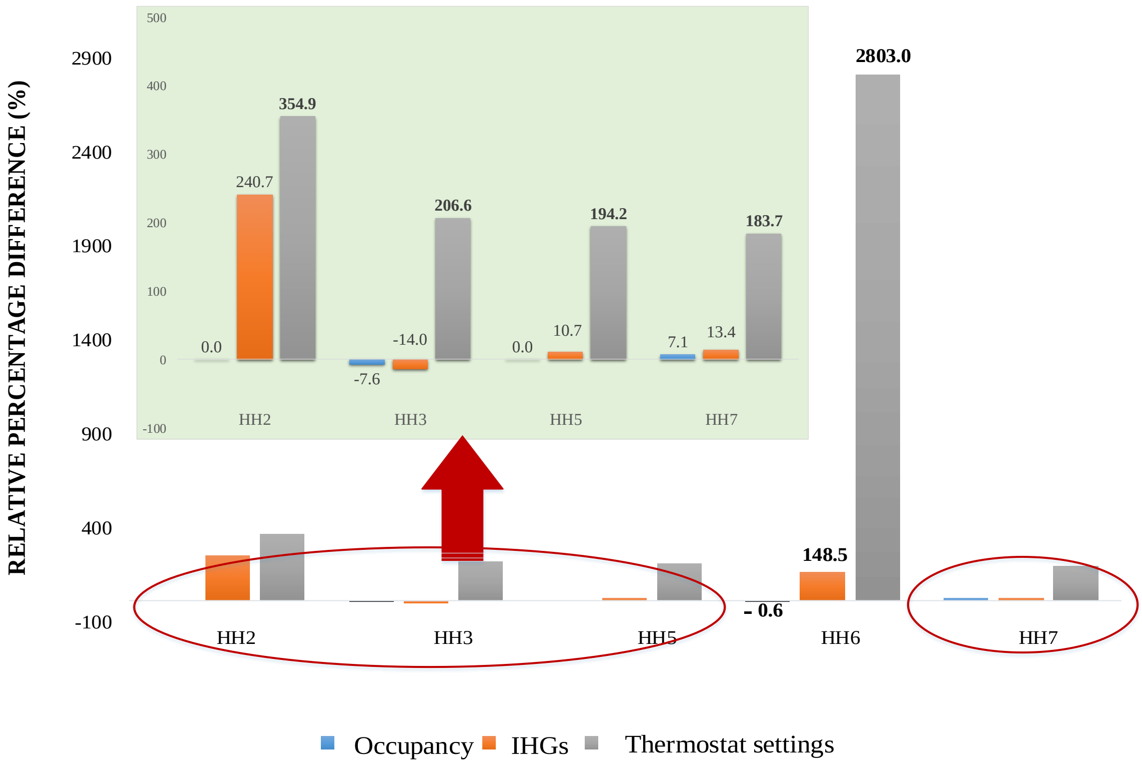

Figure 6.11 Relative change in cooling energy requirements compared to Accurate's inbuilt assumptions

AccuRate estimated the number of occupants in a dwelling based on the floor area and the number of rooms (see Equation 6-11). This estimation, however, did not reflect the actual occupancy in the sample households. In this study, the actual number of occupants was used in protocol equations (Equations 6-2 – 6-10) to work out the internal heat gains. The values of RPD calculated in Scenario 2 (see

Table 6.5) revealed that AccuRate in-built assumptions overestimated the occupancy for some households (e.g. for HH3) and underestimated in other households (e.g. HH4 and HH7). This, in return, resulted in different thermal energy requirements in the households compared to the values calculated in Scenario 1 using the AccuRate in-built assumptions.

A positive value of RPD for the heating energy requirements when the actual number of occupants was incorporated into the models implied that more heating energy was required in that household compared to the values calculated by AccuRate Sustainability. The higher heating energy requirements, which had been caused by less heat gains from the occupants and appliances they used in the household meant AccuRate in-built assumptions over-predicted the occupancy and internal heat gains from occupants. Under such circumstances (**see**

Table 6.5), less cooling energy was required in the household due to the lower internal heat gains from the occupants and less use of appliances by them. HH3 is a clear example of overestimating the occupancy by AccuRate Sustainability (**Figure** 6.11). Heating requirements with actual occupancy increased for this household. Given that there was only 1 occupant (not 2.3, which was assumed by AccuRate), thus there were less internal heat gains from the occupant himself and his use of appliances, which subsequently, resulted in less cooling energy requirements (see **Figure** 6.10). Heating energy requirements with actual occupancy decreased for HH4 and HH7, with more cooling energy requirements in HH7. Expect in these households that there were more actual occupants and thus more internal heat gains than what AccuRate assumed, heating and cooling requirements with actual occupancy stayed mostly the same for other households.

The relative percentage difference calculated by incorporating the actual IHGs by appliances used in the households and their time of use (Scenario 3) revealed that there was less need for heating when the actual IHGs were used. This must mean that the actual IHGs in the sample households are greater than AccuRate's assumptions for heat gains. This was expected since as discussed in Section 5.2.5, the list of appliances AccuRate uses for calculating the heat gains has not been updated for many years. With the emergence of new appliances and the growing use of electronics (e.g. more TVs, personal computers, gaming device, etc.) due to changes in households' lifestyle, it was expected that the actual heat gains from appliances used in the households to be higher than the base assumptions made by AccuRate. Appliances such as electric oven, a halogen convection oven, a coffee machine, a dryer, 2 fridge-freezers in HH6, and a industrial printer, 3 TVs, 2 PCs, a video projector, etc. in HH2, are some of the appliances used in the sample households that were not used by other households.

The results showed that compares to the BaseCase (AccuRate's inbuilt assumptions), the occupancy factor has the least impact on the households' heating and cooling energy requirements. In other words, when actual occupancy incorporated into the models, the heating and cooling energy requirements either did not changed (e.g. HH5) or changed insignificantly compare to other factors such as IHGs and thermostat settings. As shown in

Table 6.5, the difference in many cases was negligible (<5%) and no greater than 10.8% drop in heating load for HH4 and 7.6% drop in cooling energy requirements in HH3. The greatest effect was, however, related to the thermostat settings (temperature set-points together with the time of use of heating/cooling appliances) with an increase in the heating load of over 6 fold for HH4 and over 100 fold for HH12 and an increase in cooling load of over 29 fold for HH6.

In HH4 and HH12, the use of electric resistive heaters with non-adjustable thermostats (25 °C set-point) for long periods of time on a typical winter's day is likely to explain why AccuRate's inbuilt assumptions underpredict the heating energy requirements for the thermostat settings in these two households. Although HH4 used 2 electric heaters, one in the bedroom from 17:00 - 23:00 and one in the living area from 05:00 - 08:00 and from 17:00 - 23:00, HH12, used only one electric heater in the bedroom from 22:00 - 10:00 and from 14:00 - 17:00 (**Figure 6.8(b)**). The use of an evaporative cooling system from 21:00 – 05:00 on 18 °C is likely to be the reason why AccuRate's inbuilt assumptions for thermostat settings underestimate the cooling energy requirements in HH6 (see **Table** 6.3 for AccuRate's assumptions).

In contrast, AccuRate's inbuilt assumptions for thermostat settings overestimated the heating energy requirements for HH2 by 10.2% (**Figure** 6.10). Unlike AccuRate's assumptions for living spaces (conditioned between 07:00 – 24:00 on 20 °C), HH2 used the heating system only if it was required and then for a few hours (maximum of 6 hours on a very cold day) on 21 °C. Allocating less operating hours for the heating system to HH2 resulted in lower heating energy requirements in this household and the overprediction of heating energy by AccuRate's inbuilt assumptions. With regard to the cooling energy requirement in HH2, however, AccuRate base assumptions for thermostat settings underpredicted the cooling energy requirements over 4 fold. This was mainly due to the lower thermostat set-point of the HH2 cooling system (23 °C) for a minimum of 6 hours on a typical summer day. **Figure** 6.12 and **Figure** 6.13 present the breakdown of the total energy requirements from *Scenario 1*, using AccuRate's inbuilt assumptions, and *Scenario 5*, in which the actual values for occupancy, IHGs and thermostat setting were applied in calculating the thermal energy requirements of the households.

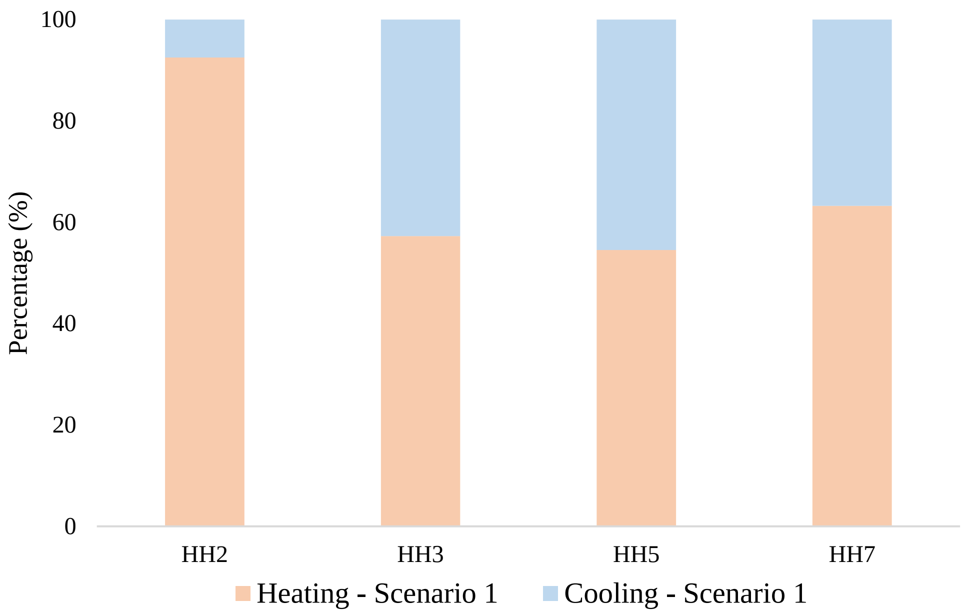

Figure 6.12 Breakdown of total energy requirements from *Scenario 1* (AccuRate base assumptions)

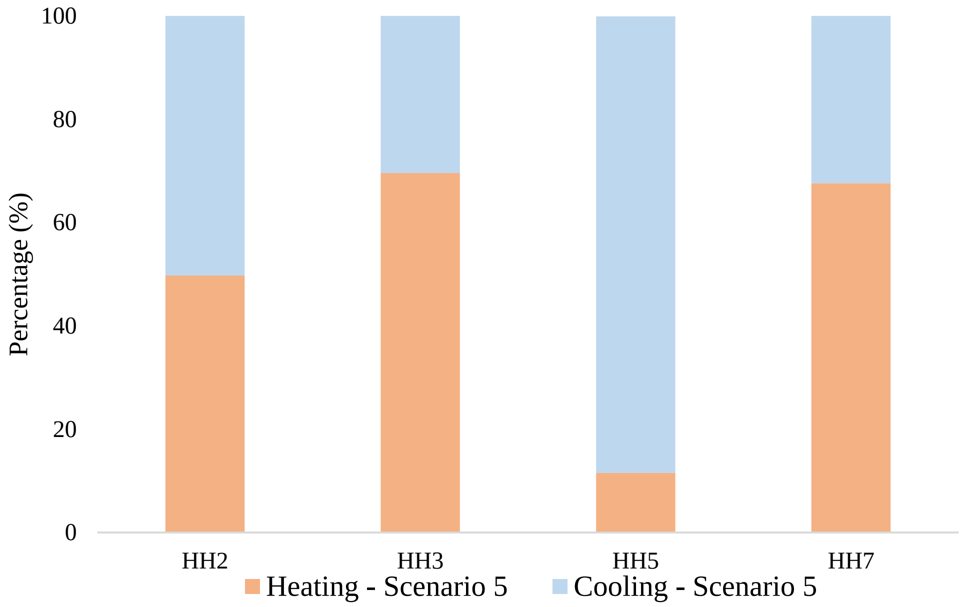

Figure 6.13 Breakdown of total energy requirements from *Scenario 5* (Actual Occupancy, IHGs and Thermostat settings)

As discussed in Section 6.2.6, heating/cooling options in both *Scenarios 1* and *5* were activated only in the zones, which were reported by the households to be heated/cooled in their real life. Therefore, in households with no heating or cooling (i.e. HH4, HH6 and HH12), no change was perceived in the breakdown of the total energy requirements between *Scenario 1* and *5*. Consequently, these households have been omitted from **Figure** 6.12 and **Figure** 6.13.

The greatest changes in the breakdown of total energy requirements occurred for HH2 and HH5. A comparison between **Figure** 6.12 and **Figure** 6.13 reveals that in both of these households, a greater proportion of cooling energy was required when the households' actual values for occupancy, IHGs and thermostat setting were incorporated into the models in *Scenario 5*. From the earlier discussion in this section, the actual values of internal heat gains in HH2 were higher that AccuRate's base assumptions. Similarly, the actual total IHGs (sensible + latent) in HH5 were found to be higher in *Scenario 5* compare to *Scenario 1*. Additionally, the thermostat set-point of the cooling systems was reported to be lower in both households (23 °C). Ultimately, the combination of higher IHGs together with lower thermostat set-points implies that more cooling energy was required to maintain a certain level of thermal comfort for the occupants in the dwellings.

By comparing the total energy requirements from *Scenario 1* and *Scenario 5*, **Figure** 6.14 creates a snapshot of how thermal energy requirements in the dwellings changed when the actual occupancy-related values were taken into account (*Scenario 5*) to substitute the base assumptions by the software. It is evident that in the majority of the cases, AccuRate Sustainability under-predicted the energy requirements of the dwellings by using its basic assumptions instead of actual values for the factors such as occupancy (household size, occupancy pattern, etc.), occupants' choice of appliances, their time of use and set-points, etc.

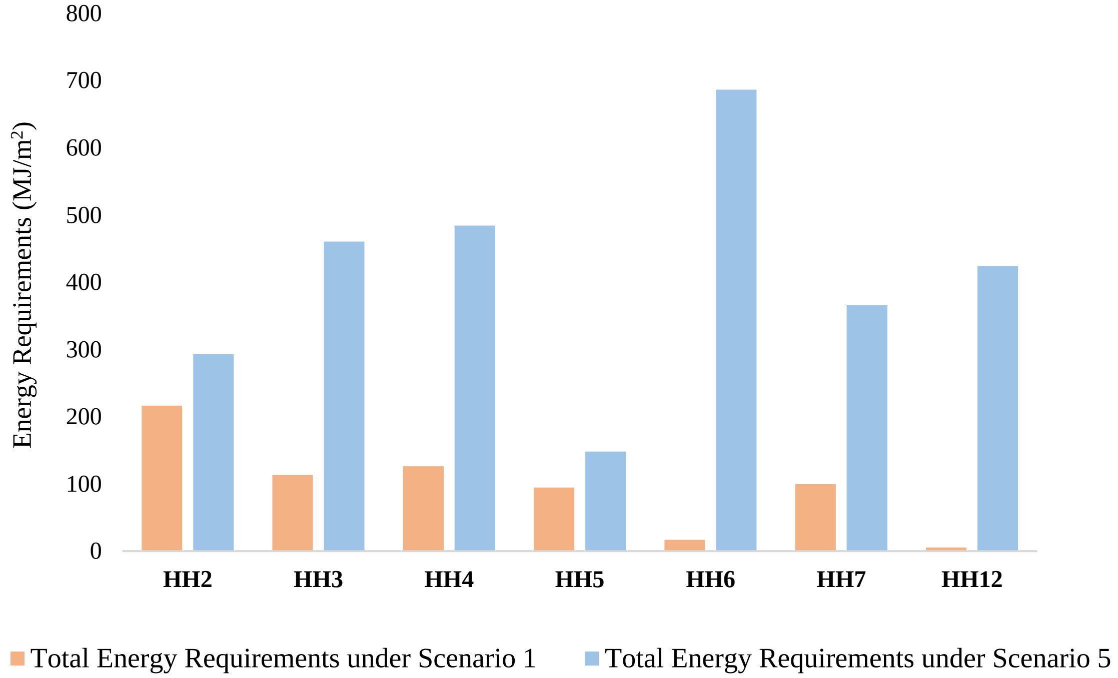

Figure 6.14 Total Energy Requirements - Accurate Base Assumptions versus Actual

Although HH2 and HH5 showed the greatest change in the proportion of heating and cooling that make up the total energy requirements, the greatest difference in the absolute energy requirements from *Scenario 1* and *5* occurred in HH4, HH6, HH3, HH12 and HH7 (**Figure** 6.14). From previous discussions, it was found that the thermostat settings of heating and cooling appliances have the highest influence on the households' thermal energy requirements compared to the other factors of occupancy and IHGs. Except for HH6, which had no heating system, and HH3, which used a reverse cycle AC with a heating temperature set-point of 24 °C, the other three households (HH4, HH7 and HH12) used different types of electric heaters with non-adjustable thermostats. These electric resistive heaters had a higher temperature compared to AccuRate's base assumptions (25 °C assumed in this study for electric heaters based on the make and model of the heaters compared to the maximum of 20 °C for heating thermostat set-point in living spaces and 15-18 °C for the heating thermostat set-point in bedrooms assumed by AccuRate). Thus, the heating energy requirement from *Scenario 5* significantly exceeded from that of *Scenario 1* for these households. Similarly, lower cooling thermostat set-points in HH6 (18 °C) and HH3 (22 °C) as compared to the AccuRate base assumptions (25 °C) expounds the existing difference between the total energy requirements from *Scenario 5* and *Scenario 1*.

From the households' survey and interviews followed by direct observations, it was found that the selected thermostat set-points in the households with adjustable thermostat settings were mostly outside the range of the AccuRate base assumptions for the Perth climate region (**Table** 6.3). For example, in HH3 the heating thermostat set-point for the two reverse cycles ACs was reported as 24 °C. According to the HoH, none of the two ACs was efficient enough to make the house thermally comfortable. Therefore, they were often run simultaneously. The cooling thermostat set-point in HH7 was mostly 18 °C on a typical summer day. However, as reported by the HoH, the AC was only turned on for a short period of time, until the indoor temperature dropped to the occupants' thermal comfort level. This duration was significantly less than the time of use of cooling appliances assumed by AccuRate Sustainability for calculating the cooling energy requirements.

Summary

In this chapter, the process of modelling the thermal energy performance of the sample dwellings using AccuRate Sustainability was discussed in detail. AccuRate Sustainability in the non-rating mode was used, which offered more flexibility for modification of some basic assumptions by the software including the option to supply/eliminate heat or coolth in different zones of a building based on the actual information collected from the households. Other actual values used for evaluating the energy requirements of the households include occupancy (number of occupants as well as heat gains from people), heat gains from lighting, key appliances, heating and cooling thermostat set-points, and time of use of appliances including heating/cooling systems. The actual thermal energy requirements of the dwellings have been predicted by using the actual values for these parameters in the AccuRate modelling.

AccuRate's base assumptions appear to under-predict the amount of internal heat gain in the households and thus calculates a greater need for heating energy and a lesser need for cooling energy than is actually required. The base assumptions also predict, in general, a higher proportion of heating to cooling requirements, and the total energy requirements based on internal heat gain considerations are greater than actual. However, the thermostat settings of heating and cooling appliances were found to have the highest impact on the thermal energy requirements of the households. Occupant behaviour in the households resulted in a greater time of use of heating/cooling appliances with lower/greater temperature set-points than AccuRate's base assumptions. This meant that taking all factors (occupancy, internal heat gains, time of use and temperature set-points) into account, the predicted actual total thermal energy requirements of the households were, on the whole, significantly greater than the total energy requirements calculated using AccuRate's base assumptions.

CHAPTER 7

DISCUSSION AND CONCLUSION

Overview of Chapter

This chapter re-visits the research questions that were proposed in Chapter 1 and discusses the results found at different stages of the research in response to these questions, as presented in Chapters 2 – 6. Where required, the outcomes are compared and contrasted with existing literature in the field of energy efficiency in residential buildings and discrepancies between the findings are debated. Finally, the chapter ends with listing the limitations that affected the process and the outcomes of the research in some way.

7.1 Revisiting the Research Questions

The first research question that led to this research was 'What are the various determinants of residential energy consumption and how do these factors affect the energy consumption in low-income social households in Perth?'. Understanding these determinants is in fact, the key step towards the design and implementation of effective policies aimed at reducing energy consumption in the residential sector. Many factors have been introduced in the literature that either directly, or indirectly, affect the energy performance of residential buildings as discussed in Chapter 2. However, the extent of the influence of each factor was found to be highly case-dependent and affected by the peculiarities of each country. Factors such as climate condition, endowment, socio-cultural norms, housing market conditions, accessibility and diversity of energy resources, appliances and equipment used in dwellings, etc. (Lenzen et al. 2006; Belaïd 2017), which significantly affect the energy performance of residential buildings, vary in different countries. Hence, studies of energy consumption at the household level may significantly differ in different countries.

Based on the findings from the existing literature, an extensive list of the factors, which potentially might affect the energy performance of the selected survey population was created, based on which, the household survey and walk-through energy audit were designed and developed. These factors included: household size, disposable household income, occupancy hours, HoH gender and education, and the presence of children and elderly in the households. Other factors such as the type of heating/cooling appliances used in the dwellings and occupants' behaviour with respect to the thermostat set-points of these systems, their time of use, occupants' sensation of thermal comfort in the dwellings with and without these appliances, and their window opening behaviour were included in the questionnaire. The aim of collecting the above information was to create an all-encompassing insight into the energy performance of the social housing dwellings as the target group in this study.

To understand how different factors may affect the energy performance of low-income social households in Perth, in-person interviews were conducted on households' energy use behaviour with the households' representatives. The information provided by the respondents to the survey questions shed light on different aspects of occupants' energy use behaviour and further assisted the evaluation of temperature changes in the sample dwellings discussed in the second research question.

This research found that the floor area adversely affected the normalized electricity consumption in the surveyed dwellings. In other words, less electricity per person, per m^2 and per person per m^2 was used in the sample households with a larger floor area. In contrast, the literature showed that larger dwellings consume more electricity due to having more lighting fixtures and electronics and/or perhaps because these dwellings have more rooms that need to be heated/cooled (Pachauri 2004; Ewing and Rong 2008). The low-income level of the surveyed households may, to a certain extent, explain the existing discrepancy in the influence of dwelling size on the electricity consumption of the households, since the majority of the participants were on low and low–middle-incomes, the households did not contain extensive electronic devices that would significantly affect their electricity consumption.

The results showed that disposable household income (DHI) inversely affected electricity consumption in the sample households, suggesting that the higher-income households spent less $ per person per m^2 on electricity compared to the lower-income households. Although it is commonly known that the eligible applicants for community housing should fall into the low or low-to-middle income categories, unexpectedly, there was one household in the survey sample that according to the income classification made by the ABS for DHI, was on high-income. Due to its potential to substantially affect the results, this household was removed from the analysis of electricity consumption. This finding was supported by another study, which found that low-income households may keep up with their energy bills through trading off their basic needs including food and healthcare to be able to pay their bills (Moore et al. 2017; European Parliment 2016). This, however, contradicts with the report by the Australian Council of Social Service (ACOSS 2018b) on the energy expenditure of Australian households based on their income level. According to ACOSS (2018), lower-income households use less energy and spend less in dollar terms on energy expenses/year (ACOSS 2018b). Similarly, some researchers found that energy consumption increases monotonically with income i.e. more energy is used by higher-income households (Kelly 2011). The lower proportion that higher-income households spend on energy (relative to their income) might be caused by using more efficient appliances in these households (Bouzarovski 2014). Some researchers, however, did not find any statistically significant correlation between household income and their electricity consumption (Kavousian et al. 2013).

This study found that more electricity was used in sample households with a female HoH. This was supported by previous studies that showed females are mostly more critical about their sensation of thermal comfort in an indoor environment and more sensitive to their deviations from an optimum comfort environment (Wang et al. 2018). Similarly, other researchers found that females feel both uncomfortably cold and hot more, are less satisfied with the room temperature than males and prefer higher room temperatures (Karjalainen 2007), suggesting that females may rely more on heating/cooling systems for maintaining their thermal comfort than their male counterparts in the same environment.

Although the floor area of dwellings, household size (number of occupants in the households), DHI, and HoH gender were shown to affect the electricity consumption in the surveyed households, other parameters including the presence of children and occupants' window opening behaviour were not found to be significant in this study. Nevertheless, other studies argued the importance of these factors and their influence on building energy performance (Brounen et al. 2012; Olivia Guerra-Santin 2009). When the average annual electricity consumption (MJ/year) in the households was plotted against these factors, the small R^2 value indicated that these factors are not significant in explaining the annual electricity consumption in the households. Having said that the ability to draw firm conclusions was affected by the small sample size and a future study with a larger sample size is needed to explore these issues in further detail. This is discussed further in Section 7.2.

The second research question that underpinned this study was 'How do occupants' presence and their behaviour with respect to using heating/cooling systems and natural ventilation affect the energy performance and occupants' thermal comfort in social housing dwellings?'. To understand how the thermal performance of the sample dwellings was affected by the occupants' presence and their actions and in order to find out whether or not occupants' behaviour with respect to the use of heating/cooling appliances and natural ventilation changed after they were educated with the guidelines, the variation in indoor temperatures was monitored in a number of sample dwelling and changes were discussed based on the information collected from the households' survey as well as from direct observations.

The exploratory analysis of temperature changes in this study examined temperature changes in the main living area, where heating/cooling took place in the majority of the sample households. A few hot/cold spells were selected in summer and winter 2015 and 2016 for three households as representatives of occupants' behavioural patterns in extreme weather conditions. To remind the reader - the analysis of temperature changes in this study aimed to create a broad insight into how the dwellings might have been heated/cooled or naturally ventilated. It, however, did not aim to deliver what exactly had happened in the dwellings or what actions were taken by the occupants when a sudden change was detected in indoor temperatures in the sample dwellings.

Evaluation of electricity consumption in the sample households revealed that while electricity consumption in some households significantly dropped in 2016 (e.g. HH2), others experienced a rise in their consumption in 2016 compared to 2015 (e.g. HH4). According to the head of a household with lower electricity consumption in 2016:

> *…// We changed 98% of our indoor and outdoor lighting to LED. We sold all but one of our TV units that were plasma and bought LED TVs. Another factor that might have made a difference is that all the plants and shrubs around and in the house are all maturing and growing larger, which could aid in lowering the ambient temperature of the property. It could even be that as our grandkids are getting older, we are spending more time away from home//…*

Temperature data recorded in a household with higher electricity consumption in winter 2016 i.e. HH4, revealed that more heating was used in this household in 2016 compared to the previous year. The actual time of use of the heating system, as perceived from the temperature data recorded in the main living area during the selected period in June 2016 was 14 hours.

This was markedly higher than in 2015 and almost twice the time of use stated by the HoH during the survey for heating appliances. The extended use of the heating system in 2016 could be explained in two ways:

1) Extreme environmental conditions in winter 2016

2) Variation in the occupants' sensation of thermal comfort

Although ambient temperature is only one of the many factors (e.g. humidity, airspeed, etc.) that affect humans' sensation of thermal comfort in the indoor environment, considering the scope of this study, it was the only external factor that was measured and incorporated into the temperature analysis together with daily global solar exposure, which was collected from the BOM. It was found that ambient temperatures were, on average, lower in winter 2016 compared to 2015. As confirmed by previous studies e.g. (Xiong et al. 2015), lower ambient temperatures will result in the different perception of thermal comfort and therefore, will affect the subsequent actions they may take, including turning on the heating system, to maintain or improve their thermal comfort.

Additionally, an individual's perception of comfortable temperature may vary over time. This phenomenon, which has been referred to as 'intra-individual' perception of thermal comfort in the literature (Wang et al. 2018) may be another reason why some households used more heating and had higher electricity consumption in 2016 compared to the previous year. Studies have found that the same person may have the different sensation of thermal comfort in the same environment from time to time. For example, in a study in controlled climate chamber with constant clothing and metabolic rate over time, Grivel and Candas (Grivel and Candas 1991) found that 75% of the participated human subjects adjusted their surrounding temperature about 1-hour after their preferred ambient temperature had been established, verifying that humans' perception of thermal comfort varies over time.

The literature suggests average Australians spend 90% or more of their time indoors (Australia. Department of Environment and Energy 2019). Hence, their thermal comfort in the indoor environment significantly matters. Studies have found that in many cases, an air-conditioning system is not necessarily required to achieve thermal comfort in an indoor environment (Ren and Chen 2018). This was also observed in this research where a household had no heating/cooling system (e.g. HH1). The occupants in this household enhanced their indoor thermal comfort by adopting low-cost strategies similar to that proposed in the guidelines such as performing natural ventilation through opening doors and windows when the ambient weather was not extreme (beyond their thermal comfort) in summer and taking advantage of solar heat gains from windows in winter. During extreme weather conditions, closing the doors/windows, drawing the curtains, adjusting clothing insulation, taking a cold shower in summer, and using a blanket in winter were some of the actions taken by the occupants to reduce their thermal discomfort in this household.

Similar to the studies, which showed that building orientation affects its energy usage e.g. (Mulyani et al. 2017; McGee et al. 2013), this study also found that building orientation and solar heat gains from windows have significant impact on the measured day-time indoor air temperatures, their divergence from the wall surface temperature, and the time lag between the ambient air and indoor air temperatures in the sample households. Hence, it is an important factor that if considered during the design stage, will result in occupants' thermal comfort in the building and will lower their operational energy consumption.

The study of temperature changes in the sample households, however, revealed that the behaviour of the occupants with respect to opening/drawing curtains significantly affect the influence of building orientation and solar heat gains from windows, especially in the absence of heating system in winter. For example, direct observations in HH1 revealed that curtains were actively opened in winter to maximise the amount of solar heat gains from the north-facing windows in the main living area. Hence, when solar heat gains rose during day-time, indoor temperatures also rose and less time lag existed between the indoor air and ambient temperature in this dwellings compared to other dwellings. However, the south-facing window in the living area in HH2 was mostly covered by the curtains. Even when the curtain was opened to increase the amount of daylight in the living area in this household, there were no direct solar heat gains from the window as it was shaded by the mature plants and shrubs around and in the house.

Temperature analysis in the sample households further revealed that indoor air, as well as the wall surface temperature in the only free-running sample dwelling i.e. HH1, fluctuated over a wider range compared to the other dwellings. For example, while indoor air temperatures in HH1 ranged between 21 °C and 38 °C in period 1 in 2015 and between 25°C and 35°C in period 2 in 2016, it ranged between 21 °C and 30 °C in period 1 in 2015 and between 23 °C and 28 °C in period 2 in 2016 in HH4. A comparison between the average damping factor in these dwellings revealed that the peaks and troughs of internal temperatures were smoothed out more effectively in HH4 and a more even temperature was maintained inside this building during extremes of ambient temperature (DF in HH1 was 0.5 in period 1 and 0.4 and in period 2 and in HH4 was 0.3 in both periods 1 and period 2). This may suggest a higher thermal mass in HH4 compared to HH1, which resulted in less fluctuation in indoor temperature. Previous studies have shown that as well as orientation, differences in design and construction of the dwellings, including insulation materials used in each building and their thermal mass are some of the other causes of different indoor temperatures in the sample households (Reardon et al. 2013b). However, in this study, the type of appliances used in the households including heating/cooling systems, and behaviour of the energy users in the dwellings were found to affect the extent of the influence of building characteristics. For example, from the designs, HH4, a 5-star building constructed in 2007 would seem to be less energy efficient than HH1, a

6.5-star building built in 2009. Further, HH4 was a west-facing building compared to HH1 where the majority of the windows in the main living area were north-facing. Despite the building rating and orientation, indoor temperatures in HH4 during the periods under investigation were closer to the ranges of indoor conditions that have been considered "acceptable" by ASHRAE standard 55 (ASHRAE 2013). **Figure** 7.1 shows the ASHRAE standard 55 range for adaptive thermal comfort in free-running buildings for 0.5 Clo (typical summer indoor clothing) and 1.0 Clo (typical winter indoor clothing) of clothing insulation.

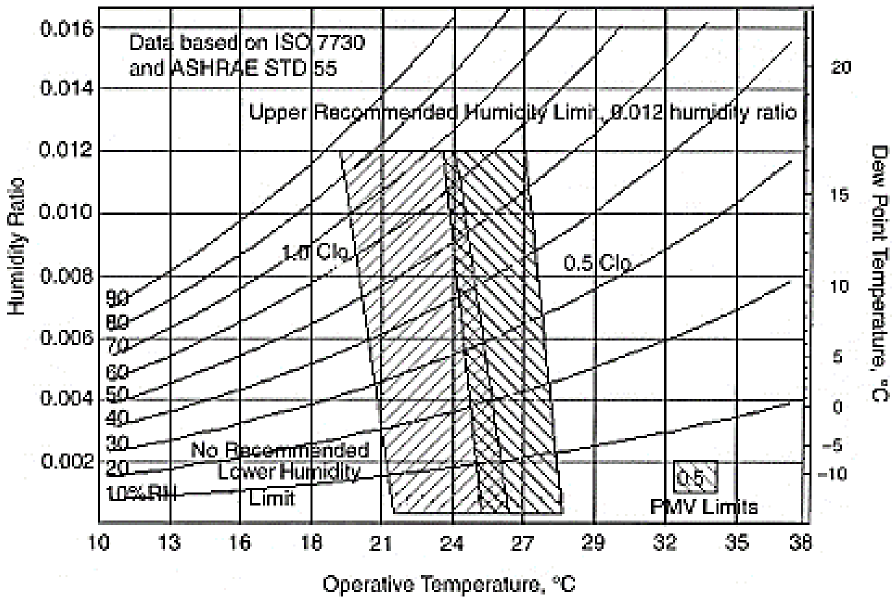

Figure 7.1 Comfort zone by ASHRAE Standard 55

(Source: ASHRAE Standard 55)

Taking into account different clothing and other weather-related factors including humidity and airspeed, as shown in **Figure** 7.1**,** summer-time indoor temperatures above 28 °C are considered "thermally uncomfortable" by ASHRAE for occupants in free-running buildings. On an extremely hot summer day when the day-time ambient temperature exceeded 40 °C, the air temperature in the living area in some dwellings (e.g. HH1) rose to 38 °C with some evidence of increased heat gains from opening either a door/window or curtains, around midday. According to ASHRAE 55, the living area on such days would have been extremely uncomfortable for the occupants. Although the variation in indoor temperatures in HH1 seemed to be slightly moderated during period 2 in 2016, which might have been caused by adopting the ventilation strategies delivered through the guidelines (partly or fully), the living area remained uncomfortably hot during the day-time and indoor temperatures on the selected peak days exceeded 28 °C. Indoor temperatures in other households (e.g. HH4) significantly reduced in summer 2016 and fell within the ASHRAE comfort zone. This variation in the indoor temperatures with no cooling system may suggest that occupants' behaviour with respect to preventing the excess solar heat gains from windows and/or preventing the hot outdoor air entering the house changed in 2016 after the occupants were educated with the guidelines.

Nevertheless, where a cooling system was actively used in a household in summer, indoor temperatures were found to be more comfortable than other households. For example, in HH2 with a reverse cycle AC, air temperatures in the living area never exceeded 29 °C, even when the ambient temperature exceeded 40°C. In addition to the possibility of conditioning the living area, different passive cooling strategies were adopted in this household e.g. attentive ventilation behaviour, covering the fences with bamboo sheets, planting evergreens surrounding the building, etc. that reduced the impact of excess solar heat gains on the dwelling in summer and resulted in less cooling energy requirements for maintaining occupants thermal comfort in the house. However, as also stated by the HoH in HH2, no evidence was found of any changes in the occupant's behaviour in accordance with the proposed guidelines.

The study found that comfortable temperatures varied in different households. This difference, which in some studies is referred to as the 'inter-individual' perception of thermal comfort (Wang et al. 2018), is supported by different researchers (Schweiker et al. 2018; Castaldo et al. 2018; Enescu 2017). For example, occupants in HH2 and HH4 used different types of heating systems to maintain or enhance their thermal comfort during cold winter days. In HH2, air temperatures in the living area on such days were mostly between 15-18 °C. Although according to ASHRAE 55 indoor temperatures below 19 °C are not comfortable for the occupants, occupants in HH2 reported that they were often satisfied with their indoor thermal comfort in winter (more satisfied than in summer). As stated by the HoH during the survey and further confirmed through direct observations, turning on the AC was the occupants' last choice upon feeling thermal discomfort in winter. Instead, they would rather adjust their clothing levels and close openings. Even when the AC was suspected to be running on a few occasions, the indoor temperature in the living area never exceeded 19 °C. As stated by the HoH during the interview, the occupants in HH2 were quite aware of the influence of temperature set-points on their energy usage and never set the AC thermostat to a high temperature (above 21 °C), which was also confirmed by the recorded temperature data in this household. However, despite the HoH stating that the heater was less likely to be used except for short periods during cold winter nights, this was not verified by the temperature data recorded in this dwelling and the AC seemed to be used only during the day-time.

Unlike HH2, HH4 was seemed to be actively heated in winter especially during the selected period in 2016, after the occupants were educated with the proposed guidelines. From temperature data recorded in this household, it was found that when the heater was running in the dwelling, air temperatures were mostly around 20 °C, which depending on the occupants' clothing insulation, could be considered 'comfortable'. During this period, sudden rises of air temperatures and their continuous divergence from the wall surface temperatures in the lounge verified that the heating system was running continuously for long periods in this household. This, as discussed in Chapter 5, could be the main reason for the household's higher electricity bills in winter 2016 compared to 2015 when less heating seemed to be used in the dwelling. As such, occupants in HH4, who seemed to apply the proposed guidelines in summer, put their thermal comfort at the forefront and used more heating energy in winter, despite their education with the proposed guidelines.

Previous studies have found that natural ventilation improves occupants' thermal comfort in the indoor environment through increasing day-time airspeed and high night-time ventilation rates in summer (Schulze and Eicker 2013). In some studies, natural ventilation has been referred to as the key "passive cooling" strategy (Reardon and Clarke 2013), which minimises the need for auxiliary sources of cooling. Due to the importance of natural ventilation in providing good indoor air quality, improving occupants' thermal comfort, and minimizing the need for mechanical heating/cooling systems, appropriate ventilation strategies (both day-time and night-time) were incorporated into the guidelines developed for the households.

Findings from direct observations in the sample households revealed that when the sample dwellings were occupied during the day-time, natural ventilation was performed to regulate indoor temperatures and let fresh air enter the buildings. However, as also discussed in the literature (Solgi et al. 2018), ventilating buildings only during the day-time is not sufficiently effective to provide complete thermal comfort and the intake of the outdoor cool air at night into the building can release the heat gained during the daytime. Analysis of temperature changes in the sample households revealed that although the proposed guidelines emphasized the significance of night-time ventilation on the occupants' thermal comfort by lowering the day-time indoor temperature, not all of the households adopted the proposed ventilation strategies after they were educated with the guidelines. For example, temperature data recorded in HH1 revealed that more ventilation was performed in this household from afternoon right through the night during period 1 in 2015. However, the divergence of the indoor air from that of the wall surface temperatures in the living area in 2016 indicated that the dwelling was ventilated only a few hours' in the evening and the openings were all closed at night due to experiencing security issues in this household. "Security" was found to be the occupants' main concern for most of the households in not performing overnight ventilation in summer. Others (e.g. HH4) were, however, mostly ventilated overnight during the periods under investigation, which resulted in lower day-time indoor temperatures in these households in summer.

Although monitoring temperature changes in the selected households created a general understanding about how the dwellings were heated/cooled or naturally ventilated through opening doors/windows, the proposed research question could have been answered with more accuracy with energy monitoring on heating and cooling systems and/or other appliances to see exactly when they were switched on and off and how much energy they consumed.

Finally, the last research question addressed in this research was 'What are the important considerations for modelling thermal performance of low-income households?'. Thermal performance of a number of sample dwellings was evaluated using AccuRate Sustainability and their heating and cooling energy requirements were calculated using the information collected from the surveys and walk-through energy audits in the households. The influence of occupants on the building thermal performance was incorporated into the models through a number of factors including actual occupancy of dwellings (i.e. number of occupants, the amount of time they spent in different zones, and heat gains from people), their choice of key appliances, time of use of appliances including heating/cooling systems, heating/cooling thermostat set-points, and heat gains from lighting. The analysis was performed through comparison of 5 scenarios: (1) BaseCase, (2) BaseCase Adjust, (3) BaseCase Adjust + IHGs, (4) BaseCase Adjust +Thermostat settings, and (5) BaseCase Adjust + IHGs + Thermostat settings, as discussed in Chapter 6.

Thermal energy requirements varied with changing the occupancy pattern in AccuRate. 'Occupancy pattern' in this context means the number of occupants in each zone and the time of day that occupant(s) spent in a zone and when they used different appliances, which resulted in internal heat gains from the occupants and their actions in the dwelling. AccuRate's estimations with regard to occupancy pattern of some zones were significantly different from the actual occupancy patterns of that zone in practice.

Thermal performance analysis of the sample dwellings with AccuRate Sustainability revealed that AccuRate's in-built assumptions for the number of occupants did not reflect (or match with) the actual values of occupancy in the dwellings. AccuRate estimated the number of occupants based on the floor area and the number of rooms in a dwelling (as discussed in Chapter 6). Since FH, as the housing provider for the sample households, did not have similar size dwellings and a limit to the number of occupants based on the dwelling size, predicting the number of occupants based on floor area and number of rooms would always lead to inaccuracies and resulted in either underestimation or overprediction of occupancy compared to the actual number of occupants in the households. For example, AccuRate estimated a total number of 5 occupants in HH6. However, only 1 person lived in this household in 2015 and the 2 people in 2016. Another example of the discrepancy between the actual number of occupants and values estimated by AccuRate was in HH3, where only 1 person lived in the dwelling instead of 2 people assumed by AccuRate. In some households, however, AccuRate's estimation for the number of occupants matched with the actual household size e.g. HH5 and HH12.

With the existing discrepancy between the occupancy estimated by AccuRate and the actual occupancy in dwellings, the energy requirements calculated from *Scenario 1* differed from the values calculated using the actual occupancy values in sample dwellings from *Scenario 2*.

Further, AccuRate assumed some fixed hours of occupancy for different zones including bedrooms, living/kitchen and living area. According to these assumptions, bedrooms are occupied from 22:00-07:00 and living zones, including living/kitchen, are occupied from

08:00-22:00. From the household survey, it was found that not all of the sample households had occupancy patterns similar to those assumed by AccuRate. For example, while the actual occupancy of the Living/kitchen and Bedroom 1 in HH5 was quite close to the AccuRate base assumptions, occupancy of Bedroom 2 was significantly different. This bedroom was used by an occupant suffering from a mental illness and was occupied almost 23 hours on a typical day. Due to the inconsistency that existed between the occupancy patterns assumed by AccuRate and the actual occupancy in the sample households, the total heat gains from occupants as well as from appliances used by them differed, and as a result, the energy requirements calculated with and without incorporating actual occupancy also differed to a certain extent. In this context, researchers have found that occupants' presence and their energy use behaviour in buildings are the major causes of the discrepancy between the predictions of simulation tools and the actual energy consumption in buildings (Ahn et al. 2017). Due to the strong influence of occupants on domestic energy consumption, some researchers e.g. (McLoughlin et al. 2012; Feng et al. 2015) established that incorporating precise occupancy values into building energy simulation tools significantly affect the accuracy of their outcomes.

Occupants affect buildings' thermal performance by their presence (heat gains from people) and different activities they perform in buildings e.g. turning on TV, lights, cooking, etc. (heat gains from appliances). Building thermal analysis with AccuRate Sustainability revealed that AccuRate assumes certain values of IHGs from people, lighting and appliances in the living zones and does not cater for the use of appliances in the bedroom. However, as discussed in Chapter 2, due to improving households' lifestyle, diverse electronic appliances have been emerging in households. Appliances such as TVs, DVD/VCRs, gaming devices, personal computers, etc., have been added into many households (Brounen et al. 2012), which significantly affect household energy consumption depending on their efficiency and how they are used by occupants. Furthermore, as discussed in Chapter 6, the list of appliances in the living zone used by AccuRate for calculating the IHGs in buildings has not been updated for quite a while. Hence, there were inconsistencies between the IHGs calculated based on the AccuRate's assumptions and the actual IHGs in the sample households. Thermal analysis of the sample dwellings through the 5 Scenarios, revealed that AccuRate's base assumptions underestimated the internal heat gains (IHGs) from different sources and thus, the simulations calculated a greater need for heating energy and a lesser need for cooling energy than is actually required in the sample households.

In order to understand to what extent IHGs estimated by AccuRate deviated from the actual IHGs in the households, a sample household was selected for which the occupancy assumed by AccuRate was equal to the actual occupancy in the household i.e. HH5, and the IHGs were calculated using AccuRate in-built assumptions as well as the actual heat gains in HH5 from the actual appliances and their actual time of use (*Scenario 3*). **Table** 7.1 compares the IHGs in bedrooms calculated in *Scenario 2* (a) and *Scenario 3* (b) and (c). It is then followed by **Table** 7.2, which compares the IHGs in the zone living/kitchen in *Scenario 2* (a) and *Scenario 3* (b).

Table 7.1 Sensible and latent heat gains (W) for bedroom a (left): Base heat gains from AccuRate b (middle): Bedroom 1, Base heat gains from ASHRAE c (right): Bedroom 2, Base heat gains from ASHRAE

Hour	**Sensible** (Watts)			**Latent**	*"Bedroom"*	
	Light Power	*People heat*	*Total*	(Watts)	***Total Sensible***	***Total Latent***
1	0	200	200	100	15	8
2	0	200	200	100	15	8
3	0	200	200	100	15	8
4	0	200	200	100	15	8
5	0	200	200	100	15	8
6	0	200	200	100	15	8
7	0	200	200	100	15	8
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	100	0	100	0	10	0
21	100	0	100	0	10	0
22	100	0	100	0	10	0
23	100	200	300	100	26	8
24	0	200	200	100	15	8
Total	**400**	**1800**	**2200**	**900**	**180**	**69**
Percentage	***12.9%***	***58.1%***	**-**	***29.0%***	**-**	-

Hour	**Sensible** (Watts)			**Latent**
	Light Power	*People heat*	*Total Sensible*	(Watts)
1	0	70	70	35
2	0	70	70	35
3	0	70	70	35
4	0	70	70	35
5	0	70	70	35
6	0	70	70	35
7	0	70	70	35
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	25	70	95	35
23	0	70	70	35
24	0	70	70	35
Total	**25**	**700**	725	**350**
Percentage	**2.3%**	**65.1%**	-	**32.6%**

Hour	**Sensible** (Watts)				**Latent**
	Appliances	*Light Power*	*People heat*	*Total Sensible*	(Watts)
1	0	0	70	70	35
2	0	0	70	70	35
3	0	0	70	70	35
4	0	0	70	70	35
5	0	0	70	70	35
6	0	0	70	70	35
7	0	0	70	70	35
8	0	0	0	0	0
9	0	0	70	70	35
10	0	0	70	70	35
11	0	0	70	70	35
12	0	0	70	70	35
13	108	0	70	178	35
14	108	0	70	178	35
15	108	0	70	178	35
16	108	0	70	178	35
17	108	0	70	178	35
18	108	25	70	203	35
19	108	25	70	203	35
20	108	25	70	203	35
21	108	25	70	203	35
22	108	25	70	203	35
23	0	0	70	70	35
24	0	0	70	70	35
Total	**1080**	**125**	**1610**	2815	**805**
Percentage	**29.8%**	**3.5%**	**44.5%**		**22.2%**

Table 7.2 Sensible and latent heat gains (W) in Living/kitchen a (left): Base heat gains from AccuRate, b (right): Base heat gains from ASHRAE

Hour	**Sensible** (Watts)			**Latent** (Watts)	***"Living/Kitchen"***	
	Appliances and Cooking	*Light Power*	*People heat*		***Total Sensible***	***Total Latent***
1	100	0	0	0	100	0
2	100	0	0	0	100	0
3	100	0	0	0	100	0
4	100	0	0	0	100	0
5	100	0	0	0	100	0
6	100	0	0	0	100	0
7	100	0	0	0	100	0
8	400	180	280	400	508	289
9	100	180	280	200	208	89
10	100	0	140	100	129	45
11	100	0	140	100	129	45
12	100	0	140	100	129	45
13	100	0	140	100	129	45
14	100	0	140	100	129	45
15	100	0	140	100	129	45
16	100	0	140	100	129	45
17	100	0	140	100	129	45
18	100	300	210	150	226	67
19	1100	300	210	750	1226	667
20	250	300	210	150	376	67
21	250	300	210	150	376	67
22	250	300	210	150	376	67
23	100	0	0	0	100	0
24	100	0	0	0	100	0
Total	**4150**	**1860**	**2730**	**2750**	**5230**	**1669**
Percentage	***36.2%***	***16.2%***	***23.8%***	***24.0%***	**-**	**-**

Hour	**Sensible** (Watts)				**Latent** (Watts)
	Appliances and Cooking	*Light Power*	*People heat*	*Total Sensible*	
1	150	0	0	150.0	0
2	150	0	0	150.0	0
3	150	0	0	150.0	0
4	150	0	0	150.0	0
5	150	0	0	150.0	0
6	150	0	0	150.0	0
7	150	0	0	150.0	0
8	184	0	150	334.0	110
9	150	0	75	225.0	55
10	150	0	75	225.0	55
11	165	0	75	240.2	55
12	150	0	75	225.0	55
13	1191	0	75	1265.5	55
14	153	0	75	227.9	55
15	150	0	75	225.0	55
16	150	0	75	225.0	55
17	150	0	75	225.0	55
18	258	0	75	333.0	55
19	261	48	75	383.9	55
20	258	24	75	357.0	55
21	258	24	75	357.0	55
22	150	0	0	150.0	0
23	150	0	0	150.0	0
24	150	0	0	150.0	0
Total	**5128**	**96**	**1125**	6348.5	**825**
Percentage	**71.5%**	**1.3%**	**15.7%**	-	**11.5%**

Overall, the actual total heat gains calculated in *Scenario 3* using ASHRAE base heat gains were significantly higher than the total heat gains AccuRate calculated in *Scenario 2*, using its base assumptions for sensible and latent heat gains and the protocol equations. As shown in **Table** 7.1, the values of total sensible and total latent heat gains calculated using AccuRate were 180 W and 69 W, respectively, which, using the base heat gains from ASHRAE, rose to 725 W and 350 W, respectively, in Bedroom 1 and 2815 W and 805 W, respectively, in Bedroom 2.

People were found to be one of the main sources of internal heat gains in bedrooms. For example, in HH5, they accounted for 87.1% of the total IHGs when AccuRate's base assumptions were used in *Scenario 2*. When the actual occupancy was incorporated into *Scenario 3*, the total heat gains from people stood at 97.7% in Bedroom 1 but 66.7% in Bedroom 2. In fact, the type of appliances AccuRate uses in its assumptions together with how they are assumed to be used by occupants is likely to justify why people were the main contributors to the total heat gains in bedrooms. From the household survey, it was found that in almost all sample households including HH5, there was at least one bedroom with electronics including TV, PC, etc. which noticeably affected the IHGs in this zone. In HH5, almost a third of the total heat gains in Bedroom 2 was from the LCD, DVD, which was used for 10 hours on an average day (see **Table** 7.1 (c)).

In the zone of type living/kitchen, 47.8% of the total heat gain was sourced from the people (and perhaps some from evaporation that occurs during cooking) when base heat gains from AccuRate was used, which was greater than either appliances or lighting in *Scenario 2*). However, as **Table 7.2 (b)** shows, appliances and cooking accounted for the major internal heat gains in this zone (71.5%) when actual occupancy was used together with the base heat gains from ASHRAE (*Scenario 3*).

Lighting accounted for the least IHGs in bedrooms (e.g. 13% in *Scenario 2* and 2.3% and 3.5% for Bed 2 and Bed 3 in *Scenario 3* in HH5) as well as in the living/kitchen (e.g. 16% in *Scenario 2* and 1.3% in *Scenario 3* in HH5). Compared to the base heat gains from ASHRAE, AccuRate overestimated the heat gains from lighting. Two reasons are likely to explain the higher total heat gains from lighting calculated by AccuRate and its assumptions compared to the actual heat gains in HH5. Firstly, AccuRate's base assumptions for lighting did not take into account the trend towards low power lighting that has occurred in the last 15 years. AccuRate assumed 100 W power draw from 19:00 – 23:00 in bedrooms (i.e. 400 Wh over 24 hours) and 180 W power draw from 07:00 – 09:00 and 300 W power draw from 17:00 – 22:00 in living/kitchen (i.e. 1860 Wh over 24 hours). Both the time of use as well as the base heat gains from this source were higher than the actual situation in HH5. 20 W CFLs were used in different zones in HH5 (in the living/kitchen zone, there were three 20 W CFLs). Taking into account the Lighting Use Factor (LUF) = 1 and Special Allowance (SA) = 1.25 from ASHRAE (ASHRAE 2013), heat gain from a CFL in the bedroom was only 25 W. Using the actual time of use reported by the HoH, heat gains from lighting were significantly lower in this household compared to the calculations using AccuRate base assumptions. Secondly, AccuRate's assumptions did not consider the improved efficiency of new globes, which result in less heat gain from these sources.

As discussed in Chapter 4, occupants in the sample households were educated by a series of guidelines that addressed different areas of energy inefficiency in their households. The focus of the proposed guidelines was mainly on natural ventilation and the use of heating and cooling appliances in summer and winter. In order to find out how thermal energy requirements in a household were affected by thermostats set-point of their heating/cooling appliances, the actual values of the heating and cooling thermostat set-points were substituted with the values recommended to the occupants in the proposed guidelines. This situation will be referred to as *Scenario 6*. Note that only the households with adjustable thermostats on reverse cycle air-conditioning systems i.e. HH2, HH3, and HH7 are assumed to apply to this part of the study and therefore, only these households are considered in *Scenario 6*. Note that the actual time of use reported by the HoHs was used in both *Scenario 5* and *Scenario 6*. **Table** 7.3 and **Figure** 7.2 and **Figure** 7.3 show how much thermal energy each household can save if they set their thermostat on the temperature settings proposed by the guidelines.

Table 7.3 Expected energy savings in households with the adjustable thermostat setting

HH	Zone	Actual thermostat settings (°C) applied by the households	Time of use	Recommended thermostat settings	Heating Energy Requirements (MJ/m^2)		Cooling Energy Requirements (MJ/m^2)		RPD in the total energy requirements from scenario 5 and scenario 6 (%)
					Original (Scenario 5)	Modified (Scenario 6)	Original (Scenario 5)	Modified (Scenario 6)	
HH2	Living	Heating: 21 Cooling: 23	Heating: 7:00 am-10:00 am, 03:00 pm– 07:00 pm Cooling: 10:00 am-06:00 pm	**Heating:** Living Spaces: 20 °C Bedroom: 18 °C **Cooling:** 25 °C	145.9	98.5	147.33	43.79	-51.5
HH3	Living, Living/ Kitchen	Heating: 24 Cooling: 23	Heating: 05:00 am – 05:00 pm Cooling: 05:00 am – 10:00 am, 1:00 pm – 10:00 pm		320.4	83.8	140.1	40.0	-73.1
HH7	Living /Bedroom	Heating: 22 Cooling: 18	Heating: 07:00 pm – 09:00 pm Cooling: 04:00 pm – 05:00 pm		247.3	228.4	118.48	37.2	-27.4

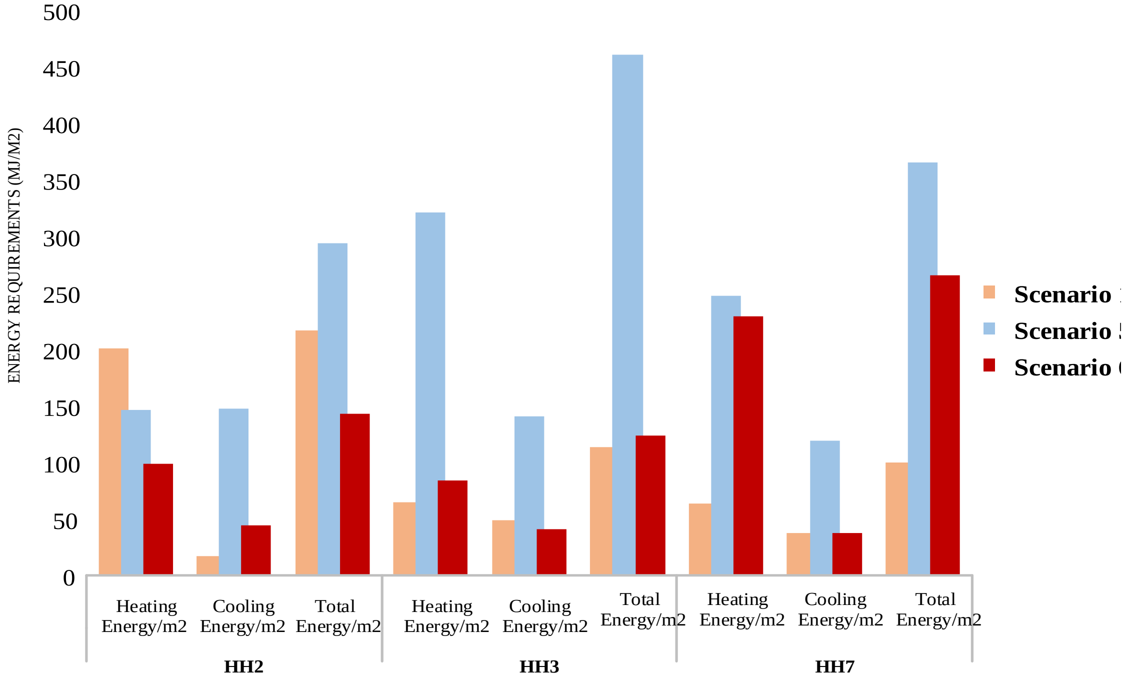

Figure 7.2 Savings in thermal energy requirements in households with adjustable thermostat

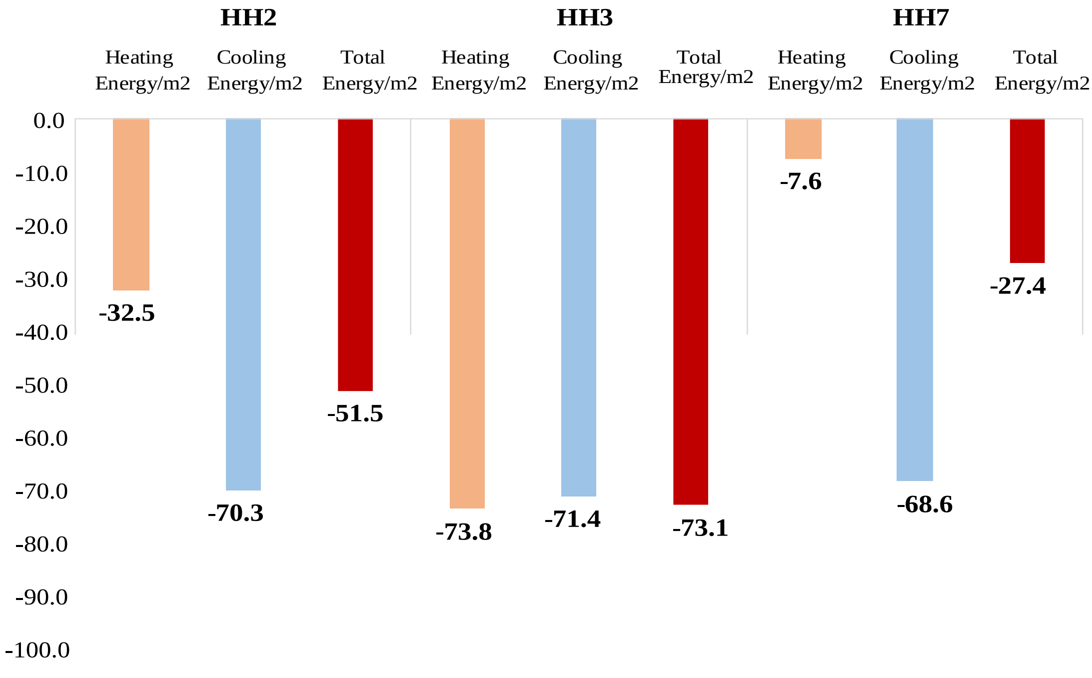

Figure 7.3 Relative percentage difference of heating, cooling and total energy requirements from Scenario 5 and 6

The relative difference in the heating, cooling and total energy requirements between *Scenario* 5 and 6 in all three households are significant in many cases. As shown in **Figure** 7.3, a total saving of over 50% in HH2 and over 70% in HH3 can be achieved by adjusting the thermostat set-points using the temperatures recommended to the occupants in the guidelines. However, HH7 has 2 electric resistive heaters in the bedrooms with non-adjustable thermostats, and the heating energy requirements in this household drop by only 7.6% (see **Figure** 7.3).

The heating, as well as the total energy requirements in HH3 and HH7 and the cooling energy requirements in HH2 from *Scenario 6*, exceeded the energy requirements from *Scenario 1* (**Figure** 7.2). This is mainly due to applying different operating times for heating and cooling appliances in the two scenarios. While AccuRate's inbuilt assumptions for the time of operating heating and cooling systems were used in *Scenario 1*, the actual values as reported by the HoH during the interview were applied in *Scenario 6*, resulting in the discrepancy between the energy requirements from the two scenarios.

Overall, thermal performance analysis with AccuRate Sustainability suggested that the key factors that affect the thermal performance of the selected dwellings were to be assumptions surrounding the thermostat settings of the heating/cooling systems and the time of use of these appliances. Note that time of use of systems may be longer in low-income households where unemployment and illness may mean that occupants spend more time in the house. Additionally, AccuRate's assumptions regarding the use of appliances in zones and the type of lighting globes are outdated. This in return, may result in an unrealistic insight into the thermal energy performance of buildings being assessed with this tool. Thus, updating these assumptions in building energy assessment software such as AccuRate is required for improved accuracy of the modelling process.

7.2 Limitations of the Research

Despite detailed planning for the data collection stage, unpredictable situations were encountered during the fieldwork that hindered the effective collection of data and it was not possible to overcome all of the constraints that had the potential to become sources of error. All conclusions drawn above are thus made with due reference to the following limitations:

(i) The small sample size affected the statistical significance of the study. Despite support from the Foundation Housing to involve more participants, only a few interested households finally agreed to take part in the study.

(ii) The withdrawal of households from the research at different stages of the project, due to reasons such as privacy issues, moving from social housing property to private rental dwellings, etc. made it difficult to carry out the research smoothly and generalise the results.

(iii) The collection of temperature data was affected by issues inherent to the data loggers such as data incompleteness and inconsistency, the presence of erroneous records, and inaccurate values. An attempt has been made to minimise the data inconsistency by pre-processing the raw data prior to analysis to eliminate the effect of these issues.

(iv) It was not possible to get high-resolution electricity bills and therefore, assumptions were made to calculate the daily consumption. Online electricity bills, which provided data over a period of two months were used to estimate the households' electricity usage during the period under investigation.

(v) While working with the AccuRate Sustainability software, it was found that the list of appliances AccuRate uses to calculate the heat gains of dwellings has not been updated with recent appliances. Hence, the internal heat gains calculated by AccuRate did not precisely reflect the actual heat gains from newer appliances, which have been added, due to changes in lifestyle, into average Australian dwellings.

(vi) AccuRate Sustainability was not flexible enough for modelling different aspects of actual occupants' behaviour through the software interface. Indeed, the calculation of thermal energy requirements with AccuRate, which was mostly based on fixed and outdated assumptions by the software could not be modified by the user through the interface. In order to overcome this problem, a workaround was devised whereby 'scratch' files input to the software engine were modified to incorporate occupancy and different aspects of occupants' behaviour into the models.

7.3 Conclusion

This research project was designed and developed with the aim of providing insight into both the influence of occupants' presence and their behaviour, so-called "occupants' implicit and explicit impact", on the energy performance of social housing dwellings as well as the nature of occupants' thermal comfort in the indoor environment. As such, the outcomes of this research are a proposal for how the energy consumption and the ensuing high energy expenditures (relative to the income level of the majority of social households) can be managed in low-income households living in social dwellings. The achievement of this would be of great benefit to both social households as well as social housing providers.

The sample size at different stages of this study was small and the availability of data required for a specific analysis varied. Although the same sample size could not be maintained at every stage, the households incorporated into each part of analysis were those, who, from long-term observations, were found to have exceptional behavioural patterns, especially with respect to the use of heating and cooling appliances and/or naturally ventilating of their house.

Temperature monitoring was performed in a number of sample households with the aim of identifying the influence of occupants' behavioural activities on the thermal performance of dwellings and to find out whether or not educating the occupants with the proposed guidelines resulted in any changes in their behaviour, mainly with respect to the use of heating and cooling appliances and natural ventilation. Variation in indoor temperatures and their influence on the occupants' thermal comfort were discussed in this study, based on extended direct observations in the sample dwellings, interviewing the occupants at different intervals, and subjective interpretation of the researcher based on direct interactions with the households. Although no firm conclusions could be made, the overall process shed lights on the occupants' behavioural patterns and the subsequent temperature fluctuations in the indoor environment in the selected households, which could be improved upon in order to lower their energy consumption.

While using AccuRate Sustainability for estimating the building heating/cooling requirements, it was found that the tool was not flexible enough for modelling different aspects of occupant behaviour directly through the software interface due to using fixed and unrealistic assumptions relating to occupants and how they may contribute to the building thermal performance, as well as for how different zones are conditioned in a building. Although, with the support provided by the software developer team at CSIRO, the actual occupants' presence (e.g. the actual number of occupants and the heat gains from them) and some aspects of their behaviour (e.g. major appliances used in the households and their time of use, heating/cooling thermostat set-points and their time of use, lighting, etc.) were incorporated into the models, AccuRate's assumptions for other behavioural activities including occupants' window opening behaviour, which may, to a significant extent affect the thermal energy requirements of buildings, could not be adjusted. As such, the study strongly encourages that modelling tools that are used for the energy assessment of buildings, including AccuRate Sustainability, should be further improved to enable modification of the basic assumptions made by the software to reflect the actual energy use patterns. By replacing these assumptions with more realistic data, the outcomes of buildings' thermal performance assessments using these tools would be more accurate, reliable, and significant, and potentially lead to significant energy savings in the building sector.

7.4 Lessons learned

This research project was only made possible through the direct contribution of low-income households living in social housing dwellings in Perth, Western Australia. The outcomes of this research are, therefore, expected to assist these households and many other social household residents who are struggling with their daily energy usage and pave the way for them to curtail their energy expenditure in more effective ways. Through extended liaison with occupants in the sample households, a number of major areas were identified, which directly or indirectly affect the energy performance of the existing social housing dwellings including:

- The inefficiency of existing buildings
- Lack of information conveyed to the householders
- Inefficient basic electrical appliances used by the householders
- Lack of security

Based on the above discussions, the following lessons learned may help reduce energy consumption in social housing dwellings:

(i) Inspect the following items before acquiring or build new housing lots:

    - Insulation on the roof
    - Curtains /blinds
    - Seals in the doors and windows
    - Hot water system

(ii) When initiating a new contract with tenants, guidelines explaining the DOs and DONTs on energy use can be discussed with (not only delivered to) the occupants.

(iii) Regular follow-ups are required to ensure that occupants effectively apply the guidelines. This can be performed during the regular inspections of properties by the housing providers.

(iv) Security was found to be the primary concern of the majority of the sample households for not performing natural ventilation especially overnight. Adding security screens can help the householders to allow natural ventilation and minimize the need for mechanical air-conditioning systems.

7.5 Recommendations for Future Research

Based on the findings of this research some suggestions for valuable future research in this area are:

(i) Apply a similar approach with a larger sample size in order to shed more light on the energy performance of the social housing sector.

(ii) Conduct a broader investigation on energy use behaviour by data monitoring of actual energy appliance usage patterns and thus evaluate the energy performance of low-income households.

(iii) Carry out a study on the benefits of energy savings on the health and well-being of occupants in social housing.

(iv) Map new policy frameworks that will drive improved energy efficiency in the social housing sector.

7.6 Contribution to Knowledge

The present study contributes to a significantly less explored realm in energy performance of low-income social housing in Australia through:

(i) Creating an inclusive insight into the energy consumption in low-income households, which spend a significant portion of their income on energy;

(ii) Shedding a light on how different behavioural patterns can affect the energy performance of low-income social households;

(iii) Confirming the fact that despite difficulties in paying energy bills, households may put their indoor thermal comfort at the forefront and use auxiliary heating/cooling at the expense of cutting from other basic needs.

(iv) Revisiting AccuRate's base assumptions which often under-predict the amount of internal heat gain in the households and thus calculates a greater need for heating energy and a lesser need for cooling energy than is actually required.

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LIST OF APPENDICES

Appendix 3A Questionnaire for Households

2014

Murdoch UNIVERSITY

Household ID:

Address:

Questionnaire for Households

This survey is a part of a PhD research program which mainly aims at **optimising energy consumption and thermal comfort** in Perth residential buildings. Increasing energy prices and household energy consumption due to lifestyle changes during the last couple of years have made energy efficiency of the house the most cost-effective way of cutting down on household energy bills.

The purpose of this survey is to identify the links between energy use behaviour and energy performance of the house. The benefit of involvement in this study might potentially reduce your energy bills.

This questionnaire will be used to collect information on householders' energy consumption and their perception of thermal comfort. After completion of the first survey and detailed analysis of the results, guidelines will be developed and tested to assist you to be more efficient in your energy use. To accomplish this, the second survey will be conducted on a voluntary basis for testing the effectiveness of the proposed guidelines.

If you would like to take part in the second survey, you can do so through by contacting Parisa Esmaeili Moakher on +61 8 9360 2382 or by sending email to p.esmaeilimoakher@murdoch.edu.au.

The questionnaire is in three sections:

- Basic household information
- Information on electrical appliances used in your house (Walk-through Audit)
- Information on how and when the appliances are used

Photographs if taken would be of the interior and exterior of the house and with the consent of householders. Few parameters such as the temperature of the house, airflow and leakage into and out of the house might also need to be measured during the process.

Your participation in this study is entirely voluntary. You may withdraw at any time without discrimination and prejudice. However, if you withdraw after completion of the survey, all information you provided might be used for further analysis. Your responses will be processed strictly confidential and only group data will be made available where needed. Your name and identifying details will not be passed onto a third party or used in any publication arising from the research.

If you are willing to assist in this study by participating in this survey, please complete the consent form. It is estimated that the questionnaire survey will take approximately 45 minutes to 1 hour to complete.

If you would like to take part in the follow-up survey, please tick the box:

□ Yes

□ No

1) Which, if any, of the following utility bills, are included in your rent?
   - ☐ Electricity
   - ☐ Gas
   - ☐ Water
   - ☐ None of the Above
2) Which of the following categories best describes your ability to afford your last electricity bill?

☐ Very difficult

☐ Somewhat Difficult

3) ☐ Not difficult at all
4) Do you give us permission to monitor and have access to your electricity, gas and water bills for the last two years?

☐Yes

☐No

Socio-Demographic Information

5) We would like to know a few details about the people who live in the household to help understand how you use electricity. Your name and personal information will remain strictly confidential.

Code:	Occupants	Gender	Age	Employment Status	Level of Education	Years of residency in the house
		M/F	Age 12^- =A 13 to 19 =B 20 to 60 =C Age 60^+ =D	Unemployed = U Employed = E Retired = R	None = 0 Primary= 1 High/Secondary = 2 University degree = 3 Higher degree= 4	0-2 years= A 2-4 years= B 4-6 years= C 6+ years= D
Date: ______/______/______	1: respondent					
Building type:	2					
	3					
Year of Construction:	4					
	5					
Phone Number:	6					
	7					

Presence of Occupants at Home

6) Please indicate on the table below the approximate number of hours each family member spend at home during weekdays and weekends.

Occupants	**Morning**		**Afternoon**		**Evening**		**Night**	
	(500 am–12:00 pm)		(12:00 pm–05:00 pm)		(05:00 pm–09:00 pm)		(09:00 pm–5:00 am)	
	W-D	W-E	W-D	W-E	W-D	W-E	W-D	W-E
1: Respondent								
2								
3								
4								
5								
6								
7								
Overall Occupancy Hours								

Heating, Ventilation and Air Conditioning System

7) During winter and summer, how do you rate your comfort at home without the heater/cooler on? On the scale of -3 to +3 with -3 being “cold” and +3 being “hot”.

	Winter		**Summer**	
	Day	Night	Day	Night
-3= cold				
-2= cool				
-1= slightly cold				
0= Natural comfort				
+1= slightly warm				
+2= warm				
+3= Hot				

8) If you do not feel naturally comfortable at home during Winter and Summer, please rank the following actions which you take to overcome your level of discomfort (in order of first, second, third and fourth).

	Winter		Summer	
	Day	Night	Day	Night
Adjusting your clothes				
Close/Open windows				
Using blinds				
Switching on the heater/AC				
Other, please specify				

9) Which part of the house do you usually heat during Winter or cool during Summer to achieve thermal comfort?

Area	Winter	Summer
Living area		
Bedrooms		
Kitchen		
Bathroom		
All		
None		

10) If you use heater /AC to heat your house, do you know at what temperature you usually set it to feel comfortable? (The degree at which if you reduce it, you may feel cold and if increase it, you might feel hot.)

☐Yes

☐No, please go to question 12

11) On average, at what temperature do you set your heater in cold winter day? ____________°C

12) On average, at what temperature do you set your AC on the hot summer day? ____________°C

13) What is the type of temperature control of your heating/cooling appliances?

Area	Heating Appliances	Cooling Appliances
Manual switches on radiators/ heaters		
Manual thermostat (none programmable)		
Programmable thermostat (clock thermostat)		
No thermostat		

14) In case of manually control system, how often do you usually alter the temperature setting of your appliances based on the temperature of your house to achieve thermal comfort?

☐Always

☐Often

☐Sometimes

☐Never

15) Tick those items of clothing you usually wear at home during cold winter day/hot summer day? (More than one option can be selected)

Clothing Ensembles	Winter	Summer
Light short sleeve shirt		
Light long sleeve shirt		
Heavy short sleeve shirt		
Heavy long sleeve shirt		
Light trousers		
Heavy trousers		
Light jacket		
Heavy jacket		
Others, please specify		

16) To give us an overview of approximately where and when you turn the heating system on during weekdays and weekends, please fill out the following table.

17)

Area	Morning (5:00 am–12:00 pm)		Afternoon (12:00 pm–05:00 pm)		Evening (05:00 pm–09:00 pm)		Night (09:00 pm–5:00 am)	
	W-D	W-E	W-D	W-E	W-D	W-E	W-D	W-E
Living area								
Bedrooms								
kitchen								
Bathroom								
Overall Hours								

18) If you use any heating system to have a thermally comfortable house, what do you do to reduce its use at home?

____

19) To give us an overview of approximately where and when you turn the cooling system on during weekdays and weekends, please fill out the following table.

Area	Morning (5:00 am–12:00 pm)		Afternoon (12:00 pm–05:00 pm)		Evening (05:00 pm–09:00 pm)		Night (09:00 pm–5:00 am)	
	W-D	W-E	W-D	W-E	W-D	W-E	W-D	W-E
Living area								
Bedrooms								
kitchen								
Bathroom								
Overall Hours								

20) Do you usually close the windows at home when the heater/cooler is on?

☐Yes

☐No

☐The windows will remain open or closed as they were before the heating or cooling system is turned on.

21) How do you get fresh air throughout the house?

☐Opening windows and grills

☐Fans and mechanical devices

☐Both

☐I don't know

22) Where and when do you usually open the windows? If you use any of the doors for getting fresh air such as doors to balcony, please consider them as a window.

Summer	**Morning**		**Afternoon**		**Evening**		**Night**	
	(5:00 am–12:00 pm)		(12:00 pm–05:00 pm)		(05:00 pm–09:00 pm)		(09:00 pm–5:00 am)	
Area	W-D	W-E	W-D	W-E	W-D	W-E	W-D	W-E
Living area								
Bedrooms								
kitchen								
Bathroom								
Winter								
Area								
Living area								
Bedrooms								
kitchen								
Bathroom								

Hot Water System

23) Do you know the type of hot water system in your house?

☐Electric heat pump

☐Storage water heater using electricity as fuel

☐Solar water heater

☐Storage water heater using gas as fuel

☐Gas instantaneous

☐None

☐Other, please specify ___________________________________

☐I don't know

24) What is the thermostat set point for the hot water system?

☐Warm (32.2 °C- 43.3 °C)

☐Hot (54.4 °C -70 °C)

☐Very hot (70+ °C)

☐I don't know

25) Do you usually alter the temperature set point of the hot water system in your house in summer and winter?

☐Yes

☐No

26) Approximately how many showers and baths are taken by the occupants in your house per week and how long does it take on average?

	Summer				Winter			
	Morning	**Afternoon**	**Evening**	**Night**	**Morning**	**Afternoon**	**Evening**	**Night**
Number of showers taken per day								
Approximate number of minutes each shower takes								

Lighting System and Appliances in Use

27) Do you switch off the interior lights when they are not in use?

☐Yes

☐No

28) During the day, when natural light is adequate, do you switch any lights on?

☐Yes, please specify the reason. ____

☐No

29) Does your washing machine have temperature setting?

☐Yes

☐No

☐I don't know

30) If yes, what is the usual water temperature of your washing machine?

☐Cold (16-°C)

☐Warm (37 °C)

☐Hot (59+°C)

31) Do you usually switch the appliances off at the wall when you don’t use them?

☐Yes

☐No

Appendix 3B Walk-Through Energy Audit

Group	Name of appliances	Number of appliances	Model No.	Wattage	Size	Time of use Morning =A Afternoon = B Evening = C Night =D	Number of loads per week	Average minute/ day	Star rating	Annual energy consumption estimation	When not in use, I: Turn it Off = 1 Leave it On Standby = 2 Leave it on = 3
Kitchen	Dishwasher										
	Microwave										
	Electric Oven										
	Rice cooker										
	Electric kettle										
	Slow cooker										
	Coffee-maker										
	Extractor fan										
	Toaster										
	Small appliances										
Refrigeration	Refrigerator										
	Freezer										
	Fridge freezer										
laundry	Washing machine										
	Dryer										
	Iron										
Space-conditioning	Ceiling fan										
	Air-conditioner										
	Heater										
	Dehumidifier										
Entertainment	Laptop										
	Computer										
	Printer										
	Radio										
	Video-games										
	DVD player										
	VCR										
	Stereo										
	TV										

Miscellaneous	Hair drier										
	Vacuum cleaners										
	Instant gas water heater										
	Electric blanket										
Others											

Type of lighting	**Number of fixtures**
Interior	
Small incandescent (<40 watts)	
Medium incandescent (40-75 watt)	
Large incandescent (>75 watts)	
Compact Fluorescent Lamp	
Tube-type fluorescent Lamp	
Circular Fluorescent	
Halogen Bulbs	
LED	
Exterior	
Small incandescent (<40 watts)	
Medium incandescent (40-75 watt)	
Large incandescent (>75 watts)	
Compact Fluorescent Lamp	
Tube-type fluorescent Lamp	
Circular Fluorescent	
Halogen Bulbs	
LED	

Appendix 3C Ethics Approval

Division of Research & Development
Research Ethics and Integrity Office

Chancellery Building
South Street
MURDOCH WA 6150
Telephone: (08) 9360 6677
Facsimile: (08) 9360 6686
human.ethics@murdoch.edu.au

www.murdoch.edu.au

Friday, 01 August 2014

Dr Tania Urmee
School of Engineering and Information Technology
Murdoch University

Dear Tania,

Project No.	2014/121
Project Title	Optimal functional design of energy efficient residential building based on actual occupant's behaviour in social housing in Perth, Western Australia

Thank you for addressing the conditions placed on the above application to the Murdoch University Human Research Ethics Committee. On behalf of the Committee, I am pleased to advise the application now has:

OUTRIGHT APPROVAL

Approval is granted on the understanding that research will be conducted according the standards of the ***National Statement on Ethical Conduct in Human Research* (2007), the *Australian Code for the Responsible Conduct of Research* (2007)** and **Murdoch University policies** at all times. You must also abide by the **Human Research Ethics Committee's standard conditions of approval (see attached).** All reporting forms are available on the Research Ethics and Integrity web-site.

I wish you every success for your research.

Please quote your ethics project number in all correspondence.

Kind Regards,

[redacted]

Dr. Erich von Dietze
Manager
Research Ethics and Integrity

cc: Dr Samuel Gyamfi and Parisa Esmaeili Moakher

Appendix 3D Information Letter

Investigator (s) Parisa Esmaeili Moakher

Contact Person Parisa Esmaeili Moakher
Address School of Engineering and Information Technology
Murdoch University (South Street)
Western Australia, 6150

Telephone No. +61 8 9360 2382

You are invited to participate in this study

Background

Research has shown that energy prices constitute the major part of Australian household's expenses. Over the past few decades, energy prices, as well as household energy consumption due to lifestyle changes, have significantly increased. Hence, enhancing the energy efficiency of this sector has introduced a potentially cost-effective way to cut down on household energy bills. We are interested to learn whether this is the case with Perth residential buildings. Therefore, we are inviting you to participate in household energy use behaviour survey over the next few weeks.

The aim of the Study

The purpose of this survey is to identify the links between energy use behaviour and performance of the house. So, we will ask you to answer a few questions about the people who live in the household and how do they use energy in the house. This is to find out whether there are benefits to you from participating in this study. If you consent to take part, it is important that you understand the purpose of the study and answer the questions during the interview. Please make sure you ask any question you may have, and all your questions have been answered to your satisfaction before you agree to participate.

What Does Your Participation Involve?

If you decide to participate in this study, you might be asked to provide:

1. Basic information about householders such as their age, level of education, etc.
2. Information on electrical appliances which are used in your house (Walk-through Audit)
3. Information on how and when the appliances such as washing machine, refrigerator, etc. are used.
4. Information on how you use the heating and cooling appliances or hot water system in the house during summer and winter. This may include questions about the temperature set point of the heater/AC or frequency and the average duration of showers/baths taken.

To find out how the occupants’ behaviour changes with respect to indoor and outdoor temperature fluctuation, temperature loggers are known as thermochrons will be installed inside and outside of the buildings for approximately one year. Data loggers record the temperature of the house and data will need to be read by the researcher every 1.5 months. The process of reading data will take only a few minutes and will be performed with an appointment with householders. Detailed information about the loggers can be found in Thermochrons Information & Safety Sheet.

Photographs if taken would be of the interior and exterior of the house for further analysis and with your consent. No photographs will be taken from any individual.

If you indicate that you are willing to participate, you will be required to give permission for the release of information held about the household on the Foundation Housing database to the research team.

It is estimated that the questionnaire survey will take approximately 45 minutes to 1 hour to complete. Another hour might be needed for a walk-through energy audit in your house.

Voluntary Participation and Withdrawal from the Study

It is important to understand that your involvement in this study is voluntary. While we would be pleased to have you participate, we respect your right to decline at any time without providing an explanation. There will be no consequences to you if you decide not to participate and this will not affect the service you are being provided. If you withdraw, the information you provided might be used for further analysis upon your consent. Otherwise, all will be destroyed.

Privacy

Your privacy is very important to us. Your participation in this study and any information will be treated in a confidential manner. No name or identity will be revealed as it will be stored separately from the data and these will be accessible only to investigators. Only group data will be made available where needed. Your name and identifying details will not be used in any publication arising from the research. Photographs if taken would be of the interior and exterior of the house and with the consent of householders. Data will be stored on the candidate's portable hard drive, the supervisor's portable hard drive and the University computer hard drive. Data security will be managed using password protected computers and secure locations for hard drives. Following the study, the data will be deleted from the candidate’s hard drives and will be stored with the SEIT office for future research by School researchers. Data in the School office will also be deleted after 5 years of storage.

Possible Benefits

You might notice a reduction in your energy bills after a certain period of time (e.g. after implementing the proposed guidelines). It is intended that the principles distilled from this project to be applied throughout the Perth residential sector. We will be interested to see if you experience any other benefits from this study.

Possible Risks

There are no specific risks anticipated with participation in this study. However, if you find that you or other family members are becoming distressed, you may withdraw from the study or may discontinue participation at any time without discrimination or prejudice.

Questions

If you would like to discuss any aspect of this study, please feel free to contact either Parisa Esmaeili Moakher on +61 8 9360 2382 or my supervisor Dr Tania Urmee on +61 8 9360 1316. Either of us would be happy to discuss any concerns you may have about this study.

Once we have analysed the information, you will be informed about the result through Foundation Housing Limited team. You can expect to receive this feedback in about 3 years of this study.

We would like to thank you in advance for your assistance with this research project. If you are interested to take part in this survey, please contact Parisa Esmaeili Moakher on +61 8 9360 2382. We look forward to hearing from you soon.

This study has been approved by the Murdoch University Human Research Ethics Committee (Approval 2014/121). If you have any reservation or complaint about the ethical conduct of this research, and wish to talk with an independent person, you may contact Murdoch University's Research Ethics Office (Tel. 08 9360 6677 or e-mail ethics@murdoch.edu.au). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 3E Consent Form

I have read the participant information sheet, which explains the nature of the research and the possible risks. The information has been explained to me and all my questions have been satisfactorily answered. I have been given a copy of the information sheet to keep.

I am happy to be interviewed and for the interview to be audio recorded as part of this research. I understand that I do not have to answer particular questions if I do not want to and that I can withdraw at any time without needing to give a reason and without consequences to myself.

I agree that research data from the results of the study may be published provided my name or any identifying data is not used. I have also been informed that I may not receive any direct benefits from participating in this study.

I understand that all information provided by me is treated as confidential and will not be released by the researcher to a third party unless required to do so by law.

I have also been informed that data will be stored on the candidate's portable hard drive, the supervisor's portable hard drive and university computer hard drive. Data security will be managed using password protected computers and secure locations for hard drives. Following the study, the data will be deleted from the candidate's hard drives and will be stored with the SEIT office for future research by School researchers. Data in the School office will be deleted after 5 years of storage.

Participant's name: ________________________

Signature of Participant: ________________________ Date: …..../..…../……

I confirm that I have provided the Information Letter concerning this study to the above participant; I have explained the study and have answered all questions asked of me.

Signature of researcher: ________________________ Date: …..../..…../…….

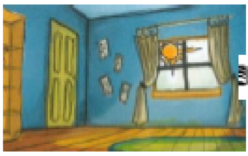
Appendix 4A Socio-Economic and Technical Characteristics of the Surveyed Households

HH	Building Type	Year of Construction	No. of Bedrooms	Floor Area (m^2)	Years of Residency	HH Size	HoH Gender	HoH Education Level	Average Electricity Consumption in 2013 (kWh)	Average Electricity Consumption in 2014 (kWh)	Electricity Analysis
HH 1	SD	2010	3	233.69	1.3	8	M	2	3805.8	3326.1	✓
HH 2	SD	2008	4	122.63	6	2	F	2	3111.2	3489.8	✓
HH 3	TH	2008	2	104.26	4	1	M	2	3961.8	4093.7	-
HH 4	SD	2008	3	125.83	2.4	4	F	2	4820.6	7548.6	✓
HH 5	SD	2011	2	101.35	3.5	2	F	3	2398.1	2415.5	*
HH 6	SD	2010	3	111.91	4	2	F	3	2777.3	2525.6	*
HH 7	SD	2010	3	118.56	2.3	3	M	3	3613.8	3601.3	*
HH 8	SD	2008	4	192.77	0.83	6	M	2	RM	RM	-
HH 9	SD	2008	5	145.63	0.33	8	M	3	RM	RM	-
HH 10	SD	2008	3	107.87	5	2	F	2	DA	DA	-
HH 11	SD	2010	3	144.19	4	2	F	3	7163	4747.3	✓
HH 12	SD	2011	3	193.88	3	5	M	2	3815.5	5381.9	✓
HH13	SD	2008	4	150	2	6	M	3	3412.2	3088	✓
HH14	SD	2011	4	198	3	4	F	2	4345	4842.6	✓
HH 15	SD	2008	3	125	1.3	4	F	2	DA	DA	-
HH 16	SD	2010	5	142.57	3.8	6	M	2	5312.3	4383.3	✓
HH 17	SD	2008	4	201.88	3	6	F	0	5612.1	4830	✓

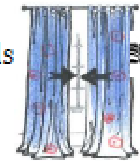
HH: Household, SD: Single Detached, TH: Town House, DA: Did not Agree, RM: Recently Moved
HoH Education: None = 0, Primary = 1, Secondary/High School = 2, University Degree = 3
*These households are removed from electricity analysis as they either used the gas heating system or electric water heater

Appendix 4B General Guidelines for Households

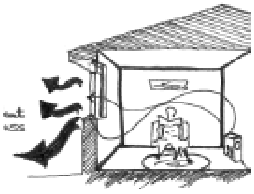
DOs and DON'Ts in Winter



Open all the curtains and blinds in the Morning



Close them all in the evening



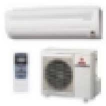
Close all the windows and curtains before turning on the heater!

Set heater temperature at:
- 20 °C: kitchen/living area
- 15-18°C: Bedrooms

Every 1 degree above 20 °C adds 10% to the running cost of the heating system

- ❑ Adjust the heaters louvers down towards the floor (if applicable). This warms up the entire room.
- ❑ Save up to 75% of the heat loss by only heating the rooms in use and close the openings to the cooler rooms
- ❑ Use heavy curtains to reduce heat loss through window

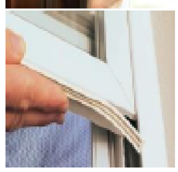
Choose the Heater Carefully

Heating Appliances	Purchase Cost	Running Cost	Environmentally Friendly	
Portable Heater	✓	✓✓✓	✓	
Gas Heater	✓✓	✓✓	✓✓	
Reverse-Cycle AC	✓✓✓	✓	✓✓✓	

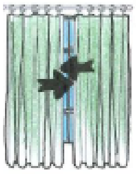
Check the air leak through doors and windows

⚠ 15-25% heat is lost through the unsealed doors and windows!

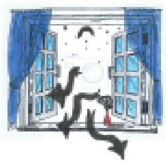
- ➢ Test the windows or door for leaks by burning an incense stick or a candle near all its connections;
- ➢ If the smoke flickers, you have an air leak;
- ➢ Tighten up around the windows and doors by adding new weather-stripping.



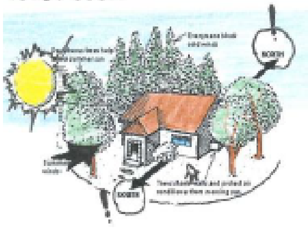
DOs and DON'Ts in Summer



Close all the doors, windows and blinds in the morning!

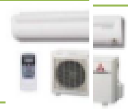


Open the windows and curtains in the evening and night!

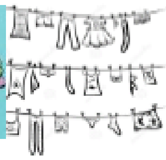


Cool the house by shading the windows especially those located in East and West!

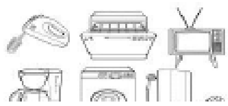
- ❑ Install the air conditioner on the shady side of the house
- ❑ Set the temperature at around 25 °C
- ❑ Use Economical Cooling appliances

	Economical Cooling Appliances are:	
1	Fan	
2	Evaporative Cooler	
3	Reverse-Cycle AC	

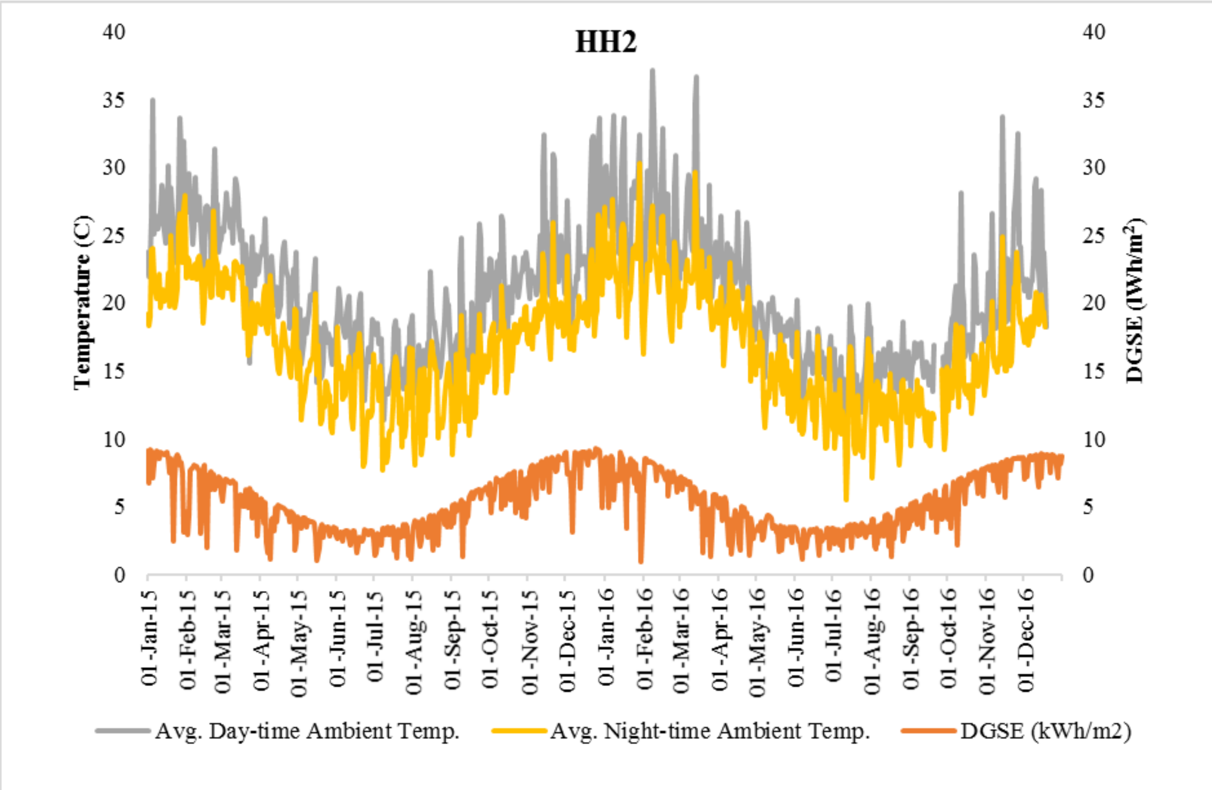
DOs and DON'Ts

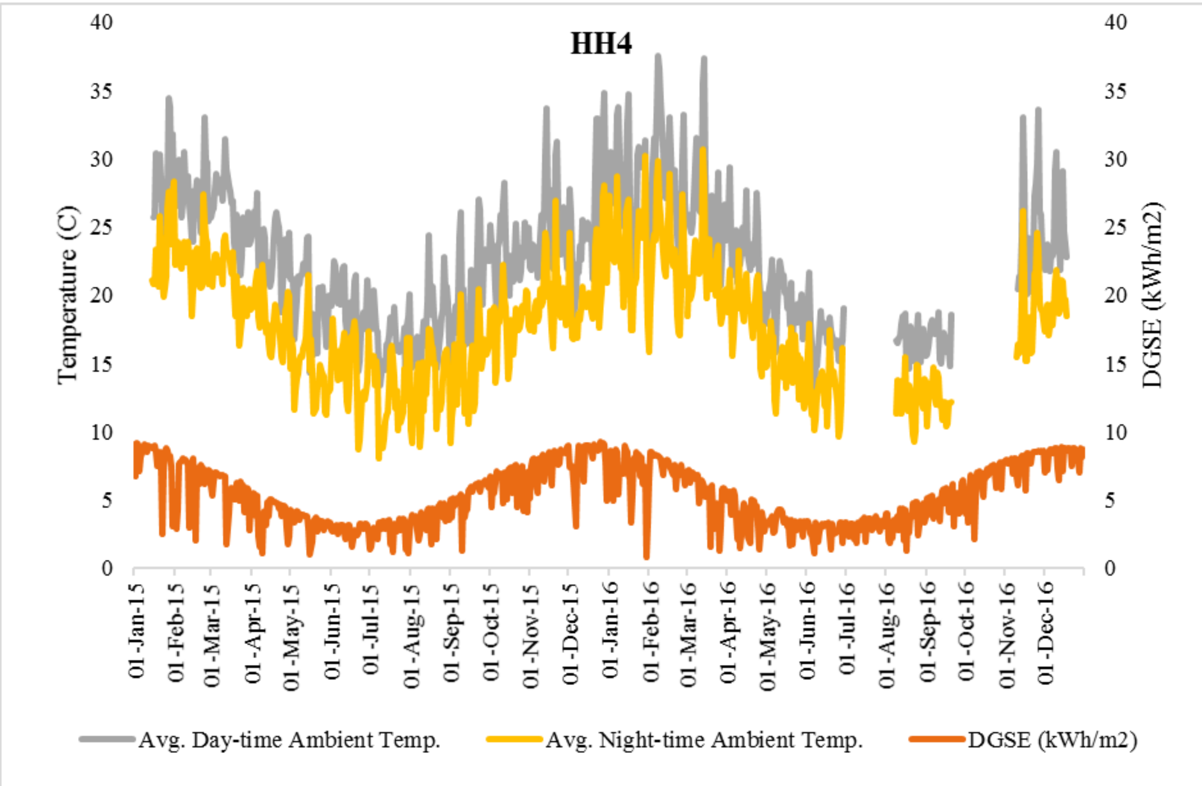


- ➢ Use washing machine with full load
- ➢ Say NO to cloth dryers! Hang the cloths outside
- ➢ Switch off the appliances at the wall or power strips.
- ➢ Avoid opening the oven door when cooking
- ➢ Boil as much water as you need
- ➢ Unplug the charger when your mobile phone is fully charged.
- ➢ Set fridge temperature to 4 °C or 5 °C and freezer temperature -15 °C to -18 °C. Every degree lower that uses around 5% more energy.
- ➢ Use Energy Efficient lamps (CFL or LED)
- ➢ Use heat generating appliances to the later time of the day.



Appendix 5A Overview of External Factors



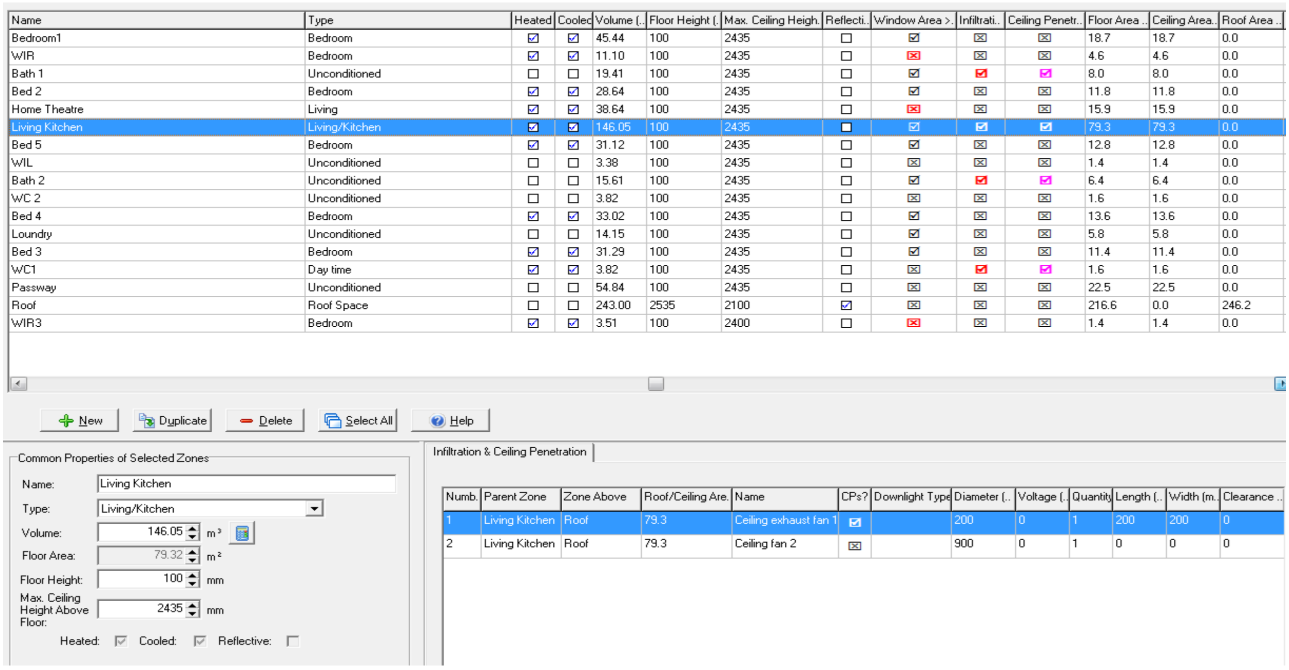


Appendix 6A Details of External Walls in the Sample Dwellings

HH	**External wall**	**Material**	**Thickness**	**Colour**		**Solar Absorption**	
				External	**Internal**	**External**	**Internal**
HH 1	Cavity Brick (Uninsulated + wet plaster)	Generic extruded clay brick (110 mm) Air Gap (40 mm) Generic extruded clay brick (110 mm) Plaster (cement: sand 1:4) (15 mm)	250 mm	Light	Light	30%	30%
HH 2	Cavity Brick (Uninsulated + wet plaster)	Generic extruded clay brick (110 mm) Air Gap (40 mm) Generic extruded clay brick (110 mm) Plaster (cement: sand 1:4) (15 mm)	250 mm	Medium	Light	50%	30%
HH3	Cavity Brick (Uninsulated + wet plaster)	Generic extruded clay brick (110 mm) Air Gap (40 mm) Generic extruded clay brick (110 mm) Plaster (cement: sand 1:4) (15 mm)	250 mm	Medium	Light	50%	30%
HH4	Cavity Brick (Uninsulated + wet plaster)	Generic extruded clay brick (90 mm), (110 mm) Air Gap (40 mm) Generic extruded clay brick (90 mm), (110 mm) Plaster (cement: sand 1:4) (15 mm)	230 mm, 250 mm	Light	Light	30%	30%
HH5	Brick Veneer (Uninsulated) Cavity Brick (insulated R1.3 + wet plaster)	Generic extrude clay brick (110 mm) Generic extruded clay brick (90 mm), (110 mm) Air Gap (40 mm) Rockwool batt: R 1.3 Generic extruded clay brick (90 mm), (110 mm) Plaster (cement: sand 1:4) (15 mm)	110 mm 230 mm, 250 mm	Light	Light	30%	30%
HH6	Brick Veneer (Uninsulated) Cavity Brick (insulated R1.3 + wet plaster)	Generic extrude clay brick (110 mm) Generic extruded clay brick (90 mm), (110 mm) Air Gap (40 mm) Rockwool batt: R 1.3 Generic extruded clay brick (90 mm), (110 mm) Plaster (cement: sand 1:4) (15 mm)	110 mm 230 mm, 250 mm	Light	Light	30%	30%
HH7	Cavity Brick	Generic extruded clay brick (110 mm)	230 mm, 250 mm	Light	Light	30%	30%

	(insulated R1.3 + wet plaster)	Air Gap (40 mm) Rockwool batt: R 1.0 Generic extruded clay brick (110 mm) Plaster (cement: sand 1:4) (15 mm)					
HH8	Cavity Brick (Uninsulated + wet plaster)	Generic extruded clay brick (110 mm) Air Gap (40 mm) Generic extruded clay brick (110 mm) Plaster (cement: sand 1:4) (15 mm)	250 mm	Light	Light	30%	30%

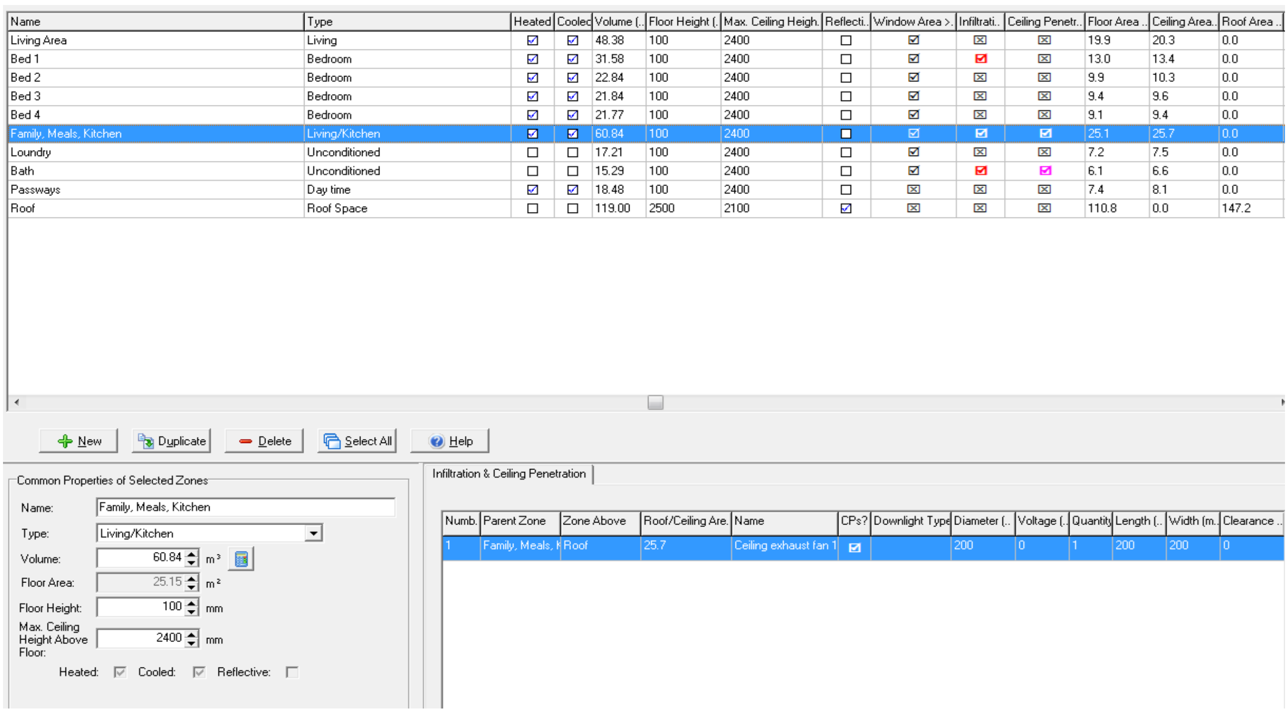
Appendix 6B Defined Zones in the Sample Households



Name	Type	Heated	Cooled	Volume (..	Floor Height (.	Max. Ceiling Heigh.	Reflecti..	Window Area >.	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bedroom1	Bedroom	☑	☑	45.44	100	2435	☐	☑	☒	☒	18.7	18.7	0.0
WIR	Bedroom	☑	☑	11.10	100	2435	☐	☒	☒	☒	4.6	4.6	0.0
Bath 1	Unconditioned	☐	☐	19.41	100	2435	☐	☑	☑	☑	8.0	8.0	0.0
Bed 2	Bedroom	☑	☑	28.64	100	2435	☐	☑	☒	☒	11.8	11.8	0.0
Home Theatre	Living	☑	☑	38.64	100	2435	☐	☒	☒	☒	15.9	15.9	0.0
Living Kitchen	Living/Kitchen	☑	☑	146.05	100	2435	☐	☑	☑	☑	79.3	79.3	0.0
Bed 5	Bedroom	☑	☑	31.12	100	2435	☐	☑	☒	☒	12.8	12.8	0.0
WIL	Unconditioned	☐	☐	3.38	100	2435	☐	☒	☒	☒	1.4	1.4	0.0
Bath 2	Unconditioned	☐	☐	15.61	100	2435	☐	☑	☑	☑	6.4	6.4	0.0
WC 2	Unconditioned	☐	☐	3.82	100	2435	☐	☒	☒	☒	1.6	1.6	0.0
Bed 4	Bedroom	☑	☑	33.02	100	2435	☐	☑	☒	☒	13.6	13.6	0.0
Loundry	Unconditioned	☐	☐	14.15	100	2435	☐	☑	☒	☒	5.8	5.8	0.0
Bed 3	Bedroom	☑	☑	31.29	100	2435	☐	☑	☒	☒	11.4	11.4	0.0
WC1	Day time	☑	☑	3.82	100	2435	☐	☒	☑	☑	1.6	1.6	0.0
Passway	Unconditioned	☐	☐	54.84	100	2435	☐	☒	☒	☒	22.5	22.5	0.0
Roof	Roof Space	☐	☐	243.00	2535	2100	☑	☒	☒	☒	216.6	0.0	246.2
WIR3	Bedroom	☑	☑	3.51	100	2400	☐	☒	☒	☒	1.4	1.4	0.0

Numb.	Parent Zone	Zone Above	Roof/Ceiling Are.	Name	CPs?	Downlight Type	Diameter (..	Voltage (..	Quantity	Length (..	Width (m..	Clearance ..
1	Living Kitchen	Roof	79.3	Ceiling exhaust fan 1	☑		200	0	1	200	200	0
2	Living Kitchen	Roof	79.3	Ceiling fan 2	☒		900	0	1	0	0	0

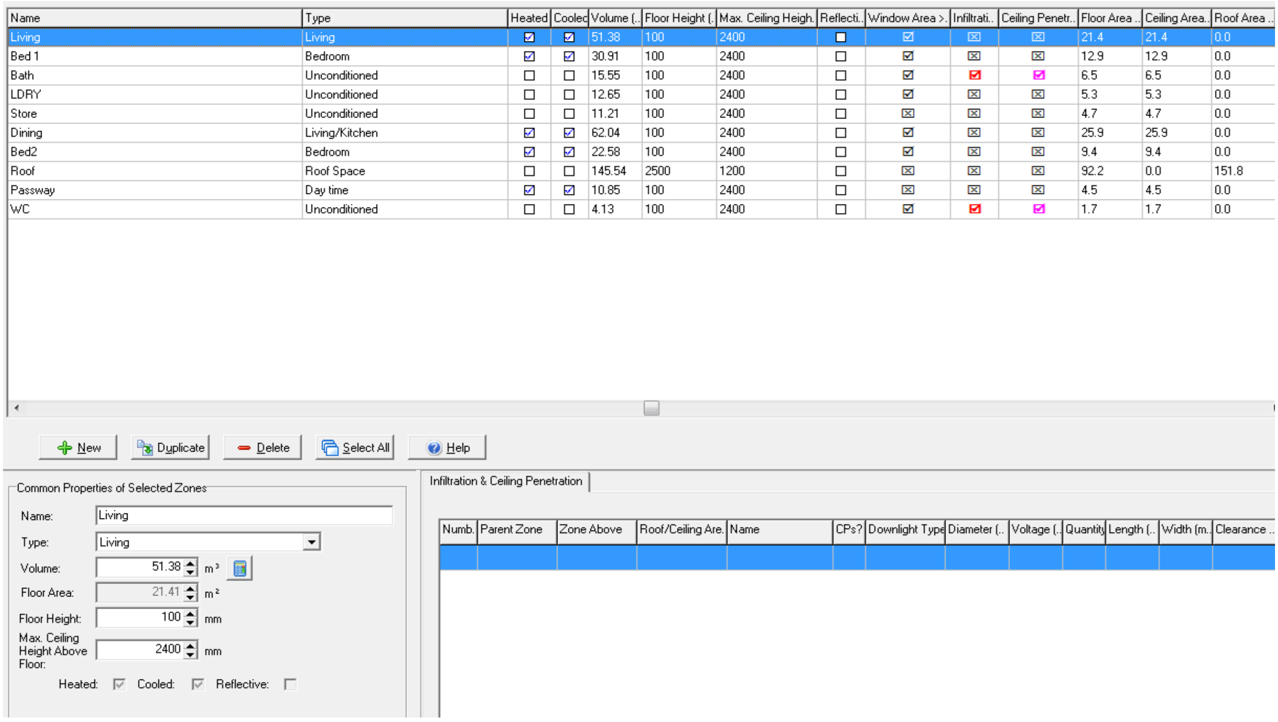
Different zones in the household 1



Name	Type	Heated	Cooled	Volume (..	Floor Height (.	Max. Ceiling Heigh.	Reflecti..	Window Area >.	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Living Area	Living	☑	☑	48.38	100	2400	☐	☑	☒	☒	19.9	20.3	0.0
Bed 1	Bedroom	☑	☑	31.58	100	2400	☐	☑	☑	☒	13.0	13.4	0.0
Bed 2	Bedroom	☑	☑	22.84	100	2400	☐	☑	☒	☒	9.9	10.3	0.0
Bed 3	Bedroom	☑	☑	21.84	100	2400	☐	☑	☒	☒	9.4	9.6	0.0
Bed 4	Bedroom	☑	☑	21.77	100	2400	☐	☑	☒	☒	9.1	9.4	0.0
Family, Meals, Kitchen	Living/Kitchen	☑	☑	60.84	100	2400	☐	☑	☑	☑	25.1	25.7	0.0
Loundry	Unconditioned	☐	☐	17.21	100	2400	☐	☑	☒	☒	7.2	7.5	0.0
Bath	Unconditioned	☐	☐	15.29	100	2400	☐	☑	☑	☑	6.1	6.6	0.0
Passways	Day time	☑	☑	18.48	100	2400	☐	☒	☒	☒	7.4	8.1	0.0
Roof	Roof Space	☐	☐	119.00	2500	2100	☑	☒	☒	☒	110.8	0.0	147.2

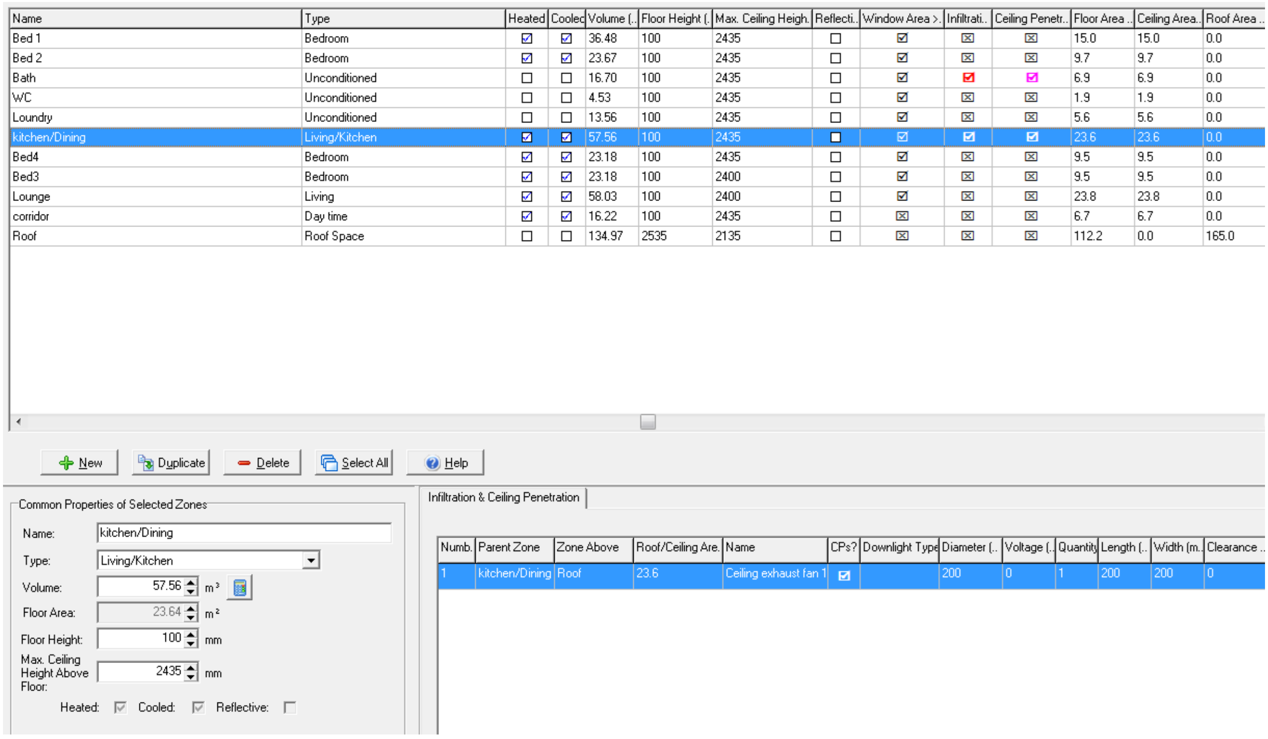
Numb.	Parent Zone	Zone Above	Roof/Ceiling Are.	Name	CPs?	Downlight Type	Diameter (..	Voltage (..	Quantity	Length (..	Width (m..	Clearance ..
1	Family, Meals, K	Roof	25.7	Ceiling exhaust fan 1	☑		200	0	1	200	200	0

Different zones in the household 2



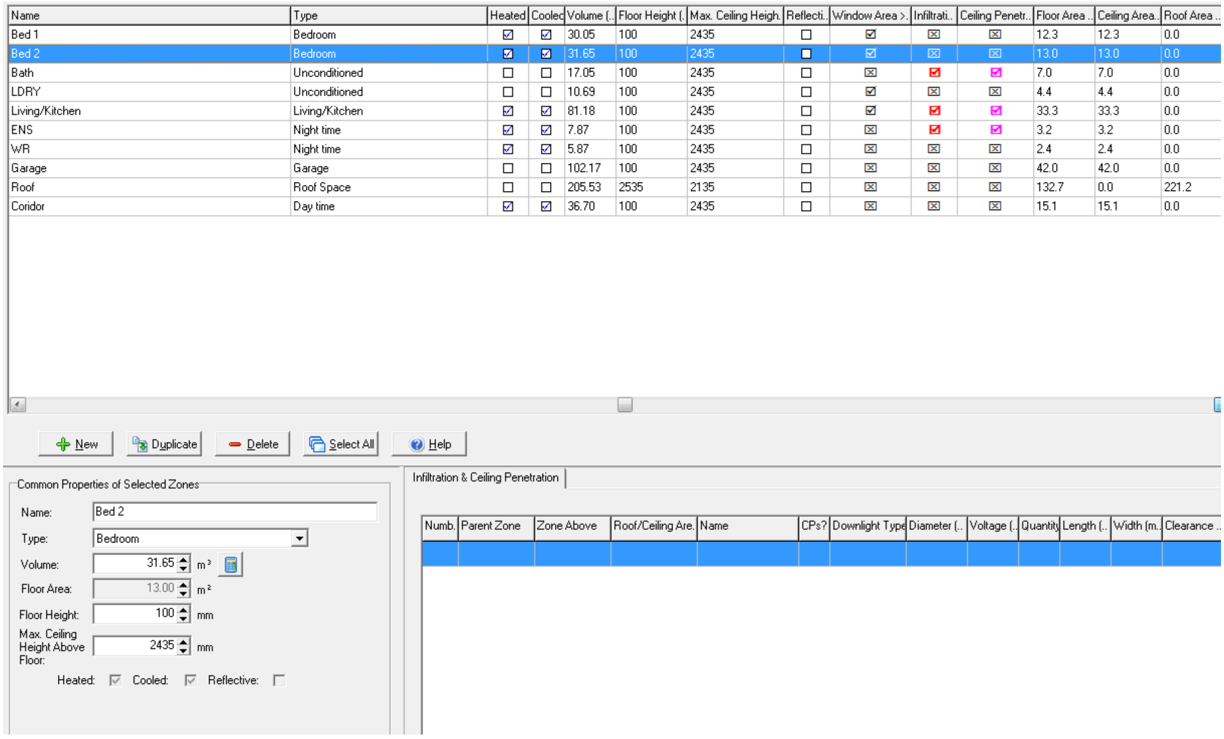
Name	Type	Heated	Cooled	Volume (..	Floor Height (..	Max. Ceiling Heigh..	Reflecti..	Window Area >..	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Living	Living	☑	☑	51.38	100	2400	☐	☑	☒	☒	21.4	21.4	0.0
Bed 1	Bedroom	☑	☑	30.91	100	2400	☐	☑	☒	☒	12.9	12.9	0.0
Bath	Unconditioned	☐	☐	15.55	100	2400	☐	☑	☑	☑	6.5	6.5	0.0
LDRY	Unconditioned	☐	☐	12.65	100	2400	☐	☑	☒	☒	5.3	5.3	0.0
Store	Unconditioned	☐	☐	11.21	100	2400	☐	☒	☒	☒	4.7	4.7	0.0
Dining	Living/Kitchen	☑	☑	62.04	100	2400	☐	☑	☒	☒	25.9	25.9	0.0
Bed2	Bedroom	☑	☑	22.58	100	2400	☐	☑	☒	☒	9.4	9.4	0.0
Roof	Roof Space	☐	☐	145.54	2500	1200	☐	☒	☒	☒	92.2	0.0	151.8
Passway	Day time	☑	☑	10.85	100	2400	☐	☒	☒	☒	4.5	4.5	0.0
WC	Unconditioned	☐	☐	4.13	100	2400	☐	☑	☑	☑	1.7	1.7	0.0

Different zones in the household 3



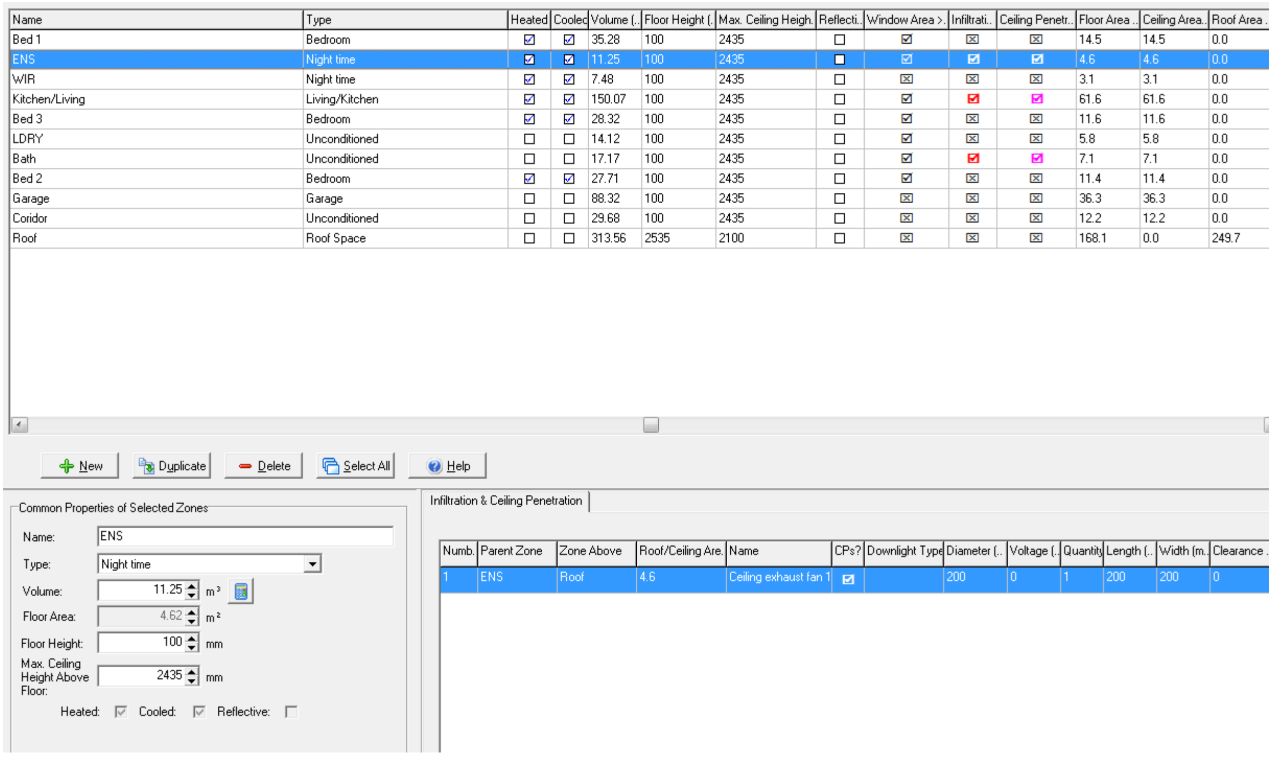
Name	Type	Heated	Cooled	Volume (..	Floor Height (..	Max. Ceiling Heigh..	Reflecti..	Window Area >..	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bed 1	Bedroom	☑	☑	36.48	100	2435	☐	☑	☒	☒	15.0	15.0	0.0
Bed 2	Bedroom	☑	☑	23.67	100	2435	☐	☑	☒	☒	9.7	9.7	0.0
Bath	Unconditioned	☐	☐	16.70	100	2435	☐	☑	☑	☑	6.9	6.9	0.0
WC	Unconditioned	☐	☐	4.53	100	2435	☐	☑	☒	☒	1.9	1.9	0.0
Loundry	Unconditioned	☐	☐	13.56	100	2435	☐	☑	☒	☒	5.6	5.6	0.0
kitchen/Dining	Living/Kitchen	☑	☑	57.56	100	2435	☐	☑	☑	☑	23.6	23.6	0.0
Bed4	Bedroom	☑	☑	23.18	100	2435	☐	☑	☒	☒	9.5	9.5	0.0
Bed3	Bedroom	☑	☑	23.18	100	2400	☐	☑	☒	☒	9.5	9.5	0.0
Lounge	Living	☑	☑	58.03	100	2400	☐	☑	☒	☒	23.8	23.8	0.0
corridor	Day time	☑	☑	16.22	100	2435	☐	☒	☒	☒	6.7	6.7	0.0
Roof	Roof Space	☐	☐	134.97	2535	2135	☐	☒	☒	☒	112.2	0.0	165.0

Different zones in the household 4



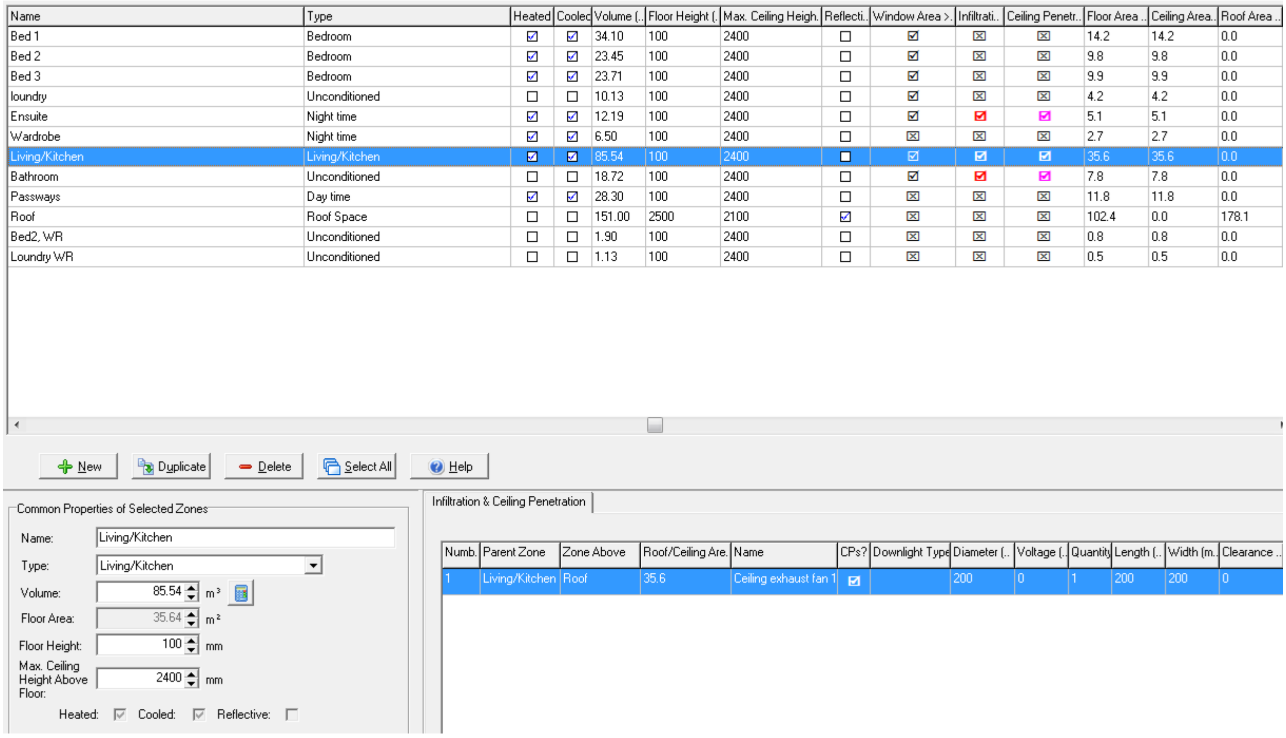
Name	Type	Heated	Cooled	Volume (..	Floor Height (.	Max. Ceiling Heigh.	Reflecti..	Window Area >.	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bed 1	Bedroom	☑	☑	30.05	100	2435	☐	☑	☒	☒	12.3	12.3	0.0
Bed 2	Bedroom	☑	☑	31.65	100	2435	☐	☑	☒	☒	13.0	13.0	0.0
Bath	Unconditioned	☐	☐	17.05	100	2435	☐	☒	☑	☑	7.0	7.0	0.0
LDRY	Unconditioned	☐	☐	10.69	100	2435	☐	☑	☒	☒	4.4	4.4	0.0
Living/Kitchen	Living/Kitchen	☑	☑	81.18	100	2435	☐	☑	☑	☑	33.3	33.3	0.0
ENS	Night time	☑	☑	7.87	100	2435	☐	☒	☑	☑	3.2	3.2	0.0
WR	Night time	☑	☑	5.87	100	2435	☐	☒	☒	☒	2.4	2.4	0.0
Garage	Garage	☐	☐	102.17	100	2435	☐	☒	☒	☒	42.0	42.0	0.0
Roof	Roof Space	☐	☐	205.53	2535	2135	☐	☒	☒	☒	132.7	0.0	221.2
Coridor	Day time	☑	☑	36.70	100	2435	☐	☒	☒	☒	15.1	15.1	0.0

Different zones in the household 5



Name	Type	Heated	Cooled	Volume (..	Floor Height (.	Max. Ceiling Heigh.	Reflecti..	Window Area >.	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bed 1	Bedroom	☑	☑	35.28	100	2435	☐	☑	☒	☒	14.5	14.5	0.0
ENS	Night time	☑	☑	11.25	100	2435	☐	☑	☑	☑	4.6	4.6	0.0
WIR	Night time	☑	☑	7.48	100	2435	☐	☒	☒	☒	3.1	3.1	0.0
Kitchen/Living	Living/Kitchen	☑	☑	150.07	100	2435	☐	☑	☑	☑	61.6	61.6	0.0
Bed 3	Bedroom	☑	☑	28.32	100	2435	☐	☑	☒	☒	11.6	11.6	0.0
LDRY	Unconditioned	☐	☐	14.12	100	2435	☐	☑	☒	☒	5.8	5.8	0.0
Bath	Unconditioned	☐	☐	17.17	100	2435	☐	☑	☑	☑	7.1	7.1	0.0
Bed 2	Bedroom	☑	☑	27.71	100	2435	☐	☑	☒	☒	11.4	11.4	0.0
Garage	Garage	☐	☐	88.32	100	2435	☐	☒	☒	☒	36.3	36.3	0.0
Coridor	Unconditioned	☐	☐	29.68	100	2435	☐	☒	☒	☒	12.2	12.2	0.0
Roof	Roof Space	☐	☐	313.56	2535	2100	☐	☒	☒	☒	168.1	0.0	249.7

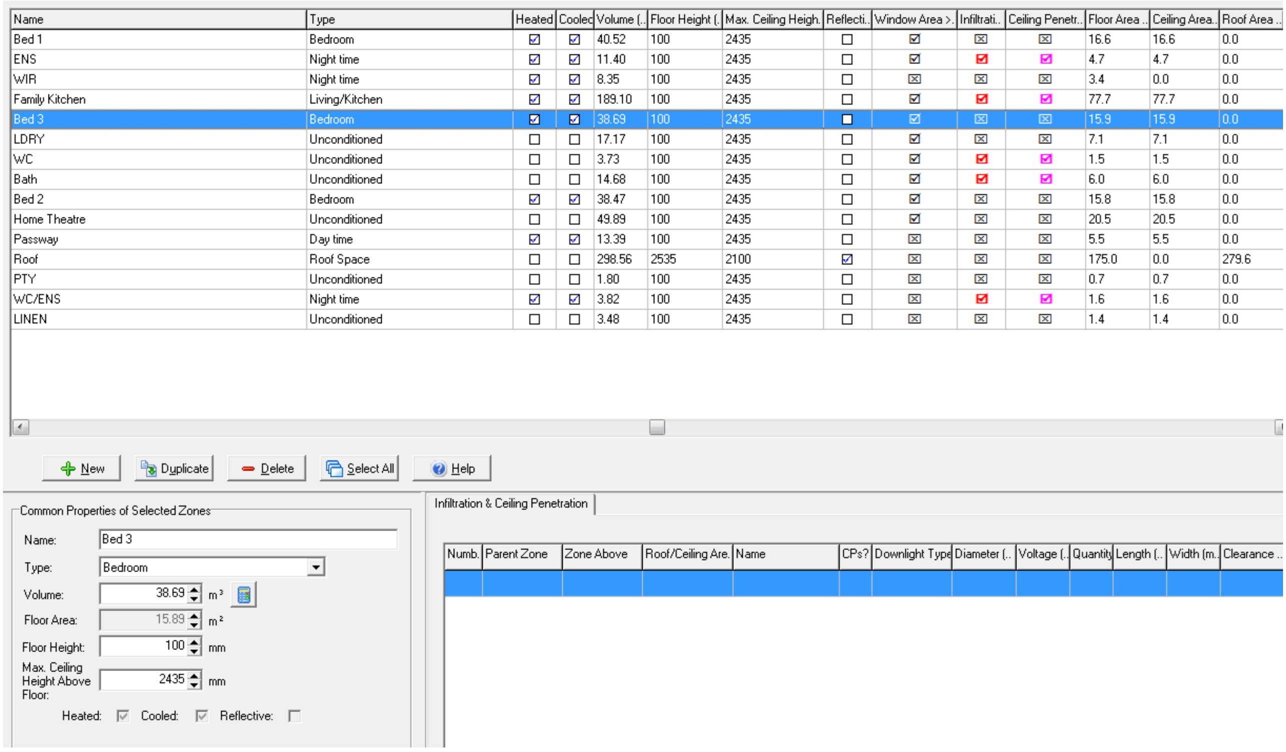
Different zones in the household 6



Name	Type	Heated	Cooled	Volume (..	Floor Height (..	Max. Ceiling Heigh..	Reflecti..	Window Area >..	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bed 1	Bedroom	☑	☑	34.10	100	2400	☐	☑	☒	☒	14.2	14.2	0.0
Bed 2	Bedroom	☑	☑	23.45	100	2400	☐	☑	☒	☒	9.8	9.8	0.0
Bed 3	Bedroom	☑	☑	23.71	100	2400	☐	☑	☒	☒	9.9	9.9	0.0
loundry	Unconditioned	☐	☐	10.13	100	2400	☐	☑	☒	☒	4.2	4.2	0.0
Ensuite	Night time	☑	☑	12.19	100	2400	☐	☑	☑	☑	5.1	5.1	0.0
Wardrobe	Night time	☑	☑	6.50	100	2400	☐	☒	☒	☒	2.7	2.7	0.0
Living/Kitchen	Living/Kitchen	☑	☑	85.54	100	2400	☐	☑	☑	☑	35.6	35.6	0.0
Bathroom	Unconditioned	☐	☐	18.72	100	2400	☐	☑	☑	☑	7.8	7.8	0.0
Passways	Day time	☑	☑	28.30	100	2400	☐	☒	☒	☒	11.8	11.8	0.0
Roof	Roof Space	☐	☐	151.00	2500	2100	☑	☒	☒	☒	102.4	0.0	178.1
Bed2, WR	Unconditioned	☐	☐	1.90	100	2400	☐	☒	☒	☒	0.8	0.8	0.0
Loundry WR	Unconditioned	☐	☐	1.13	100	2400	☐	☒	☒	☒	0.5	0.5	0.0

Numb.	Parent Zone	Zone Above	Roof/Ceiling Are.	Name	CPs?	Downlight Type	Diameter (..	Voltage (..	Quantity	Length (..	Width (m..	Clearance ..
1	Living/Kitchen	Roof	35.6	Ceiling exhaust fan 1	☑		200	0	1	200	200	0

Different zones in the household 7



Name	Type	Heated	Cooled	Volume (..	Floor Height (..	Max. Ceiling Heigh..	Reflecti..	Window Area >..	Infiltrati..	Ceiling Penetr..	Floor Area ..	Ceiling Area..	Roof Area ..
Bed 1	Bedroom	☑	☑	40.52	100	2435	☐	☑	☒	☒	16.6	16.6	0.0
ENS	Night time	☑	☑	11.40	100	2435	☐	☑	☑	☑	4.7	4.7	0.0
WIR	Night time	☑	☑	8.35	100	2435	☐	☒	☒	☒	3.4	0.0	0.0
Family Kitchen	Living/Kitchen	☑	☑	189.10	100	2435	☐	☑	☑	☑	77.7	77.7	0.0
Bed 3	Bedroom	☑	☑	38.69	100	2435	☐	☑	☒	☒	15.9	15.9	0.0
LDRY	Unconditioned	☐	☐	17.17	100	2435	☐	☑	☒	☒	7.1	7.1	0.0
WC	Unconditioned	☐	☐	3.73	100	2435	☐	☑	☑	☑	1.5	1.5	0.0
Bath	Unconditioned	☐	☐	14.68	100	2435	☐	☑	☑	☑	6.0	6.0	0.0
Bed 2	Bedroom	☑	☑	38.47	100	2435	☐	☑	☒	☒	15.8	15.8	0.0
Home Theatre	Unconditioned	☐	☐	49.89	100	2435	☐	☑	☒	☒	20.5	20.5	0.0
Passway	Day time	☑	☑	13.39	100	2435	☐	☒	☒	☒	5.5	5.5	0.0
Roof	Roof Space	☐	☐	298.56	2535	2100	☑	☒	☒	☒	175.0	0.0	279.6
PTY	Unconditioned	☐	☐	1.80	100	2435	☐	☒	☒	☒	0.7	0.7	0.0
WC/ENS	Night time	☑	☑	3.82	100	2435	☐	☒	☑	☑	1.6	1.6	0.0
LINEN	Unconditioned	☐	☐	3.48	100	2435	☐	☒	☒	☒	1.4	1.4	0.0

Different zones in the household 12

Appendix 6C IHGs in Sample Households

HH1- Zone 1: Bedroom1					
Hour	Sensible			Latent	No. of people
	Light Power	People heat	Total		
1	0	70	70	35	1
2	0	70	70	35	1
3	0	70	70	35	1
4	0	70	70	35	1
5	0	70	70	35	1
6	0	140	140	70	2
7	15	140	155	70	2
8	0	70	70	35	1
9	0	70	70	35	1
10	0	70	70	35	1
11	0	70	70	35	1
12	0	70	70	35	1
13	0	70	70	35	1
14	0	70	70	35	1
15	0	70	70	35	1
16	0	70	70	35	1
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	15	70	85	35	1
23	0	70	70	35	1
24	0	70	70	35	1
Total	30	1470	1500	735	
%	**1.3%**	**65.8%**	**-**	**32.9%**	

HH1- Zone 4: Bedroom 2					
Hour	Sensible			Latent	Number of People
	Light Power	People heat	Total		
1	0	70	70	35	1
2	0	70	70	35	1
3	0	70	70	35	1
4	0	70	70	35	1
5	0	70	70	35	1
6	0	70	70	35	1
7	0	70	70	35	1
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	70	70	35	1
17	0	0	0	0	0
18	0	70	70	35	1
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	15	70	85	35	1
23	0	70	70	35	1
24	0	70	70	35	1
Total	15	840	855	420	
%	**1.2%**	**65.9%**	**-**	**32.9%**	

HH1- Zone 5: Living						
Hour	Sensible				Latent	Number of People
	Applinces and Cooking	Light Power	People heat	Total		
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	70	70	45	1
11	0	0	70	70	45	1
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	108	0	280	388	180	4
17	108	0	280	388	180	4
18	108	30	280	418	180	4
19	108	30	280	418	180	4
20	108	30	210	348	135	3
21	108	30	280	418	180	4
22	108	30	140	278	90	2
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Total	756	150	1890	2796	1215	
%	**18.8%**	**3.7%**	**47.1%**	**-**	**30.3%**	

HH1- Zone 6: Living/Kitchen						
Hour	Sensible				Latent	Number of occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	0	0	150	0	0
7	191	0	150	341	110	2
8	150	0	300	450	220	4
9	150	0	75	225	55	1
10	150	0	75	225	55	1
11	150	0	75	225	55	1
12	150	0	0	150	0	0
13	2231	0	0	2231	0	0
14	150	0	0	150	0	0
15	150	0	0	150	0	0
16	708	0	300	1008	220	4
17	150	0	225	375	165	3
18	150	30	450	630	330	6
19	150	30	75	255	55	1
20	150	0	0	150	0	0
21	150	0	0	150	0	0
22	150	0	0	150	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	6280	60	1725	8065	1265	
%	**67.3%**	**0.6%**	**18.5%**	-	**13.5%**	

HH1- Zone 7: Bedroom 5						
Hour	Sensible				Latent	Number of People
	Applainces	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	0	70	70	35	1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	180	0	0	180	0	0
17	180	0	70	250	35	1
18	180	30	70	280	35	1
19	180	30	70	280	35	1
20	180	30	70	280	35	1
21	180	30	70	280	35	1
22	180	30	70	280	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	1260	150	1050	2460	525	
%	**42.2%**	**5.0%**	**35.2%**		**17.6%**	

HH1- Zone 11: Bedroom 4					
Hour	Sensible			Latent	Number of People
	Light Power	People heat	Total		
1	0	140	140	70	2
2	0	140	140	70	2
3	0	140	140	70	2
4	0	140	140	70	2
5	0	140	140	70	2
6	0	140	140	70	2
7	0	140	140	70	2
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	30	70	100	35	1
21	30	70	100	35	1
22	7.5	140	147.5	70	2
23	0	140	140	70	2
24	0	140	140	70	2
Total	67.5	1540	1607.5	770	
%	**2.8%**	**64.8%**	-	**32.4%**	

HH1- Zone 13: Bedroom 3					
Hour	Sensible			Latent	Number of People
	Light Power	People heat	Total		
1	0	140	140	70	2
2	0	140	140	70	2
3	0	140	140	70	2
4	0	140	140	70	2
5	0	140	140	70	2
6	0	140	140	70	2
7	0	140	140	70	2
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	70	70	35	1
17	0	70	70	35	1
18	0	0	0	0	0
19	0	0	0	0	0
20	30	70	100	35	1
21	30	70	100	35	1
22	30	140	170	70	2
23	0	140	140	70	2
24	0	140	140	70	2
Total	90	1680	1770	840	
%	**3.4%**	**64.4%**	**-**	**32.2%**	

HH2- Zone 1: Living					
Hour	Sensible		Total Sensible	Latent	Number of Occupants
	Light Power	People heat			
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	140	140	90	2
9	0	140	140	90	2
10	0	140	140	90	2
11	0	140	140	90	2
12	0	140	140	90	2
13	0	140	140	90	2
14	0	140	140	90	2
15	0	140	140	90	2
16	0	140	140	90	2
17	0	140	140	90	2
18	22.5	140	162.5	90	2
19	22.5	140	162.5	90	2
20	22.5	140	162.5	90	2
21	22.5	140	162.5	90	2
22	22.5	140	162.5	90	2
23	0	0	0	0	0
24	0	0	0	0	0
Total	112.5	2100	2212.5	1350	
%	**3.2%**	**58.9%**	**-**	**37.9%**	

HH2- Zone 2: Bedroom 1					
Hour	Sensible		Total Sensible	Latent	Number of Occupants
	Light Power	People heat			
1	0	140	140	70	2
2	0	140	140	70	2
3	0	140	140	70	2
4	0	140	140	70	2
5	0	140	140	70	2
6	0	140	140	70	2
7	0	140	140	70	2
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	22.5	140	162.5	70	2
24	0	140	140	70	2
Total	22.5	1260	1282.5	630	
%	**1.2%**	**65.9%**	**-**	**32.9%**	

HH2- Zone 3: Bedroom 2				
Hour	Sensible		Total Sensible	Latent
	Light Power	People heat		
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
Total	0	0	0	0
%	**0%**	**0%**	**0%**	**0%**

HH2- Zone 4: Bedroom3					
Hour	Sensible		Total Sensible	Latent	Number of Occupants
	Light Power	People heat			
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	22.5	70	92.5	35	1
12	22.5	70	92.5	35	1
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
Total	45	140	185	70	
%	**17.6%**	**54.9%**	-	**27.5%**	

HH2- Zone 5: Bedroom4				
Hour	Sensible		Total Sensible	Latent
	Light Power	People heat		
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
Total	0	0	0	0
%	**0%**	**0%**	**0%**	**0%**

HH2- Zone 6 : Living/Kitchen						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	0	0	150	0	0
7	150	0	0	150	0	0
8	217.5	0	0	217.5	0	0
9	150	0	0	150	0	0
10	150	0	0	150	0	0
11	300	0	0	300	0	0
12	150	0	0	150	0	0
13	150	0	0	150	0	0
14	150	0	0	150	0	0
15	150	0	0	150	0	0
16	150	0	0	150	0	0
17	150	0	0	150	0	0
18	150	0	0	150	0	0
19	354.5	45	0	399.5	0	0
20	150	45	75	270	55	1
21	150	45	75	270	55	1
22	150	0	0	150	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	4022.0	135	150	4307.0	110	
%	**91.1%**	**3.1%**	**3.4%**	**-**	**2.5%**	

HH3- Zone 1: Living						
Hour	Sensible			Total Sensible	Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat			
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	108	0	70	178	45	1
18	108	25	70	203	45	1
19	108	25	0	133	0	0
20	108	25	70	203	45	1
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Total	432	75	210	717	135	
%	**50.7%**	**8.8%**	**24.6%**	**-**	**15.9%**	

HH3- Zone 2: Bedroom1					
Hour	Sensible		Total Sensible	Latent	Number of Occupants
	Light Power	People heat			
1	0	70	70	35	1
2	0	70	70	35	1
3	0	70	70	35	1
4	0	70	70	35	1
5	0	70	70	35	1
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	6.9	70	76.9	35	1
23	0	70	70	35	1
24	0	70	70	35	1
Total	6.9	560.0	566.9	280.0	
%	**0.8%**	**66.1%**	**-**	**33.1%**	

HH3- Zone 6: Living/Kitchen						
Hour	Sensible			Total	Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat			
1	213	0	0	213	0	0
2	213	0	0	213	0	0
3	213	0	0	213	0	0
4	213	0	0	213	0	0
5	213	0	0	213	0	0
6	261.4	43	75	379.4	55	1
7	213	43	75	331	55	1
8	213	0	75	288	55	1
9	213	0	75	288	55	1
10	213	0	75	288	55	1
11	213	0	0	213	0	0
12	213	0	0	213	0	0
13	213	0	0	213	0	0
14	215.9	0	75	290.9	55	1
15	213	0	75	288	55	1
16	213	0	75	288	55	1
17	213	0	0	213	0	0
18	213	43	0	256	0	0
19	261.4	43	75	379.4	55	1
20	213	43	0	256	0	0
21	213	43	75	331	55	1
22	213	0	0	213	0	0
23	213	0	0	213	0	0
24	213	0	0	213	0	0
Total	5211.7	258	750	6220	550	
%	**77.0%**	**3.8%**	**11.1%**	**-**	**8.1%**	

HH3- Zone 7: Bedroom2				
Hour	Sensible		Total	Latent
	Light Power	People heat		
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
Total	0	0	0	0
%	**0%**	**0%**	**0%**	**0%**

HH4- Zone 1: Bedroom 1						
Hour	Sensible				Latent	Number of Occupant
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	108	13.8	70	191.8	35	1
11	108	13.8	70	191.8	35	1
12	108	13.8	70	191.8	35	1
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	108	0	0	108	0	0
17	108	0	0	108	0	0
18	108	13.8	0	121.8	0	0
19	108	13.8	0	121.8	0	0
20	108	13.8	70	191.8	35	1
21	108	13.8	70	191.8	35	1
22	108	13.8	70	191.8	35	1
23	108	13.8	70	191.8	35	1
24	0	0	70	70	35	1
Total	1188	123.75	980	2291.75	490	
%	**42.7%**	**4.4%**	**35.2%**	**-**	**17.6%**	

HH4- Zone 2: Bedroom 2						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	17.5	70	87.5	35	1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	17.5	70	87.5	35	1
17	0	17.5	0	17.5	0	0
18	0	17.5	70	87.5	35	1
19	0	17.5	70	87.5	35	1
20	0	17.5	70	87.5	35	1
21	0	17.5	70	87.5	35	1
22	0	17.5	70	87.5	35	1
23	0	17.5	70	87.5	35	1
24	0	0	70	70	35	1
Total	0	157.5	1050	1207.5	525	
%	**0.0%**	**9.1%**	**60.6%**	**-**	**30.3%**	

HH4- Zone 6: Living/Kitchen						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	0	0	150	0	0
7	226.7	18	75	319.7	55	1
8	150	18	75	243	55	1
9	150	0	0	150	0	0
10	150	0	0	150	0	0
11	150	0	0	150	0	0
12	1220.8	0	0	1220.8	0	0
13	150	0	0	150	0	0
14	150	0	0	150	0	0
15	154.4	0	0	154.4	0	0
16	150	0	75	225	55	1
17	150	0	150	300	110	2
18	184.7	0	0	184.7	0	0
19	150	0	0	150	0	0
20	154.4	18	0	172.4	0	0
21	150	18	0	168	0	0
22	150	18	0	168	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	4791.0	90	375	5256.0	275	
%	**86.6%**	**1.6%**	**6.8%**	**-**	**5.0%**	

HH4- Zone 8: Bedroom 3					
Hour	Sensible			Latent	Number of Occupants
	Light Power	People heat	Total		
1	0	70	70	35	1
2	0	70	70	35	1
3	0	70	70	35	1
4	0	70	70	35	1
5	0	70	70	35	1
6	0	70	70	35	1
7	0	70	70	35	1
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	17.5	70	87.5	35	1
23	17.5	70	87.5	35	1
24	0	70	70	35	1
Total	35	700	735	350	
%	**3.2%**	**64.5%**	**-**	**32.3%**	

HH4- Zone 7: Bedroom 4						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	25	0	70	95	35	1
2	25	0	70	95	35	1
3	25	0	70	95	35	1
4	25	0	70	95	35	1
5	25	0	70	95	35	1
6	25	0	70	95	35	1
7	25	17.5	70	112.5	35	1
8	25	0	0	25	0	0
9	25	0	0	25	0	0
10	25	0	0	25	0	0
11	25	0	0	25	0	0
12	25	0	0	25	0	0
13	25	0	0	25	0	0
14	25	0	0	25	0	0
15	25	0	0	25	0	0
16	288	0	140	428	70	2
17	288	17.5	140	445.5	70	2
18	288	17.5	140	445.5	70	2
19	288	17.5	140	445.5	70	2
20	288	17.5	140	445.5	70	2
21	288	17.5	140	445.5	70	2
22	25	17.5	70	112.5	35	1
23	25	0	70	95	35	1
24	25	0	70	95	35	1
Total	2178	122.5	1540	3840.5	770	
%	**47.2%**	**2.7%**	**33.4%**	-	**16.7%**	

HH4- Zone 9: Living						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	108	0	70	178	45	1
16	108	0	70	178	45	1
17	108	0	70	178	45	1
18	108	0	70	178	45	1
19	0	13.8	0	13.8	0	0
20	0	13.8	0	13.8	0	0
21	0	13.8	0	13.8	0	0
22	0	13.8	0	13.8	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Total	432	55	280	767.0	180	4
%	**45.6%**	**5.8%**	**29.6%**	**-**	**19.0%**	

HH5- Zone 1: Bedroom 1						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	0	70	70	35	1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	25	70	95	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	0	25	700	725	350	
%	**0.0%**	**2.3%**	**65.1%**	**-**	**32.6%**	

HH5- Zone 2: Bed2						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	0	70	70	35	1
8	0	0	0	0	0	0
9	0	0	70	70	35	1
10	0	0	70	70	35	1
11	0	0	70	70	35	1
12	0	0	70	70	35	1
13	108	0	70	178	35	1
14	108	0	70	178	35	1
15	108	0	70	178	35	1
16	108	0	70	178	35	1
17	108	0	70	178	35	1
18	108	25	70	203	35	1
19	108	25	70	203	35	1
20	108	25	70	203	35	1
21	108	25	70	203	35	1
22	108	25	70	203	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	1080	125	1610	2815	805	
%	**29.8%**	**3.5%**	**44.5%**	**-**	**22.2%**	

HH5- Zone 6: Living/Kitchen						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	0	0	150	0	0
7	150	0	0	150	0	0
8	184.0	0	150	334	110	2
9	150	0	75	225	55	1
10	150	0	75	225	55	1
11	165.2	0	75	240.2	55	1
12	150	0	75	225	55	1
13	1190.5	0	75	1266	55	1
14	152.9	0	75	227.9	55	1
15	150	0	75	225	55	1
16	150	0	75	225	55	1
17	150	0	75	225	55	1
18	258	0	75	333	55	1
19	260.9	48	75	383.9	55	1
20	258	24	75	357	55	1
21	258	24	75	357	55	1
22	150	0	0	150	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	5127.5447	96	1125	6349	825	
%	**71.5%**	**1.3%**	**15.7%**	**-**	**11.5%**	

HH6- Zone 1: Bedroom 1						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	13.8	70	83.8	35	1
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	6.9	70	76.9	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	0	20.625	560	580.6	280	
%	**0.0%**	**2.4%**	**65.1%**	**-**	**32.5%**	

HH6- Zone 4: Living/Kitchen						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	18.75	75	243.8	55	1
7	154.4	18.75	75	248.2	55	1
8	150	0	0	150	0	0
9	150	0	0	150	0	0
10	150	0	0	150	0	0
11	150	0	0	150	0	0
12	150	0	0	150	0	0
13	150	0	0	150	0	0
14	150	0	0	150	0	0
15	150	0	0	150	0	0
16	150	0	0	150	0	0
17	180.3	18.8	150	349.1	110	2
18	150	18.8	75	243.8	55	1
19	850	32.5	75	957.5	55	1
20	150	32.5	75	257.5	55	1
21	150	32.5	75	257.5	55	1
22	150	0	0	150	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	4334.7	172.5	600	5107	440	
%	**78.1%**	**3.1%**	**10.8%**		**7.9%**	

HH6- Zone 5: Bedroom 3						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	13.8	70	83.8	35	1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	108	13.8	70	191.8	35	1
19	108	13.8	70	191.8	35	1
20	108	13.8	70	191.8	35	1
21	108	13.8	70	191.8	35	1
22	108	13.8	70	191.8	35	1
23	108	13.8	70	191.8	35	1
24	108	13.8	70	191.8	35	1
Total	756	110	980	1846	490	
%	**32.4%**	**4.7%**	**42.0%**	**-**	**21.0%**	

HH6- Zone 8: Bedroom 2					
Hour	Sensible			Latent	Number of Occupants
	Light Power	People heat	Total		
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
Total	0	0	0	0	0
%	**0%**	**0%**	**-**	**0%**	

HH7- Zone 1: Bedroom 1						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	4.7	70	74.7	35	1
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	18.8	70	88.8	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	0	23.438	490	513.4	245	
%	**0.0%**	**3.1%**	**64.6%**	**-**	**32.3%**	

HH7- Zone 2: Bedroom 2						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	0	13.8	70	83.8	35	1
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	108	13.75	70	191.8	35	1
20	108	13.75	70	191.8	35	1
21	108	13.75	70	191.8	35	1
22	0	13.75	70	83.8	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	324	68.8	910	1303	455	
%	**18.4%**	**3.9%**	**51.8%**	**-**	**25.9%**	

HH7- Zone 3: Bedroom 3					
Hour	Sensible			Latent	Number of Occupants
	Light Power	People heat	Total		
1	0	70	70	35	1
2	0	70	70	35	1
3	0	70	70	35	1
4	0	70	70	35	1
5	0	70	70	35	1
6	0	70	70	35	1
7	11.3	70	81.3	35	1
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	22.5	70	92.5	35	1
19	22.5	70	92.5	35	1
20	22.5	70	92.5	35	1
21	22.5	70	92.5	35	1
22	22.5	70	92.5	35	1
23	0	70	70	35	1
24	0	70	70	35	1
Total	123.8	980	1104	490	
%	**7.8%**	**61.5%**	**-**	**30.8%**	

HH7- Zone 7: Living/Kitchen						
	Sensible					
Hour	Applinces and Cooking	Light Power	People heat	Total	Latent	Number of Occupants
1	150	0	0	150	0	0
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	9.4	75	234.4	55	1
6	150	0	0	150	0	0
7	179.8	18.8	150	348.6	110	2
8	150	0	0	150	0	0
9	150	0	0	150	0	0
10	150	0	0	150	0	0
11	150	0	0	150	0	0
12	150	0	0	150	0	0
13	150	0	0	150	0	0
14	150	0	0	150	0	0
15	150	0	75	225	55	1
16	150	0	75	225	55	1
17	316.6	18.75	225	560.4	165	3
18	258	18.75	150	426.8	110	2
19	1386.5	18.75	75	1480	55	1
20	150	37.5	75	262.5	55	1
21	150	18.8	75	243.8	55	1
22	150	0	0	150	0	0
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	5140.9	140.6	975	6257	715	
%	**73.7%**	**2.0%**	**14.0%**	-	**10.3%**	

HH12- Zone 1: Bedroom 1						
	Sensible					
Hour	Appliances	Light Power	People heat	Total	Latent	Number of Occupants
1	0	0	280	280	140	4
2	0	0	280	280	140	4
3	0	0	280	280	140	4
4	0	0	280	280	140	4
5	0	0	210	210	105	3
6	0	0	210	210	105	3
7	0	22.5	210	232.5	105	3
8	0	0	70	70	35	1
9	0	0	70	70	35	1
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	11.25	0	11.25	0	0
23	0	0	280	280	140	4
24	0	0	280	280	140	4
Total	0	33.75	2450	2484	1225	
%	**0.0%**	**0.9%**	**66.1%**	-	**33.0%**	

HH12- Zone 4: Living/Kitchen						
	Sensible					
Hour	Applinces and Cooking	Light Power	People heat	Total	Latent	Number of Occupants
1	150	0	0	150	0	
2	150	0	0	150	0	0
3	150	0	0	150	0	0
4	150	0	0	150	0	0
5	150	0	0	150	0	0
6	150	0	0	150	0	0
7	150	0	0	150	0	0
8	179.8	0	225	404.8	165	3
9	150	0	150	300	110	2
10	258	0	150	408	110	2
11	258	0	150	408	110	2
12	2339	0	150	2489	110	2
13	150	0	150	300	110	2
14	150	0	150	300	110	2
15	258	0	150	408	110	2
16	258	0	300	558	220	4
17	258	22.5	300	580.5	220	4
18	1298.5	22.5	300	1621	220	4
19	154.4	22.5	300	476.9	220	4
20	150	45	375	570	275	5
21	150	45	300	495	220	4
22	150	45	300	495	220	4
23	150	0	0	150	0	0
24	150	0	0	150	0	0
Total	7511.7	202.5	3450	11164	2530	
%	**54.9%**	**1.4%**	**25.2%**	-	**18.5%**	

HH12- Zone 9: Bedroom 3						
Hour	Sensible				Latent	Number of Occupants
	Appliances	Light Power	People heat	Total		
1	0	0	70	70	35	1
2	0	0	70	70	35	1
3	0	0	70	70	35	1
4	0	0	70	70	35	1
5	0	0	70	70	35	1
6	0	0	70	70	35	1
7	70	22.5	70	162.5	35	1
8	70	22.5	0	92.5	0	0
9	70	0	0	70	0	0
10	70	0	0	70	0	0
11	70	0	0	70	0	0
12	70	0	0	70	0	0
13	70	0	0	70	0	0
14	70	0	0	70	0	0
15	70	0	0	70	0	0
16	70	0	70	140	35	1
17	70	0	70	140	35	1
18	70	22.5	70	162.5	35	1
19	70	22.5	70	162.5	35	1
20	70	22.5	0	92.5	0	0
21	70	22.5	70	162.5	35	1
22	70	22.5	70	162.5	35	1
23	0	0	70	70	35	1
24	0	0	70	70	35	1
Total	1120	157.5	1050	2328	525	
%	**39.3%**	**5.5%**	**36.8%**	**-**	**18.4%**	

HH12- Zone 5: Bed2					
Hour	Sensible			Latent	Number of Occupants
	Light Power	People heat	Total		
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	0	0	0
24	0	0	0	0	0
Total	0	0	0	0	0
%	**0%**	**0%**	**-**	**0%**	**0%**

HH12- Zone 10: Living						
Hour	Sensible				Latent	Number of Occupants
	Applinces and Cooking	Light Power	People heat	Total		
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Total	0	0	0	0	0	
%	**0%**	**0%**	**0%**	**-**	**0%**	