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CRC

RP1024: Informing the Next Generation Residential Energy Assessment Tools

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Disclaimer

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

Executive Summary

The Nationwide House Energy Rating Scheme, commonly known as NatHERS, which is applied through software tools such as AccuRate Sustainability, has become the predominant pathway for complying with energy efficiency requirements within the National Construction Code of Australia. Current energy efficiency regulations have remained unchanged for a decade and there is an intention to increase these requirements, through mandating a higher minimum star rating for buildings. Furthermore, existing energy efficiency regulations only cover the building envelope, through the energy needed for space heating and cooling, and not the energy efficiency of major appliances. In addition, current regulations do not incorporate sufficient quality assurance processes, in relation to compliance. Finally, the current regime is inconsistent with international best practice. This project aimed to review, analyse and recommend changes, in light of these issues.

Examination of measured energy for heating and cooling across a number of houses confirmed that a higher star rated home constitutes reduced energy needed for heating and cooling. This result confirms the potential for the scheme to reduce energy costs for heating and cooling, at least up to around 7.5-star homes. However, the study recommended that a number of changes to the assumptions used in AccuRate Sustainability, in relation to the building envelope, are needed to ensure continued robustness and to become consistent with international standards.

A whole-of-house energy assessment method was proposed, including major appliances and end-uses. It was found that greater opportunities exist to reduce whole-of-house energy consumption, through increasing energy efficiency requirements of appliances, in comparison to those in regarding the building shell. A novel method to include the impact of rooftop solar PV and battery technology was developed, based on assessed imported energy from the grid. Unlike international schemes, the proposed methodology will only value self-consumption through energy storage and demand management technologies.

In comparison to international schemes, Australia lags far behind. This is attributable to these schemes being used to encourage energy efficiency in housing, well beyond minimum performance standards. As a result, the robustness of the software tools, combined with a strong quality assurance process, adds value, which in turn the market supports. It is recommended that Australia follow this path, and that a process of continuous improvement be applied to the NatHERS software tools to enable it to be used in the design of energy efficient housing, and promotion, beyond minimum performance requirements. A compliance inspection process and associated metrics are also proposed, to ensure that houses perform to their designed specifications and capability.

The original context of NatHERS was to reduce greenhouse gas emissions. With the rapid transition to renewable energy underway in the Australian energy system, this context is no longer valid. It is recommended that a transition towards energy efficiency regulations that exist within a health and well-being assessment framework be set in motion. This framework would consider factors such as indoor air quality, together with enhancing thermal comfort and minimising household energy costs. Ultimately, this shift will enable the building industry to use these regulations and mechanisms to deliver improved householder amenity for future Australian homeowners.

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Acronyms and Abbreviations

Acronym / Abbreviation	Description
ABCB	Australian Building Codes Board
ABRD	Approved Building Reference Document
ABS	The Australian Bureau of Statistics
AC and A/C	Air Conditioner
AccuRate	One of the accredited NatHERS rating tools
AccuRate Sustainability	One of the accredited NatHERS rating tools, which can run in a non-rating (research) mode
ACH	Air Changes per Hour
ACH@50Pa	Air Changes per Hour at 50 Pascals
ACT	Australian Capital Territory
ACTHERS	ACT variation of NatHERS
Aecom	American multinational engineering firm
AGO	Australian Greenhouse Office
AIRAH	The Australian Institute of Refrigeration, Air conditioning and Heating
AMEC	Australian Minerals and Energy Council
AS/NZS	Australian Standard / New Zealand Standard
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
AusZEH	enhanced version of Accurate Sustainability
avg	average
Bath	Bathroom
BCA	Building Code of Australia
Bedarfsausweis	Demand Certificate (German context)
BERS Pro	Building Energy Rating Pro - One of the accredited NatHERS rating tools
BoM (and BOM)	Bureau of Meteorology
BR	Bayesian Regularization (machine learning algorithm)
Br	Bedroom
Bridged + R-Val. Deg'n	Thermally-bridged and R-Value Degradation
Bridged Only	only Thermally-bridged
BRRT	Building Regulation Review Taskforce
CFL	Compact Fluorescent Lamp (or Lightbulb)
Chenath	Primary engine of NatHERS
Clim. Change + Bridged + R-Val. Deg'n'	combined impact of climate-changed RMY file, thermal-bridging and R-value degradation
Clim. Change Only	only climate-changed RMY file
COAG	Council of Australian Governments
COP	Coefficient of Performance
CSIRO	Commonwealth Scientific and Industrial Research Organisation
dB(A)	decibels (A-weighted)
DBT	Dry Bulb Temperature
DEWHA	The Department of the Environment, Water, Heritage and the Arts
DG	Double Glazed
DTS	Deemed to Satisfy
EER	Energy Efficiency Ratio
EGH	Ener-Guide House
EGNH	Ener-Guide New House
EN15251	The European standard EN15251
Energieausweis	Energy Certificate (German context)
EnergyPlus	whole building energy simulation program
EnEV	Energy Saving Ordinance
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	Europe
Ext.	External
FirstRate 5	One of the accredited NatHERS rating tools
GEMS	Greenhouse and Energy Minimum Standards
GHG	greenhouse gas

GJ	Giga Joule (1x10^9 Joules)
H/C (and H&C)	Heating and Cooling
HEGIRS	House Electrical Grid Impact Rating Scheme
HERS	Home Energy Rating Scheme (American context)
HVAC	Heating Ventilation and Air Conditioning
IEA BESTEST	International Energy Agency Building Energy Simulation Test and Diagnostic Method
IECC	The International Energy Conservation Code
incl.	including
Inst.	Instantaneous
Insul.	Insulation
Int.	Internal
IQR	Installation Quality Rating
ISO	The International Organization for Standardization
KfW Efficiency House	House eligible for bank KfW Bankengruppe loan
Kit/liv	Kitchen / Living
kJ	Kilo Joule (1x10^3 Joules)
LED	Light Emitting Diode
LM	Levenberg-Marquardt (machine learning algorithm)
Low-E	Low Emissivity
LP	Lochiel Park
LPG	Liquified (or Liquid) Petroleum Gas
MATLAB	Software environment for engineers and scientists
max.	maximum
Mech. Vent.	Mechanical Ventilation
MEPS	Minimum Energy Performance Standard
min.	minimum
MJ	Mega Joule (1x10^6 Joules)
ML	Mawson Lakes
MNECB	Model National Energy Code of Canada
MNECH	Model National Energy Code for Houses
NatHERS	Nationwide House Energy Rating Scheme
NCC	National Construction Code
NCCARF	The National Climate Change Adaptation Research Facility
NEM	National Electricity Market
NFRC	National Fenestration Rating Council
NGA	National Greenhouse Accounts
NHER	National Home Energy Rating Scale
NRCan	Natural Resources Canada
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development
OEE	Office of Energy Efficiency
Pa	Pascal (unit of pressure)
Passivhaus	globally recognized ultra-efficient building system developed in Germany
PDF	Portable Document Format
PE	Purchased Energy
PMV	Predicted Mean Vote
PMV-PPD	Predicted Mean Vote-Predicted Percentage Dissatisfied
PPD	Predicted Percentage Dissatisfied
PV	Photo-voltaic
QLD	Queensland
RBEES	Residential Building Energy Efficiency Study
RCAC	Reverse-Cycle Air-Conditioner
RdSAP	Reduced Data version of SAP
RESNET	Residential Energy Services Network
RMY	Reference Meteorological Year
R-Val. Deg'n Only	only R-Value Degradation
SA	South Australia
SAP	Standard Assessment Procedure
SCG	Scaled Conjugate Gradient (machine learning algorithm)

SET*	Standard Effective Temperature
SG	Single Glazed
SHGC	Solar Heat Gain Coefficient
SHW	Proportion of water heating energy saved by using solar hot water system
SOC	State of Charge (energy storage context)
SST	Summer Set point Temperature
STC	Small-scale Technology Certificate
TRNSYS	Transient Systems Simulation Program
TSR	Total Solar Reflectance
TV	Television
UK	United Kingdom
Unadj.	unadjusted
uPVC	Unplasticised Polyvinyl Chloride
URL	Uniform Resource Locator
Verbrauchsausweis	Usage Certificate (German context)
VIC	Victoria
WCED	World Commission on Environment and Development
WERS	Window Energy Rating Scheme
WHO	The World Health Organization
WUFI	Wärme Und Feuchte Instationär

List of Symbols

Symbol	Description	SI Units
A_c	solar collector area	m^2
ASR	absorbed solar radiation	W/m^2
a_r	fraction (Q_e) of return duct air that does not leak out of duct to exterior	
a_s	fraction (Q_e) of supply duct air that does not leak out of duct to exterior	
B_r	return conduction fraction	
B_s	supply conduction fraction	
CO_2	carbon dioxide	
CO_2-e	carbon dioxide equivalent (impact that creates same amount of warming)	
COP_{rated}	rated COP	
DE	delivery efficiency of ducted cooling system	
$E_{cooling}$	cooling energy	
EER_{rated}	rated EER	
$E_{heating}$	heating energy	
E_{la}	lighting (and some appliance) energy	
$E_{n,cap}$	Dedicated cooling capacity to zone n	kW
$E_{produced}$	energy produced	
E_{used}	energy used	
E_{wh}	water heating energy	
$h_{amb,r}$	enthalpy of air surrounding return ducts	J/kg
h_{in}	enthalpy of indoor air entering return register	J/kg
K_{inclin}	collector non-ideal orientation factor	
K_s	system solar factor	
kWh	energy storage capacity of a battery	
kWh/m^2	kilo Watt-hours per square metre	
MJ/m^2	Mega Joules per square metre	
PE_{frac}	fraction of Purchased Energy	
Q_e	air handler flow rate	m^3/s
R value	correlation coefficient (applies to Machine Learning section only)	
R^2	coefficient of determination given by Excel	
R-value (and R-Val.)	thermal resistance	$m^2.K/W$
$STC_{max\ achievable}$	maximum achievable number of STCs	
$STC_{systems}$	system STC	
T_a	ambient temperature	°C
$T_{amb,s}$	temperature of air surrounding supply ducts	°C
T_m	mean monthly outdoor temperature	°C
T_n (and $T_{neutral}$)	neutral temperature	°C
$T_{operation}$	indoor temperature between switch on and off	°C
$T_{runningaverage}$	running average outdoor temperature	°C
T_{sp}	temperature of air in supply plenum	°C
$T_{switchon}$	switch on temperature	°C
U-value	thermal transmittance (reciprocal of R-value)	$W/m^2.K$
v	indoor air movement speed	m/s
Δ_k	change	%
ΔT	difference in temperature	°C
Δt_r	temperature difference between indoor air and air surrounding return ducts	
ρ_{in}	Density of indoor air	Kg/m^3

1 Informing the Next Generation Residential Energy Assessment Tools: CRC for LCL Project RP1024

1.1 Project Background

Building energy efficiency was not a major home design concern in Australia until the oil shock of the 1970s [1, 2]. Historically, with the absence of active cooling, Australia's houses were designed to be somewhat responsive to the local climate with small rooms, high ceilings and surrounding verandas to ensure thermal comfort of its occupants. Verandas provided enough shading from sunlight and at the same time, adequate airflow to be comfortable during hot summers. During winter, wood or coal open fires could reasonably heat small rooms during cold periods. Over the decades, mechanical heating and cooling systems eventually became a dominant feature of the Australian home, not only because it allowed more open and spacious floor plans with greater quantities of natural light, but more so due to the availability of cheap and convenient energy sources, such as electricity, heating oil and natural gas. As the oil crisis hit in the 1970's and threatened the energy security of the country, it provoked discussions about the efficient use of energy in buildings. Governments promoted energy conservation research and considered mandating thermal insulation in new buildings as a suitable mechanism to reduce the country's dependence on imported energy resources [1-3].

The next decade observed an increasing global concern about anthropogenic climate change with the publication of the well-known report 'Our Common Future' by World Commission on Environment and Development (WCED) in 1987. The report recognised that the existing pattern of energy use and economic growth was not sustainable from environmental perspectives. The global concern was recognised in Australia and the negative impact of energy consumption on the environment was politically elevated when the Australian Government signed the 1989 Toronto Convention (Australian Minerals and Energy Council [1, 2, 4]. The country recognized the need to reduce Greenhouse Gas (GHG) emission and committed to develop energy efficiency standards for both residential and commercial buildings as a valid mitigation strategy for limiting these [1, 2, 4-6]. During this period, one of the technical reports highlighted that Australia was the only OECD country without building energy regulations [7, 8]. In 1990, a funding commitment was made to develop mathematical models for energy efficient buildings by December 1993 as well as a nationwide house energy-rating scheme (NatHERS). This scheme was developed to encourage cost-effective energy efficient building design, which was inspired by a similar program (National Home Energy Rating System) and the use of MVM Starpoint computer software that assigns a star rating to residential buildings in the United Kingdom (UK) [1, 9]. In 1992, after Australia signed the United Nations Framework Convention on Climate Change [UNFCC], the need for building energy regulations was further emphasized and the National Greenhouse Response Strategy called for expediting the development of NatHERS by 1994 [5]. The policy objectives were: i) improving building energy efficiency; ii) encouraging minimum energy use; and iii) switching to energy sources with lower GHG emissions. However, little progress was made by 1995 in establishing nationally consistent voluntary codes and rating scheme and hence; the progress report called for further actions [5, 10].

During this period and beyond, household energy costs were increasing significantly. In later periods average household energy bills rose by 70% in the five years leading to 2013 [2, 11]. This increase in bills is largely attributed to increased energy costs, for example in the period 2003-13, the costs of electricity rose in Adelaide by 41%, and the cost of gas rose by 40% in Sydney and 78% in Perth [12].

It is expected that these utility prices and hence energy bills will continue to increase. In July 2017, residential customers in Adelaide experienced an electricity price increase of 16.1% [13].

Many different factors contributed to this increase such as deregulation and privatization of electricity generation and supply. Expansion of existing electricity transmission networks coupled with 'gold-plating' of the network system also increased the fixed-costs for the end-users [14]. Furthermore, for many years, energy pricing was cheaper in Australia than in the UK and most of the European Union [15]. Cheap electricity resulted in energy wastage through poor building thermal efficiency as well as by using inefficient appliances and equipment [16, 17]. However, the energy price has now increased to the world average price leaving the users with financial burden due to using inefficient buildings, appliances and equipment [1].

The movement towards the efficient use of energy in buildings in Australia, therefore, was driven by three major policy influences [1, 2]: i) energy security due to the oil shock; ii) environmental concern due to the anthropogenic climate change; and iii) increased household energy cost due to the increased energy price. Given the domestic and international contexts, Australia saw its first national minimum building energy performance standards only in 2003, stringency of which was further increased once in 2006 and once in 2010 [18-20]. However, even though national standards are fairly new in Australia, several states and tertiary governments such as Victoria (VIC), Australian Capital Territory (ACT) and New South Wales (NSW) enforced building efficiency regulations in early 1990s through local council and planning authorities [1, 2].

In Victoria, regulations for the insulation of new houses were recommended as early as 1978 by a parliamentary committee; however, was not adopted as a policy until 1986. This contrasts to other jurisdictions such as in Sweden where triple glazing was mandated in 1979. Finally, insulation requirements for external walls and ceiling were incorporated into the local building codes and came into effect in 1991 through Building Control Act [21]. In the ACT, mandatory wall insulation for new homes was introduced in 1992. Further to this, in late 1995, the ACTHERS rating system (a variant to NatHERS) was introduced and the ACT government set the minimum building fabric performance requirement as 4 ACTHERS/NatHERS stars in May 1996 [3]. The NSW government enforced a mandatory minimum NatHERS 3.5 stars standard in 1997, which was delivered through local council planning schemes [22]. However, there was a lack of support for building energy regulations in Northern and Southern states. Tasmania was concerned about increased cost due to increased energy efficiency, whereas, Queensland was convinced that insulation heavy strategies in southern states are not appropriate for warm-humid climate [2].

In the absence of a nationally consistent energy standard, implementation of different energy standards in different states became an issue for the building industry, particularly for the building materials suppliers and the large construction firms who operated across different states. Given the situation, majority of industry players called for consistent national codes [1]. With Prime Minister Howard's commitment to introducing mandatory minimum energy standards in 1997, Australian Greenhouse Office (AGO) commissioned research to identify the scope of adding the energy efficiency standards in the Building Code of Australia [23, 24]. By 2000, funding was made for energy efficiency regulations and the Australian Building Codes Board (ABCB) was given the responsibility to establish cost-effective minimum energy performance standards. In parallel, the CSIRO energy simulation engine Chenath was accepted as the national reference software tool and AGO worked with CSIRO to upgrade the NatHERS scheme and associated tools for regulatory use in all Australian climates [25]. In 2003, when the first national minimum building energy standards were introduced, Victoria and the ACT government already had enforced a NatHERS 4-star equivalent residential energy standard. The decision was not to reduce the existing performance requirements in these states; however, in hot humid climate states, the standards were set to 3.5 stars. A prescriptive ‘deemed to satisfy’ (DTS) solution approximating the NatHERS level was then created by the building regulators and was incorporated into the national standards. In 2006, the minimum performance requirement was increased from 3.5/4 to 5 stars and in 2010; it was further increased to 6 stars [18-20]. It should be noted that the use of NatHERS, for achieving energy efficiency associated aspects of NCC compliance, is only one of three other available pathways to compliance.

The developments in Australia need to be contrasted internationally. Throughout many jurisdictions in the OECD, energy efficiency of both housing and appliances was more advanced than in Australia. It should be highlighted that even today Australia’s development lags these regions and therefore many of the strategies and lessons learnt can be readily adopted and effectively implemented at minimal cost in the Australian context.

The creation of a building thermos-physical transient model, under NatHERS was supported by the building industry to enable maximum flexibility for energy efficiency assessment of the building shell, avoiding what was perceived as costly prescriptive DTS regulations.

Over the last decade, building modelling has moved from the fringe energy efficiency assessment approach to the dominant approach as opposed to using DTS, with the full support of the ABCB from 2009. The primary engine of NatHERS is Chenath which has been demonstrated to be a powerful tool capable of modelling the transient thermal characteristics of buildings, demonstrably benchmarked against internationally recognized software using the IEA BESTEST methodology [2, 26, 27]. The primary goal of applying NatHERS in the National Construction Code (NCC) is to improve the energy efficiency of building shell, to reduce the greenhouse gas emissions associated with heating and cooling to achieve thermal comfort. Over the last decade, AccuRate has been used to improve the energy efficiency of buildings flexibly, enabling the industry to achieve compliance at minimum cost to the consumer. With the stated goal of reducing greenhouse gas emissions through cost effective energy efficiency measures through building design, it is critical that the modelling and its efficacy is regularly reviewed and updated.

Although the 2nd Generation NatHERS has been significantly successful in improving the thermal comfort of the Australian households; the software covers design of the building fabric only (floor plan and construction materials). It has been argued that the transition to low carbon living calls for a new generation of energy assessment and design tools, capable of rating homes beyond the building fabric and encompassing appliances and renewable energy generation. It has been emphasized by many authors that the tools need to include 100% of household energy end-use, tools that reward industry for the integration of energy efficient technologies and control systems, and tools that recognise the importance of integrating solar energy technologies in reducing the carbon footprint of the residential sector [1, 2]. Furthermore, recent research by industry and government has demonstrated the need for improved compliance processes and tools for the residential sector.

This project builds upon existing developments here and internationally, and in parallel with the existing thermal comfort calculation engine improvements, aims to support the development of the next generation design and rating tools, which can accommodate contemporary building designs, advanced construction systems, energy efficient appliances and equipment. This project aims to support the energy efficient house design industry and shifts the low carbon design focus to the initial design stages delivering lower cost and higher performance housing. It is anticipated that the next generation tools may provide governments and the building sector with a more comprehensive assessment of the full energy and carbon emission impact of each new house design for the betterment of the community.

1.2 NatHERS Calculation and its Accredited Rating Tools

NatHERS predicts a thermal heating and cooling (sensible and latent) load, based on building material thermal properties, climate zone typical meteorological year data, and assumed occupancy profiles. Being a transient numerical simulation of the heat transfer and ventilation flow through the building, the Chenath engine calculates the thermal load needed to achieve the set point each hour [28] of one year. This thermal energy is then adjusted by the conditioned floor area interpolated from [29], which fundamentally applies an area adjustment (scaling) factor to fairly compare smaller and larger dwelling with each other. This adjustment is required given that heat transfer through the building fabric is proportional to the building surface area, and that smaller dwellings have larger surface to floor area ratios than larger buildings [30].

With the advent of 2nd Generation NatHERS compliant software tools, such as AccuRate®, FirstRate® and BERS Pro®, has included modifications and improvements to the Chenath engine utilising data from post occupancy studies and an expansion of climate zones and climate data. These three software applications are the only tools that exist to produce a NatHERS rating and compliance certificate under the code. Their use is spread relatively evenly across state jurisdictions however with a bias towards the FirstRate software in Victoria and South Australia [31], whereas BERS Pro is used more widely in the eastern states.

NatHERS provides a unique star band that ranges from 0.5 to 10, which vary for each clime zone yet allows comparisons between buildings across Australia. Table 1-1 shows the maximum thermal load (predicted by the Chenath engine and area-adjusted) allowed per star band, for some of Australia's 69 climate zones. A comprehensive summary for each climate zone and range of star ratings can be found in [32]. The column highlighted in yellow represents the area-adjusted thermal load for each listed climate zone that corresponds to the current 6-star requirement for newly built houses.

Table 1-1: NatHERS energy Star Bands Rating, numbers correspond to thermal load (MJ/m^2) [G]. The yellow column represents current 6-star requirement for new houses.

Climate Zone	Location	Energy Rating (Stars)									
		1	2	3	4	5	6	7	8	9	10
1	Darwin	773	648	555	480	413	349	285	222	164	119
10	Brisbane	203	139	97	71	55	43	34	25	17	10
13	Perth	387	251	167	118	89	70	52	34	17	4
16	Adelaide	480	325	227	165	125	96	70	46	22	3
21	Melbourne	559	384	271	198	149	114	83	54	25	2
26	Hobart	723	498	354	262	202	155	113	71	31	0
59	Mt Lofty	987	706	518	391	301	230	166	105	48	1

1.3 Project Objectives

Given the project background and aim, the objectives of this project, through the use and investigation of AccuRate Sustainability, include the following with a general focus on compliance pathways:

- Review existing modelling assumptions and recommend those assumptions that require modification.
- Comparison of measured energy usage in the home to that evaluated by AccuRate and AccuRate Sustainability.
- Investigate and recommend updates to assumptions, with a specific focus on cooling using measured data.
- Broaden the scope of the rating software to include all major energy end uses in the home.
- Advise on solar energy, energy storage technologies, and smart demand management technologies.
- Develop compliance metrics to ensure the robustness of the house energy assessment.

Within the project it was recognised that with the rapidly changing scope of building energy evaluation in Australia and internationally additional tasks were conducted which would further inform the scheme (NatHERS) over the long-term, supporting the use of the scheme beyond compliance.

- The application of machine learning to predict whole-of-house energy usage (and more importantly facilitate a platform / mechanism to predict energy consumed by the growing number of *other* appliances).
- Combined impact of insulation R-value degradation, thermal-bridging, and climate-changed RMY files; the latter includes modification to accommodate the inclusion of a heatwave and corresponding adjustments to solar irradiation.
- Comparison of high star rated NatHERS designs vs. actual energy usage for heating and cooling devices across different locations with different star ratings.
- Summarise house energy rating schemes used in the international context that are used beyond compliance, and propose some whole-of-house approaches that could be used to rate new houses built in Australia.
- Extension of a PV and battery storage module that lead to the development of the proposed household electrical grid impact rating scheme (HEGIRS).
- Provide insight into a rating scheme of the future, i.e. beyond the current version of NatHERS.

1.4 Project Limitation

This project has recommended new assumptions to improve the output of the tool; based on limited measurement and evaluations. The focus of the study related mostly to non-tropical climate zones in Australia, however many of the recommendations are also applicable to these climate zones.

Note that project has been completed almost exclusively using AccuRate Sustainability and despite being focussed on this accredited rating tool, the bulk of assumptions relating to the building envelope listed throughout Chapter 2, also relate to other NatHERS accredited software, which utilise the same Chenath engine.

1.5 Structure of the Report

This report is organized in seven chapters. Brief descriptions of all the chapters are given below:

- Chapter 1 introduces the Background to energy assessment in Australian housing.
- Chapter 2 presents the review of NatHERS and AccuRate Sustainability assumptions and settings.

- Chapter 3 presents the interrogation of AccuRate relative to available empirical and monitoring data.
- Chapter 4 presents the new assumptions and associated validation results.
- Chapter 5 presents a whole-of-house energy assessment methodology for Australian houses.
- Chapter 6 presents the items to be disclosed in the universal certificate as part of compliance and metrics.
- Chapter 7 presents a discussion of the future of NatHERS.
- Chapter 8 presents a summary of conclusions and recommendations.

2 Review AccuRate Sustainability Assumptions and Settings

To assess the thermal performance of a building, one of the three accredited rating tools is used that requires an assessor to create a model of the building. This building model requires a significant amount of information regarding the various aspects of the building, such as the: building location, size and function of different rooms and spaces, construction type, construction and window materials, size and specifications of openings including shading elements and building orientation.

Each of the three accredited NatHERS rating tools, i.e. BERS Pro, FirstRate5 and AccuRate, create a scratch file that is fed into the Chenath engine to assess the thermal performance of the building. This is common amongst the accredited rating tools, despite the different user interface in each tool. For example, AccuRate Sustainability requires an assessor to enter building data building through five different tabs, these are: Construction, Zones, Shading, Elements and Ventilation.

Regardless of which rating tool is used, it is important to recognise that the engine makes use of several assumptions that cannot be modified. These fixed assumptions are based on: occupancy, occupants' behaviour, infiltration, ventilation, internal heat load and thermal properties of the construction and window materials.

This chapter documents and critically reviews the existing assumptions and settings used by AccuRate Sustainability, in Section 2.1. Note that in addition to predicting the thermal performance of a building, this version of the rating tool also encompasses several additional modules, to calculate the energy consumption of lighting, water heater and heating and cooling appliances, unlike the other two accredited rating tools (FirstRate5 and BERS Pro). These modules can only be accessed in 'Non-Rating' mode, and the assumptions used by the additional modules are examined in Section 2.1.2. Note that each subsection concludes with a list of recommended actions to be taken, as identified by the process of review.

The 2nd Generation NatHERS software, AccuRate, integrated a multi-zone ventilation model for natural ventilation, a new model for occupant thermal comfort and the air movement driven by ceiling fans to form an improved model for cooling energy requirement calculations. However, monitored data was insufficient at the time to conduct a full review of all the assumptions and settings used for the cooling model.

This chapter reviews assumptions and settings based on literature from either the NatHERS scheme, the public domain or the Help documentation associated with AccuRate Sustainability. The following chapter validates some of these assumptions, using existing empirical data available from CSIRO, University of South Australia and other research institutes, where possible.

2.1 Assumptions relating to AccuRate Sustainability

AccuRate Sustainability makes a number of assumptions regarding the thermostat settings for heating and cooling, window operation behaviours, as well as internal heat loads of a building's different zones. Each of these elements has an impact on the thermal energy required to maintain thermal comfort within a building, and the subsequent star rating. As such, each element is further discussed in this chapter.

2.1.1 Heating and Cooling Assumptions

The existing heating and cooling thermostat settings used in AccuRate Sustainability are specified in the Protocol for House Energy Rating Software [33]. Details of the heating and cooling thermostat settings and the assumed occupant behaviours can be found in Baharun et al. [34]. These settings and assumptions of the existing heating and cooling model are reproduced and analysed here.

The assumed trigger temperatures (setpoint / threshold temperatures) for invoking heating and cooling vary for based on heating or cooling mode, the climate zone (for cooling only) and the zone within the building. This is further described in subsections 2.1.1.1 and 2.1.1.2, and then summarised for all Australian climate zones in subsection 2.1.1.3. Subsections 2.1.1.4 and 2.1.1.5 discuss the effect of air movement on comfort temperature, and the other cooling and heating operation assumptions made by AccuRate Sustainability, respectively.

2.1.1.1 Thermostat Setting: Heating

In AccuRate, for living spaces, a heating thermostat setting of 20°C is used. For sleeping spaces, the heating thermostat setting is at 18°C from 7:00 to 9:00 and 16:00 to 24:00, and 15°C from 24:00 to 7:00. The existing heating thermostat setting is simplified by assuming the triggering temperature to be the same as the thermostat setting. The living space heating thermostat setting of 20°C is a common design indoor temperature for heating recommended by ASHRAE [35]. It should be noted that by analysing the ASHRAE database for naturally ventilated and mixed-mode buildings, Zhang et al. [36] found that for winter indoor temperatures between 16.5 and 27.5°C, the acceptability vote was generally around or above 80%, although the number of votes at 17 and 18°C are very low. This means that heating thermostat setting can potentially be lower than 20°C. This may support the 18°C set point for bedrooms in the existing heating model in AccuRate.

2.1.1.2 Thermostat Setting: Cooling

The cooling thermostat is set equal to the neutral temperature, T_n, for the corresponding climate zone defined in Equation 1, up to a limit of 28.5°C, above which both the neutral temperature and the cooling thermostat are taken to be 28.5°C.

Equation 1

$$T_n = 17.8 + 0.31T_m$$

where T_n is the neutral temperature and T_m is the mean monthly outdoor air temperature. Equation 1 is consistent with ASHRAE Standard 55-2013 [35].

At neutral temperature, an occupant feels neither too warm nor too cool. For simplicity, the January value of Tm is used in AccuRate to establish the neutral temperature for cooling purpose. The upper and lower temperature limits of the comfort zone at 50% relative humidity are taken to be the neutral temperature ± 2.5°C, which corresponds to 90% acceptability of the ASHRAE adaptive thermal comfort model [37].

The ASHRAE adaptive thermal comfort model defines acceptable indoor conditions for free run buildings when votes are cast within the three central categories of comfort scale (slightly cool, neutral or slightly warm). For common naturally ventilated building designs, the ASHRAE standard specifies that the allowable indoor operative temperature shall be determined using the 80% acceptability limits. ASHRAE55-2013 [35] recommends using a 90% acceptability limit for those buildings which require high occupant expectations of thermal environments. In this sense, the current 90% acceptability limit used in AccuRate for residential buildings may be too strict.

It is noted that the ASHRAE adaptive thermal comfort model was established based on empirical data mainly from office buildings [38] whose occupants are relatively restricted in their adaptive measures and perceived control of the environment in comparison with those in residential buildings. Direct application of the ASHRAE adaptive model to residential buildings has been questioned by previous studies [39-43].

2.1.1.3 Summary of Thermostat settings for All Climate Zones

A list of each climate zones trigger temperatures is summarised in Table 2-1, which also indicates the Building Code of Australia (BCA) climate zone, to which the NatHERS climate zone belongs. A visual tool that allows users to determine NatHERS climate zones can be found in [44].

Table 2-1: Assumed NatHERS trigger temperatures for heating and cooling.

AccuRate Climate Zone	**BCA Climate Zone**	**Typical Location**	**Heating Trigger Temperature (°C)**		**Cooling Trigger temperature (°C). All conditioned zones)**
			Living, Living / kitchen, Garage, Other zones	**Bedroom zones. Lower value applies to 01:00-7:00, higher to 8:00-9:00 and 16:00-24:00**	
1	1	Darwin Airport	20.0	15.0 or 18.0	26.5
2	1	Pt Hedland	20.0	15.0 or 18.0	27.0
3	3	Longreach	20.0	15.0 or 18.0	27.0
4	3	Carnarvon	20.0	15.0 or 18.0	26.0
5	1	Townsville	20.0	15.0 or 18.0	26.5
6	3	Alice Springs	20.0	15.0 or 18.0	26.5
7	2	Rockhampton	20.0	15.0 or 18.0	26.0
8	4	Moree MO	20.0	15.0 or 18.0	26.0
9	2	Amberley	20.0	15.0 or 18.0	26.0
10	2	Brisbane	20.0	15.0 or 18.0	25.5
11	2	Coffs Harbour MO	20.0	15.0 or 18.0	25.0
12	5	Geraldton	20.0	15.0 or 18.0	25.0
13	5	Perth	20.0	15.0 or 18.0	25.0
14	7	Armidale	20.0	15.0 or 18.0	24.0
15	5	Williamtown AMO	20.0	15.0 or 18.0	25.0
16	5	Adelaide	20.0	15.0 or 18.0	25.0
17	5	Sydney RO	20.0	15.0 or 18.0	25.5
18	6	Nowra RAN	20.0	15.0 or 18.0	24.5
19	3	Charleville	20.0	15.0 or 18.0	27.0
20	4	Wagga AMO	20.0	15.0 or 18.0	25.0
21	6	Melbourne RO	20.0	15.0 or 18.0	24.0
22	6	East Sale	20.0	15.0 or 18.0	23.0
23	7	Launceston	20.0	15.0 or 18.0	22.5
24	7	Canberra Airport	20.0	15.0 or 18.0	24.0
25	8	Cabramurra	20.0	15.0 or 18.0	23.0
26	7	Hobart	20.0	15.0 or 18.0	23.0
27	4	Mildura AMO	20.0	15.0 or 18.0	25.0
28	6	Richmond	20.0	15.0 or 18.0	24.5
29	1	Weipa	20.0	15.0 or 18.0	26.0
30	1	Wyndham	20.0	15.0 or 18.0	27.5
31	1	Willis Island	20.0	15.0 or 18.0	26.5
32	1	Cairns	20.0	15.0 or 18.0	26.5
33	1	Broome	20.0	15.0 or 18.0	27.0
34	1	Learmonth	20.0	15.0 or 18.0	26.5
35	2	Mackay	20.0	15.0 or 18.0	26.0
36	2	Gladstone	20.0	15.0 or 18.0	26.0
37	3	Halls Creek	20.0	15.0 or 18.0	27.0
38	3	Tennant Creek	20.0	15.0 or 18.0	27.0
39	3	Mt Isa	20.0	15.0 or 18.0	27.0
40	3	Newman	20.0	15.0 or 18.0	28.0
41	4	Giles	20.0	15.0 or 18.0	27.5
42	4	Meekatharra	20.0	15.0 or 18.0	28.0
43	4	Oodnadatta	20.0	15.0 or 18.0	27.0
44	4	Kalgoorlie	20.0	15.0 or 18.0	26.0

AccuRate Climate Zone	BCA Climate Zone	Typical Location	Heating Trigger Temperature (°C)		Cooling Trigger temperature (°C). All conditioned zones)
			Living, Living / kitchen, Garage, Other zones	Bedroom zones. Lower value applies to 01:00-7:00, higher to 8:00-9:00 and 16:00-24:00	
45	4	Woomera	20.0	15.0 or 18.0	26.0
46	4	Cobar AMO	20.0	15.0 or 18.0	26.5
47	4	Bickley	20.0	15.0 or 18.0	24.5
48	4	Dubbo Airport	20.0	15.0 or 18.0	25.0
49	4	Katanning	20.0	15.0 or 18.0	24.5
50	5	Oakey	20.0	15.0 or 18.0	25.0
51	5	Forrest	20.0	15.0 or 18.0	25.5
52	5	Swanbourne	20.0	15.0 or 18.0	25.0
53	5	Ceduna	20.0	15.0 or 18.0	24.5
54	5	Mandurah	20.0	15.0 or 18.0	25.0
55	5	Esperance	20.0	15.0 or 18.0	24.0
56	5	Mascot AMO	20.0	15.0 or 18.0	24.5
57	6	Manjimup	20.0	15.0 or 18.0	23.5
58	6	Albany	20.0	15.0 or 18.0	23.5
59	6	Mt Lofty	20.0	15.0 or 18.0	23.0
60	6	Tullamarine (Melbourne Airport)	20.0	15.0 or 18.0	24.0
61	6	Mt Gambier	20.0	15.0 or 18.0	23.5
62	6	Moorabbin	20.0	15.0 or 18.0	24.0
63	6	Warrnambool	20.0	15.0 or 18.0	23.0
64	6	Cape Otway	20.0	15.0 or 18.0	23.0
65	7	Orange AP	20.0	15.0 or 18.0	23.0
66	7	Ballarat	20.0	15.0 or 18.0	23.5
67	7	Low Head	20.0	15.0 or 18.0	23.0
68	7	Launceston Airport	20.0	15.0 or 18.0	23.5
69	8	Thredbo Valley	20.0	15.0 or 18.0	22.5

Review / recommendation: The assumptions regarding thermostat settings / trigger temperatures, need to be updated in AccuRate Sustainability, based on evidence gathered by CSIRO from rigorous monitored data. This is elaborated further discussed Section in 3.1.

2.1.1.4 *Effect of Air Movement on Comfort Temperature*

In AccuRate, the cooling effect of air movement on the extension of the upper comfort temperature limit is shown in Equation 2, as stated by Aynsley and Szokolay [45].

Equation 2

$$\Delta T = 6(v - 0.2) - 1.6(v - 0.2)^2$$

where *v* is the indoor air movement speed; this is limited to 1.5 m/s.

It is noted that ASHRAE 55-2013 [35] limits the occupant-controlled air speed to 1.2 m/s. Compared to ASHRAE 55-2013 (2013), Equation 2 gives an increase in the acceptable operative temperature limits ΔT of 4.4°C, at an air movement speed of 1.2 m/s, which is twice the value of 2.2°C given in ASHRAE 55-2013.

Review / recommendation: It is recommended that the applicability of Equation 2 should be re-examined.

2.1.1.5 *Cooling and Heating Operation Assumptions*

In AccuRate, heating and cooling in one zone of a house is assumed to be independent of any other zone in the house and will only be required at hours when natural ventilation cannot satisfy thermal comfort in the zone. Natural ventilation is achieved by using permanent openings and user-controlled openings. Openings in walls (external or between zones), floors and ceilings can be specified as being either permanent or user-controlled. Permanent openings are those that are open 24 hours a day, 365 days a year. All window and door openings are assumed to be user-controlled.

For a zone that is cooled, user-controlled openings are opened if the zone temperature exceeds a threshold value and exceeds the outdoor temperature minus 4°C. The threshold value is at the cooling thermostat setting. The subtraction of 4°C from the outdoor temperatures is designed to allow ventilation even if the outdoor air is slightly warmer to take advantage of any potential cooling effect due to air movement.

User-controlled openings also have an associated ‘stickiness’ period, which is the minimum number of hours that the opening or closing status should remain after occupants switch opening status. It was introduced into AccuRate to avoid unrealistic opening/closing scenarios. The default stickiness period is 3 hours. It should be noted that a recent study by Ambrose and James [46] suggests that house occupants may not operate windows and doors as frequently as assumed in AccuRate. This can lead to higher cooling energy demand in practice in comparison with AccuRate calculations.

The hourly air flow rates through openings (between indoors and outdoors, or between zones) are calculated using a zonal model [47, 48] based on opening size and direction, wind speed, direction and the buoyancy effect (stack effect). At each hour, the zone temperature and humidity with natural ventilation and no cooling is first calculated. The air speed at each opening is obtained by dividing the air flow rate at the opening by the opening area.

The average air movement speed in the zone is then estimated as the mean of the air speeds at all the openings in that zone. The zone temperature, humidity and air speed are then used to determine the thermal comfort of the zone in consideration. If the zone condition is within the comfort zone, the zone is naturally ventilated in the current hour and the calculation proceeds to the next hour. Otherwise, the user-controllable openings are closed, and natural ventilation is switched off.

Ceiling fan/s, if installed, are then turned on to provide the cooling effect from air movement. The air speed depends on the fan diameter, number of fans. The cooling benefit of ceiling fan/s is calculated based on Equation 2 and may be reduced according to the floor area. If the zone condition with natural ventilation and ceiling fan/s is insufficient to provide comfort, then the cooling energy required to maintain the zone temperature at the cooling thermostat setting is then calculated. The following cooling benefits are assumed to be achieved using ceiling fans:

- 900 mm: 0.50 m/s. Cooling benefit = 1.6°C
- 1200 mm: 0.66 m/s. Cooling benefit = 2.4°C
- 1400 mm: 0.77 m/s. Cooling benefit = 2.8°C

For a zone that is heated, at each hour, the zone temperature and humidity with natural ventilation and no heating is first calculated. If the zone temperature is lower than the heating thermostat setting, user-controlled openings are adjusted from 100% opening towards 0% opening percentage. If the zone temperature is still found to be less than the corresponding heating thermostat setting, all the user-controlled openings in the zone are closed and heating is turned on. The heating energy required to maintain the zone temperature at the heating thermostat setting is then calculated.

It should be noted that previous monitoring projects by Saman et al. [49] in Adelaide and by Ambrose et al. [50] in Melbourne, Adelaide and Brisbane for air conditioner cooling energy consumptions showed that the monitored cooling energy consumption were on average much higher than the calculated values by AccuRate. These empirical data suggest that the existing cooling model require a realistic check for its fitness to the NatHERS scheme.

From the above analysis, the following major aspects of the existing cooling model may require further upgrade and improvements:

- The heating and cooling thermostat temperatures,
- The triggering temperatures for heating and cooling,
- The cooling effect of air movement,
- The window operation rules.

Review / recommendation: Occupants generally do not open their windows as they are assumed to be, in AccuRate Sustainability. In reality, people do not ventilate and take advantage of any potential cooling effect due to air movement. As such, windows remain closed most of the time in many houses for various reasons, which is critical to calculate the heating and cooling load.

It is highly recommended that mechanical ventilation systems should be considered when designing a house and that these are incorporated into AccuRate Sustainability. It is also recommended that air leakage tests (blower door test results) need to be carried out when windows are open, such that this can be included in the building model.

It is also highly recommended that the assumptions regarding ventilation, and the subsequent potential cooling effect, be revisited and updated to reflect reality.

2.1.1.6 Occupancy and Associated Heat Gains of Zone Types

The Zones tab of AccuRate Sustainability allows an assessor to specify each room in the building model as either: living, bedroom, living/kitchen, daytime, night-time, unconditioned, garage and garage conditioned. In addition, the user is able to assign other properties in the detail section of the zone tab, including the volume, floor area, floor height and maximum ceiling height above floor of the room. It is important that an assessor correctly assigns the type of zone for each room, as occupancy and heat gains associated with them are assumed by AccuRate Sustainability. These are summarised in Table 2-2 for each of the eight zone types.

Table 2-2: Occupancy and associated heat gains of zoning types used in Accurate Sustainability.

Zone Type	Occupancy Hours	Occupancy Type	Conditioned during occupancy	Heat gains considered
Living	07:00 – 24:00	Daytime occupancy	Y	Occupancy heat gain but no cooking heat gain
Bedroom	16:00 – 09:00	Night-time occupancy	Y	Occupancy heat gain
Living/Kitchen	07:00 – 24:00	Daytime occupancy	Y	Both occupancy and cooking heat gain
Day time	07:00 – 24:00	Daytime occupancy	Y	No occupancy heat gain
Night time	16:00 – 09:00	Night-time occupancy	Y	No occupancy heat gain
Unconditioned	--	--	--	No occupancy heat gain
Garage	--	--	--	No occupancy heat gain
Garage Conditioned	07:00 – 24:00	Daytime occupancy	Y	No occupancy heat gain

In addition to the eight zones of Table 2-2, Roof Space and Sub-floor zones invoke special modelling and are not zoned as other spaces are. A downward-facing reflective surface with an emissivity of 0.05 is assumed if the Roof Space and Sub-floors are set as reflective.

Only one zone can be assumed as Living/Kitchen, when operating in rating-mode. It is commonly recommended that assessors limit the number of occupied zones they classify as ‘living’ to two. Other zones that are predominantly used during the day but are lightly occupied, e.g. a study, are better classified as a 'Day time' zone. Similarly, an ensuite (if it is a separate zone from the adjacent bedroom) should be classified as type 'Night-time' zone to avoid acquire heat gains from the bedroom.

Review / recommendation: Zoning assumptions are too simplified / generalized, and are not based on rigorous or monitored data. For example, only one zoning type can be assumed for all bedrooms. The occupancy and associated heat gains of multiple bedrooms can vary dramatically, especially if one is a spare bedroom and rarely occupied.

Occupancy duration for different zones are overestimated, such as living room and bedrooms that are assumed to be occupied for 17 hours per day even, albeit at different times of the day.

Zoning assumptions need to be improved, i.e. more zoning types need to be established along with more realistic occupancy patterns, based on rigorous monitored data.

2.1.1.7 Internal Heat Load

AccuRate Sustainability assumes the following properties, to determine the Internal Heat Load:

- Dwelling Size: 160 m^2. Living zones and bedrooms each make up 80 m^2.
- Number of occupants: 4. It is assumed that 2 adults and 2 children live in a house.

Table 2-3 - Table 2-5 summarise the times of days that sensible and latent internal heat loads are assumed for different building zones (bedrooms, living rooms with and without a kitchen).

Table 2-3: Internal load for bedrooms.

Hour	Internal Heat Load			
	Sensible			Latent Heat (W)
	Lighting (W)	People (W)	Total	
0:00-1:00	0	200	200	100
1:00-2:00	0	200	200	100
2:00-3:00	0	200	200	100
3:00-4:00	0	200	200	100
4:00-5:00	0	200	200	100
5:00-6:00	0	200	200	100
6:00-7:00	0	200	200	100
7:00-8:00	0	0	0	0
8:00-9:00	0	0	0	0
9:00-10:00	0	0	0	0
10:00-11:00	0	0	0	0
11:00-12:00	0	0	0	0
12:00-13:00	0	0	0	0
13:00-14:00	0	0	0	0
14:00-15:00	0	0	0	0
15:00-16:00	0	0	0	0
16:00-17:00	0	0	0	0
17:00-18:00	0	0	0	0
18:00-19:00	0	0	0	0
19:00-20:00	100	0	100	0
20:00-21:00	100	0	100	0
21:00-22:00	100	0	100	0
22:00-23:00	100	200	300	100
23:00-24:00	0	200	200	100

Table 2-4: Internal load for living rooms without a kitchen.

Hour	Sensible (W)			Latent Heat (W)
	Lighting	People	Total	
0:00-1:00	0	0	0	0
1:00-2:00	0	0	0	0
2:00-3:00	0	0	0	0
3:00-4:00	0	0	0	0
4:00-5:00	0	0	0	0
5:00-6:00	0	0	0	0
6:00-7:00	0	0	0	0
7:00-8:00	180	280	460	140
8:00-9:00	180	280	460	140
9:00-10:00	0	140	140	70
10:00-11:00	0	140	140	70
11:00-12:00	0	140	140	70
12:00-13:00	0	140	140	70
13:00-14:00	0	140	140	70
14:00-15:00	0	140	140	70
15:00-16:00	0	140	140	70
16:00-17:00	0	140	140	70
17:00-18:00	300	210	510	105
18:00-19:00	300	210	510	105
19:00-20:00	300	210	510	105
20:00-21:00	300	210	510	105
21:00-22:00	300	210	510	105
22:00-23:00	0	0	0	0
23:00-24:00	0	0	0	0

Table 2-5: Internal load for living rooms with a kitchen.

Hour	Sensible Heat (W)				Latent Heat (W)
	Appliances and Cooking	Lighting	People	Total	
0:00-1:00	100	0	0	100	0
1:00-2:00	100	0	0	100	0
2:00-3:00	100	0	0	100	0
3:00-4:00	100	0	0	100	0
4:00-5:00	100	0	0	100	0
5:00-6:00	100	0	0	100	0
6:00-7:00	100	0	0	100	0
7:00-8:00	400	180	280	860	140
8:00-9:00	100	180	280	560	140
9:00-10:00	100	0	140	240	70
10:00-11:00	100	0	140	240	70
11:00-12:00	100	0	140	240	70
12:00-13:00	100	0	140	240	70
13:00-14:00	100	0	140	240	70
14:00-15:00	100	0	140	240	70
15:00-16:00	100	0	140	240	70
16:00-17:00	100	0	140	240	70
17:00-18:00	100	300	210	610	105
18:00-19:00	1100	300	210	1610	105
19:00-20:00	250	300	210	760	105
20:00-21:00	250	300	210	760	105
21:00-22:00	250	300	210	760	105
22:00-23:00	100	0	0	100	0
23:00-24:00	100	0	0	100	0

In addition to the times of day where internal heat load are assumed, it was discovered that there is a mismatch between the times that heating/cooling are applied and the heat gain dur to occupancy. This is seen in Table 2-6 - Table 2-8, for numerous hours, i.e. where heating-cooling has been assumed, yet it is also assumed that the zones are unoccupied and hence do not contribute an internal heat load.

Table 2-6: Mismatch between times where heat/cooling is used and internal heat load gains due to occupancy, for bedrooms.

Hour	Heating and Cooling Operation	Internal Heat Load			
		Sensible			Latent Heat (W)
		Lighting (W)	People (W)	Total	
0:00-1:00	Y	0	200	200	100
1:00-2:00	Y	0	200	200	100
2:00-3:00	Y	0	200	200	100
3:00-4:00	Y	0	200	200	100
4:00-5:00	Y	0	200	200	100
5:00-6:00	Y	0	200	200	100
6:00-7:00	Y	0	200	200	100
7:00-8:00	**Y**	**0**	**0**	**0**	0
8:00-9:00	**Y**	**0**	**0**	**0**	0
9:00-10:00	N	0	0	0	0
10:00-11:00	N	0	0	0	0
11:00-12:00	N	0	0	0	0
12:00-13:00	N	0	0	0	0
13:00-14:00	N	0	0	0	0
14:00-15:00	N	0	0	0	0
15:00-16:00	**Y**	**0**	**0**	**0**	0
16:00-17:00	**Y**	**0**	**0**	**0**	0
17:00-18:00	**Y**	**0**	**0**	**0**	0
18:00-19:00	**Y**	**0**	**0**	**0**	0
19:00-20:00	**Y**	**100**	**0**	100	0
20:00-21:00	**Y**	**100**	**0**	100	0
21:00-22:00	**Y**	**100**	**0**	100	0
22:00-23:00	Y	100	200	300	100
23:00-24:00	Y	0	200	200	100

Table 2-7: Mismatch between times where heat/cooling is used and internal heat load gains due to occupancy, for living rooms (without a kitchen).

Hour	Heating and Cooling Operation	Internal Heat Load			
		Sensible			Latent Heat (W)
		Lighting (W)	People (W)	Total	
0:00-1:00	N	0	0	0	0
1:00-2:00	N	0	0	0	0
2:00-3:00	N	0	0	0	0
3:00-4:00	N	0	0	0	0
4:00-5:00	N	0	0	0	0
5:00-6:00	N	0	0	0	0
6:00-7:00	**Y**	**0**	**0**	**0**	**0**
7:00-8:00	Y	180	280	460	140
8:00-9:00	Y	180	280	460	140
9:00-10:00	Y	0	140	140	70
10:00-11:00	Y	0	140	140	70
11:00-12:00	Y	0	140	140	70
12:00-13:00	Y	0	140	140	70
13:00-14:00	Y	0	140	140	70
14:00-15:00	Y	0	140	140	70
15:00-16:00	Y	0	140	140	70
16:00-17:00	Y	0	140	140	70
17:00-18:00	Y	300	210	510	105
18:00-19:00	Y	300	210	510	105
19:00-20:00	Y	300	210	510	105
20:00-21:00	Y	300	210	510	105
21:00-22:00	Y	300	210	510	105
22:00-23:00	**Y**	**0**	**0**	**0**	**0**
23:00-24:00	**Y**	**0**	**0**	**0**	**0**

Table 2-8: Mismatch between times where heat/cooling is used and internal heat load gains due to occupancy, for living rooms with a kitchen.

Hour	Heating and Cooling Operation	Internal Heat Load				
		Sensible Heat				Latent Heat (W)
		Appliances and Cooking (W)	Lighting (W)	People (W)	Total	
0:00-1:00	N	100	0	0	100	0
1:00-2:00	N	100	0	0	100	0
2:00-3:00	N	100	0	0	100	0
3:00-4:00	N	100	0	0	100	0
4:00-5:00	N	100	0	0	100	0
5:00-6:00	N	100	0	0	100	0
6:00-7:00	**Y**	100	**0**	**0**	100	**0**
7:00-8:00	Y	400	180	280	860	140
8:00-9:00	Y	100	180	280	560	140
9:00-10:00	Y	100	0	140	240	70
10:00-11:00	Y	100	0	140	240	70
11:00-12:00	Y	100	0	140	240	70
12:00-13:00	Y	100	0	140	240	70
13:00-14:00	Y	100	0	140	240	70
14:00-15:00	Y	100	0	140	240	70
15:00-16:00	Y	100	0	140	240	70
16:00-17:00	Y	100	0	140	240	70
17:00-18:00	Y	100	300	210	610	105
18:00-19:00	Y	1100	300	210	1610	105
19:00-20:00	Y	250	300	210	760	105
20:00-21:00	Y	250	300	210	760	105
21:00-22:00	Y	250	300	210	760	105
22:00-23:00	**Y**	**100**	**0**	**0**	**100**	**0**
23:00-24:00	**Y**	**100**	**0**	**0**	**100**	**0**

Review / recommendation: The assumptions used regarding dwelling size and the number of occupants, are based on statistical data from the 1990's. As these are outdated and family arrangements are tending to be less 'nuclear', AccuRate Sustainability needs to address these assumptions. In addition, these should be periodically updated every time a national Census is carried out.

The internal heat loads are outdated and unrealistic, and these calculations need to be better aligned with ASHRAE reference values.

As moisture is becoming important, it is highly recommended that the internal latent load, as well as moisture producing appliances and processes, such as dishwashing, clothes washing and showers, need to be factored into the internal latent heat load calculation.

Finally, there is a mismatch between heating/cooling operation time and the occupancy heat gain times assumed in AccuRate Sustainability. It was seen that heating/cooling operation was assumed when occupancy was not. This inconsistency needs to be addressed.

2.1.1.8 Thermal Mass

Industry experts and research academics are divided whether or not AccuRate Sustainability (and other accredited rating tools) currently models the effects of internal thermal mass that does not form part of the building envelope.

Review / recommendation: It is highly recommended that future versions of AccuRate Sustainability, and the other accredited rating tools, need to be updated such that the effects of internal thermal mass that does not form part of the building envelope on building thermal energy modelling are incorporated into the software. Where this is already incorporated into the software, this should be clearly indicated in the associated documentation.

2.1.2 Construction Material Assumptions

The Construction tab in the main data book of the tool allows to set details such as materials, bridging data, surface colour and solar absorptance for external wall, window, door, floor, ceiling, Internal wall, roof, skylight and roof window of the building. Materials provided in the library are separated into of two main types, i.e. construction materials and window materials, which are discussed in subsection 2.1.2.1 and subsection 2.1.2.2, respectively. The construction materials interface allows different composite materials to be created, and allows the thickness of the materials and installation order (of materials) to be modified; AccuRate Sustainability calculates the total R and U-value automatically. In contrast, the window library contains default materials that cannot be easily customised.

2.1.2.1 Construction Materials

Construction materials can be selected from the library, where the materials are put under the external wall, window, door, floor/ceiling, internal wall, roof, skylight and roof window categories. However, the materials have been classified as the normal materials, insulation materials and air gaps. All materials have heat flow up and down resistances and capacitance values that are needed to perform the transient calculations. In total, 82 normal materials and 72 insulation materials are provided in the library, along with airgap properties for vertical, horizontal and inclined airgaps.

Review / recommendation:

The current material library is suitable to cover major typical construction practices in Australia; however, it lacks new, innovative and energy-efficient materials that are the results of the latest technology, such as ‘smart glass’, structural insulated panels, ‘cool roofing’ and phase change materials. It also does not provide some material choices for green or sustainable construction, such as straw bales, green wall or plant-based materials. Although many materials can be simulated using specified resistance values to mimic known properties, their specific inclusion within the construction materials database may be advantageous. This could serve to indirectly promote the use of sustainable materials, especially where AccuRate and other NatHERS tools are used as an integral part of the building design process. This could improve the quality of the tool and effectively reward innovative design and construction, therefore it is recommended that new materials are incorporated as part of a regular update of the construction materials database.

While specifying the materials for a construction, thickness of the materials can be modified manually; however, there is no upper limit for the material thickness, which means a concrete block’s thickness can be set at 100,000 mm. The upper limit for material thickness should be restricted to a reasonable limit to reduce the chance of accidental not s during data entry.

Only the R-value and U-value of the materials are considered. Other properties such as moisture content of the materials are not included. This should be included to enhance the accuracy of the tool.

The material properties utilised in the materials database are independent of temperature, however the properties of many insulation materials commonly used in construction vary considerably with temperature, therefore this can affect the accuracy of results. It is particularly a problem in peak summer. To avoid iteration in the modelling, a nominal average of temperature between sol-air and room-air should be considered.

2.1.2.2 Window (Glazing System) Materials and Properties

AccuRate Sustainability contains 136 types of default glazing systems that can be selected from the Default Windows library. An assessor can include up to five glazing systems from the tree list in the building model; this limitation applies to windows, roof windows and skylights. The list is sorted according to manufacturer, frame material and groups. Once selected, the system U-value and solar heat gain coefficients (SHGC) are displayed, which incorporates the area-weighted U-value and SHGC of a glazing system. Note that properties for the glass and frame are shown individually, and other properties for the glass are also shown at NFRC conditions; these additional properties include:

- Shading coefficient,
- Visible transmittance, at normal incidence,
- Ultra-violet transmittance, at normal incidence,

A glazing system, selected from the Default Windows library, displays the frame material, group identifier and glazing system properties. The glazing systems are categorized into two groups, i.e.:

- Group A is one of 68 windows that are awning, bifold, casement and tilt ‘n’ turn windows.
- Group B is one of 68 double-hung, louvre, or fixed and sliding window products.

In addition to grouping, the glazing system can be one of various types of frames, glazing, gas filling (only applies to double-glazed options), and glass coatings, as summarised in Table 2-9. The resulting glazing system properties, i.e. solar heat gain coefficient and U-values, for the 136 Default glazing systems, provided in AccuRate Sustainability, is shown in Figure 2-1.

Table 2-9: Glazing system options available to AccuRate Sustainability. Note that SG and DG represent single-glazed and double-glazed, respectively.

Frame Type	Group	Glazing	Gas Filling (DG only*)	Glass coating
• Aluminium, • Aluminium – Thermally Broken, • Composite, • Fibreglass, • uPVC, • Timber	• A • B	• •	• Air, • Argon	• Clear, • Tint, • High Solar Gain, Low-E-Clear, • Low Solar Gain, Low-E-Clear

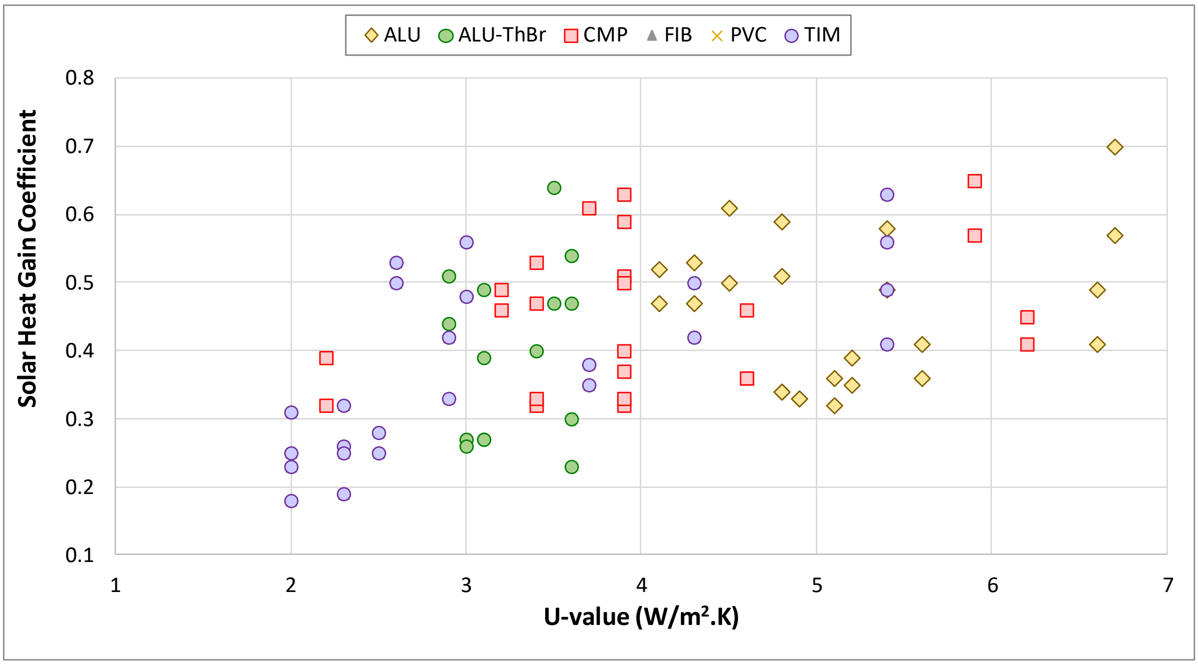


Figure 2-1: Solar heat gain coefficient vs. U-value properties for the 136 glazing systems provided in AccuRate Sustainability.

An assessor is able to select an alternative library, however they are not able to create or modify any window, roof window or skylight properties. The software documentation states that custom systems can achieve the same U-value and SHCG with a combination of glass, gap and frame that differ from the default examples. It continues to state that as such, it is not necessary for a custom system to separately match the default glass, gap and frame, to achieve the same performance.

If default glazing systems are selected for the model, the assessor is required to re-simulate the building model, after selecting the ±10% SHGC button. This is required to ensure the rating is valid, as it is possible that actual windows used in the construction may differ from those used in the building model. If custom windows are used, it is assumed that the same window performance is obtained as is modelled.

Regardless of whether a model is constructed with default or custom glazing systems, the system must be validated / verified before it is included in the building model. If this validation cannot be provided, the system shall adopt figures from the table in the Explanatory Information in volume 2, Section 3.12.2 of BCA 2014. This may inaccurately impact on glazing systems purchased from overseas, which may have their own unrecognised performance measurements, or those that are not included in the Default library yet exist on the Windows Energy Rating Scheme (WERS) database / website [51].

Recall Figure 2-1, which shows the default glazing system properties available in AccuRate Sustainability. These have SHGC that range 0.18-0.7, and U-values that range from 2-6.7, although the software allows filtering that accepts ranges from 0-1 and 10. An investigation into the properties of glazing systems, which are currently listed as available across Australia, revealed that many of these are not covered by the range covered by the Default glazing systems used in AccuRate. This is summarised in Figure 2-2, which again shows a scatter of the SHGC and U-values (this time they are categorized into Group A and Group B), together with the ranges of glazing system properties that are listed as available throughout Australia (WERS); window system data obtained from [51].

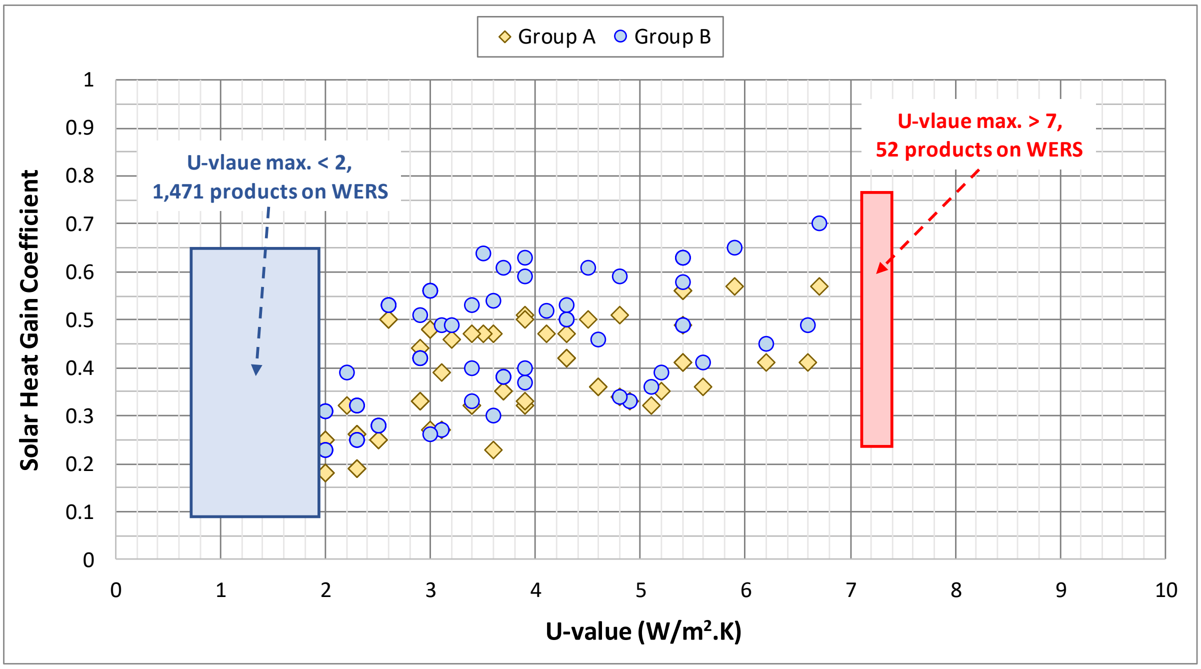


Figure 2-2: Solar heat gain coefficient vs. U-value properties for the 136 glazing systems provided in AccuRate Sustainability, classifying these by Group A and Group B.

Figure 2-2 shows that a number of WERS listed glazing products exist that have higher or lower U-values than those covered by the Default library of AccuRate Sustainability, these include:

- High-end (red box): 52 products with U-values that range from 7.1-7.4 (corresponding SHGC ranges from 0.24-0.77),
- Low-end (blue box): 1,471 products with U-values that range from 0.7-1.9 (corresponding SHGC ranges from 0.09-0.65).

Review / recommendation: Given the number of glazing system products with U-value / SHGC ranges that are not covered by AccuRate Sustainability, it is highly recommended that a custom glazing system option be incorporated into the next version of the rating tool. This is suggested, as opposed to a regularly updating the Default library (every 12 months) and dispersing the updated library to registered accredited rating tool users, as this task is a more cumbersome and time costly exercise. Regularly updating the Default library is deemed a medium priority recommendation.

In addition, it is also recommended that where custom glazing systems parameters are allowed to be entered in manually (without the need for updating the Default library), a dialogue box is created that allows the assessor to either:

- attach a PDF copy of glazing system test performance results, or
- add a URL to a product that exists in the WERS website / database.

2.1.2.3 Surface Colours, Solar Absorptance and Emissivity

AccuRate Sustainability allows the assessor to set external and internal surface colours for external walls, doors and roof constructions. It also allows the user to set surface colours for both sides of an internal wall and, top and bottom surface colours for floor and ceiling constructions and, frame colours for windows and roof windows. Colours selected contain assume values of solar absorptance (expressed as a percentage), which can be manually modified. In addition, the emissivity of the top surface of the roof can has a default value of approximately 0.8, however this can be manually adjusted. A summary of the assumed solar absorptances of each library colour is shown in Table 2-10.

Table 2-10: Solar absorptance values assumed by AccuRate Sustainability library colours.

#	Colour	Solar Absorptance
1	Dark	85%
2	Medium	50%
3	Light	30%
4	Brick (red pressed clay)	79%
5	Concrete (dry)	62%
6	Copper (aged)	57%
7	Fibro-cement (weathered)	65%
8	Galvanized Iron (new)	32%
9	Galvanized iron (weathered)	75%
10	Paint (black)	*96%*
11	Paint (light cream)	*30%*
12	Paint (light green)	*50%*
13	Paint (light grey)	*75%*
14	Paint (pink)	*49%*
15	Paint (white)	23%
16	*Tiles: Clay (light red)*	*66%*
17	*Tiles: Clay (dark purple)*	*81%*
18	*Tiles: Concrete (black)*	*91%*
19	*Tiles: Concrete(brown)*	*85%*
20	*Tiles: Concrete(uncoloured)*	*65%*

For skylights, the tool assumes the frame to be made of steel or timber covered with aluminium and by default assumes the fraction of the frame as 20%; however, the fraction can be manually modified.

Review / recommendation: The term solar absorptance needs to be renamed to total solar reflectance (TSR) consistent with industry terminology.

In addition, the skylight framing options should be expanded to include new products available on the market.

2.1.2.4 Thermal Bridging

Thermal bridging can be specified for external wall, door, floor, ceiling, roof and internal walls in AccuRate Sustainability, when used in non-rating mode. In total, two thermal bridgings can be assumed; however, the second thermal bridging is made available only if the first thermal bridging material is selected as the timber.

'Timber' is assumed as the frame material for timber and all other non-metallic materials and 'Steel' is assumed as the frame material for steel and any other metallic material.

The materials available for the thermal bridging are:

- Concrete: standard (2400 kg/m^3)
- Polystyrene expanded (k = 0.039)
- Polystyrene extruded (k = 0.028)
- Steel
- Timber (hardwood)
- Timber (softwood)

Thermal bridging data for all materials are specified in the bridging data specifier. The bridging data specifier allows the frame materials and the dimensions of studs and noggings to be nominated. The fraction of the frame can be inputted manually, or the tool can calculate it automatically if the stud and nogging dimensions are provided. The two most typical dimensions of studs and noggings (145x45; 90x45) in mm are provided for the user to select quickly. In addition, the user can specify the studs and nogging's depth, width, spacing and flange width separately. Although, manually modifiable, the stud and nogging depth by default is assumed as 100mm and the depth is assumed as 45mm which can be set between 0 and 1000mm with an increment of 10mm. Stud spacing by default is assumed as 400mm, which can be modified quickly to 480 and 600 mm either from a drop down menu or can be modified to any dimension manually without any upper limit. Similarly, nogging spacing by default is assumed as 600mm, which can be modified quickly to 675, 800 and 900 mm either from a drop-down menu or can be modified to any dimension manually without any upper limit. Flange width is active only if the frame is selected as steel and can be set between 0 and 1000mm with an increment of 10mm.

On the other hand, the data for small air gaps such as the dimensions for air thickness and width are to be provided through a dimension panel, which can be set between 0 and 100 mm with an increment of 1 mm.

Review / recommendation: Thermal bridging is available only in the non-rating mode. Since thermal bridging can have significant impact on the thermal performance of a building, to ensure accurate assessment, it is highly recommended that this should also be included in rating mode.

AccuRate Sustainability only considers thermal bridging due to framing. The tool should be updated to consider other forms of thermal bridging, such as the extended floor of a balcony.

The number of Thermal bridging materials provided in the tool are limited.

For complex construction systems, allowance should be made to include measured R-values from accredited testing bodies.

Thermal bridging calculations should follow best practice international standards.

2.1.3 Other Modelling Assumptions

2.1.3.1 Air Leakage and Infiltration Assumptions

AccuRate Sustainability allows the assessor to specify the type of various penetrations a house might expect due to its construction. Penetrations can exist in many areas of a house, such as the ceiling, roof, floor and sub-floor, and for many reasons, including the provision for lighting, exhaust fans, chimneys and ceiling fans etc. These combined penetrations can reduce the air tightness of the building and will hence impact on the air leakage.

AccuRate Sustainability allows an assessor to specify gap size around windows, such that these are small, medium or large. Despite this ability, AccuRate Sustainability does not take this into account as it assumes an air infiltration rate of 15ACH@50Pa. Nor does it allow the assessor to vary the infiltration rate.

A recent study that quantified the air leakage of newly built houses scattered around Australia found that, many new houses exceeded this 15ACH assumption [CSIRO's blower door test]. Given that a leaky house will require more actively heated or cooled air to maintain thermal comfort, it is important to be able to accurately model the air infiltration rate of a house pre and post-construction to identify the impact that on thermal energy and hence star rating.

AIRAH 2016 indicates that a house that can reduced its air infiltration rate from 35 to 10 ACH@50 Pa, is expected to reduce its:

- Peak heating load by 21-32%, for various capital cities,
- Peak sensible cooling load by 7-22%,
- Peak latent cooling load by 1-43%

Similarly, it is estimated that reducing an air infiltration rate from 20 to 10ACH@50 Pa can reduce the heating and cooling energy requirements by 10-20%, for a house in Adelaide. In this case, the house was blower-door tested before and after gaps around the walls, window frames and door frames were identified, and addressed.

Review / recommendation: It is highly recommended that AccuRate Sustainability is updated to allow the assessor to manually enter the air infiltration rate, based on an approved blower door test.

2.1.3.2 Building Shape and Orientation Customisability

The ventilation tab of the tool allows to the assessor to specify the footprint of the building as well as the orientation to be used for natural ventilation calculations. The footprint of the building is assumed to be rectangular and the dimensions of the building can be entered manually. AccuRate Suitability also allows the assessor to set the orientation of the building with respect to North through a North pointer, or by manually entering the azimuth.

Review / recommendation: The existing software interface does not allow an assessor to accurately calculate the impact of ventilation of a building that is non-rectangular, e.g. circular or curvilinear. It is recommended that AccuRate Sustainably is updated to address this limitation.

2.1.3.3 Number of User-Defined Zones

AccuRate Sustainability currently allows a maximum of 150 zones in a building model. However, many special zones can be created internally by the user interface. This reduces the number of zones available to the assessor. As such, the maximum number of user-defined zones is limited to 50, which is unlikely to be an issue for an assessor who is modelling a small house. This limit of 50 zones may be problematic when modelling large houses.

Review / recommendation: It is recommended that the maximum number of user-defined zones is increased beyond 50, as this will allow assessors to model larger buildings.

2.1.3.4 Slab-on-Ground Construction

AccuRate Sustainability currently assumes a slab-on-ground construction is directly before the floor of a building model, and that edge insulation around the slab can be selected and modelled. This edge insulation is required where underfloor heating and/or cooling is installed. However, in certain climate zones and jurisdictions, this edge insulation is contradicted by termite control regulations within the NCC.

Review / recommendation: Given possible contradiction with the NCC regarding edge insulation and termite control regulations, it is highly recommended that AccuRate Sustainability be modified such that an associated error or warning message is displayed to the assessor as they are building the model. This will allow the assessor to take action to facilitate consistency with other regulations.

2.1.3.5 Complex Roofs Modelling

Some building models may contain complex roof-spaces with multiple facets, each with specific azimuth, pitch and area. As it can be quite time-consuming describing each roof space, an alternative approach is to enter only one roof for each roof space. In this case, this roof should have a pitch of zero (rendering the azimuth irrelevant), and have an area equal to the sum of the ceiling areas adjacent to the roof-space, multiplied by 1.09 (for a 23° pitch). It is understood that the error involved is reduced, if the ceiling has bulk insulation.

Review / recommendation: It is recommended that the user interface of AccuRate Sustainability is modified to allow an assessor to quickly build complex roof space models, without assuming one roof for each roof space.

2.1.3.6 Opaque Louvres

As with windows and doors, opaque louvres are assumed to be embedded in a parent external wall. The effect of solar radiation striking the closed louvre is taken into account, however, when the louvre is open, it is assumed to be fully open, and the solar radiation entering the space is assumed to be zero.

Review / recommendation: It is highly recommended that the assumptions regarding open opaque louvers, including solar radiation of zero, are further investigated and any new information regarding dollar radiation are updated in AccuRate Sustainability.

2.1.3.7 Area Adjustment Factor

NatHERS accredited software, including AccuRate Sustainability, determines the total heating and cooling loads of a dwelling and then normalizes this by the conditioned floor area. This is then adjusted by the conditioned floor area interpolated from [29], which essentially applies an area adjustment factor to fairly compare smaller and larger dwelling; given that heat transfer through the building fabric is proportional to the building surface area, as smaller dwellings have larger surface to floor area ratios than larger buildings [30].

An example of the area-adjustment factor is shown below in Figure 2-3, which summarises these factors for 41 houses within the Lochiel Park development, SA. The total heating and cooling energy is not adjusted for a house with conditioned floor area of 196m^2.

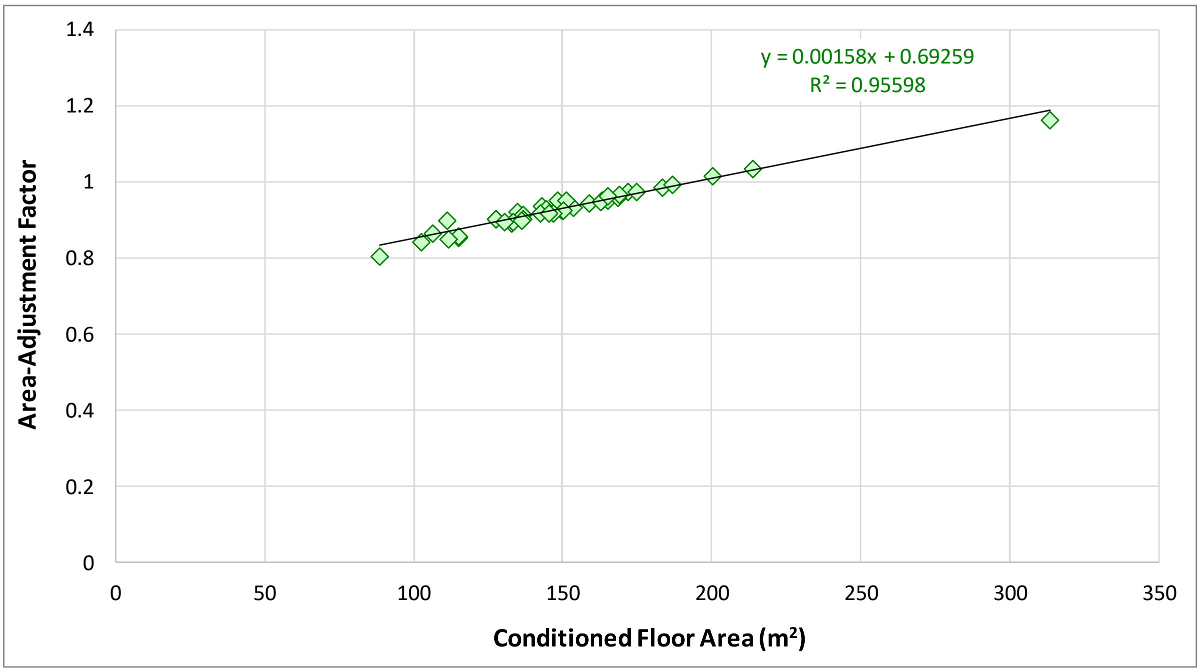


Figure 2-3: Area-adjustment factor for 41 houses within Lochiel Park, SA

Review / recommendation: Although we cannot provide comment on methodology of the area-adjustment factor assumed by AccuRate Sustainability, we have heard from industry experts that large houses (above 250m^2) are penalised more than they should be.

It is hence recommended that the area-adjustment factor is reviewed periodically, e.g. every five - ten years and adjusted where empirical evidence is gathered and shown to contradict the current assumptions.

2.2 Assumptions and Settings of Additional Modules in AccuRate Sustainability

There are four modules designed to estimate the energy consumption and associated greenhouse gas emissions associated with installed lighting systems, heating systems, cooling systems and hot water systems. There are also modules designed to estimate the water consumption of relevant appliances and the embodied energy associated with the building fabric. The following section presents the assumptions and settings used by Accurate Sustainability for the 'Lighting', 'Hotwater', 'Space Heating' and 'Space Cooling' Modules.

2.2.1 Default Assumptions and Settings

2.2.1.1 Lighting Module

Significant assumptions will be discussed in this section, including assumed physical characteristics of a zone, the rated power of luminaires and seasonal variation in lamp usage. A number of less significant assumptions have also been identified but will not be discussed. One notable assumption, deemed to be less significant, relates to assumed hours of lamp use for each zone type, especially those containing a kitchen, which differ significantly in terms of the hours where the zone is assumed to be occupied with daylight unavailable. A number of fixed assumptions, which are less significant but may soon need to be reviewed, include: 5% assumed savings associated with the existence of dimmer switches on a luminaire (i.e. manual dimming factor = 0.95); and 45% savings associated with the existence of motion sensors on a luminaire (motion sensor switching factor = 0.55)

2.2.1.1.1 Zone Characteristics

The Lighting module assumes, for the purpose of calculating lighting levels, that both the kitchen and living components of the kitchen/living zone are square.

Review / recommendation: It is unlikely that either the kitchen or living components of the kitchen/living zone will be square. This could have a significant adverse impact on the accuracy of calculated, required lighting levels. The impact of this assumption must therefore be determined and, as necessary, any associated errors should be identified and rectified. As with other aspects of AccuRate Sustainability, this could simply be addressed through the addition of instructional text describing ways to maximise accuracy, through approximation of certain specific values.

2.2.1.1.2 Minimum selectable luminaire wattage

The Lighting Module allows for the selection of lighting wattage down to a minimum of 5Watts. The modules also does not allow for the use of LED-based luminaires, whilst it does still allows for the use of incandescent luminaires.

Review / recommendation: This minimum wattage represents an outdated value, especially for LED based luminaires, the most efficient of which have rated power of less than 2 Watts.

Based on recent advances in technology, the minimum lighting wattage available for selection within the Lighting module should be reduced to a more realistic number, e.g. 1Watt. A periodic review process should be scheduled to ensure that outdated or outlawed lighting technologies, such as conventional incandescent globes, are removed and that the likely characteristics of currently available and near future lighting technology can be entered.

2.2.1.1.3 Seasonal variation in assumed lamp usage

The Lighting module assumes a year-round, fixed number of hours of lamp usage in each zone type.

Review / recommendation: The lack of variation between lamp usage during times of year with vastly different daylight hours and associated times of daylight is questionable. This is highlighted when comparing lamp usage in winter months, when days are shorter to that in summer months, when days are longer in addition to the influence of daylight saving in affected areas.

It is recommended to investigate the inclusion of different assumptions for lamp usage, especially between periods of the longest summer and shortest winter days.

2.2.1.2 Hotwater Module

Significant assumptions will be discussed in this section, including the limits to values of hot water system efficiency, energy consumption associated with all aspects of operation and maintenance and the assumed hot water delivery temperature and associated temperature difference. A number of less significant assumptions have been identified but will not be discussed. Assumptions, deemed to be less significant, relate to the way in which certain hot water appliances are assumed to be utilised, including the assumed volume of hot water use for various activities.

2.2.1.2.1 Hot Water System Efficiency

The Hotwater Module allows the input of different efficiency values for a hot water systems performance in converting various fuel types into heat. The range of available input values quoted in the AccuRate Sustainability Software Manual (Version 2.3.3.13) differs from the input values available within the Hotwater Module. These value ranges are listed in Table 2-11 below.

Table 2-11: Assumed hot water system efficiency

Hot Water System Type	Software Manual Lower	Software Manual Upper	Hotwater Module Lower	Hotwater Module Upper
Gas instantaneous	0	1	0	15
Gas storage	0	1	0	15
Oil fired	0	1	0	15
Solid fuel	0	1	0	15

Review / recommendation: The upper (highest) values for efficiency contained in both the software manual and the Hotwater Module itself are, using current technology, impossible for all of the system types listed in Table 2-11. Furthermore, the logic associated with allowing values of up to 15, which indicate an efficiency of 1500%, is highly questionable.

The maximum efficiency of gas instantaneous, gas storage, oil-fired and solid fuel hot water systems should be less than one in all cases, where no renewable system is in operation.

2.2.1.2.2 Hot Water System Control System Wattage

The Hotwater Module allows the input of a value for control system wattage of a hot water system. The default control system wattage value for the Hotwater Module is set to zero.

Review / recommendation: The default value of zero for control system wattage in the Hotwater Module represents a highly unlikely value associated with almost all hot water system types.

The default value for control system wattage of all systems in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being commonly applicable to many different types of system, e.g. 2.13W for highly efficient, very common gas instantaneous system.

2.2.1.2.3 Hot Water System Startup Loss Per Firing

The Hotwater Module allows the input of a value for startup loss per firing of a gas fired hot water system. The default value of startup loss per firing for the Hotwater Module is set to zero.

Review / recommendation: The default value of zero for startup loss per firing in the Hotwater Module represents a highly unlikely value associated with gas fired hot water systems.

The default value for startup loss per firing in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being applicable to the most popular gas instantaneous system.

2.2.1.2.4 Hot Water System Maintenance Rate

The Hotwater Module allows the input of a value for maintenance rate of a hot water system. The default maintenance rate for the Hotwater Module is set to zero.

Review / recommendation: The default value of zero for maintenance rate in the Hotwater Module represents a highly unlikely value associated with almost all hot water system types.

The default value for maintenance rate of all systems in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being commonly applicable to many different types of system, e.g. 2.13W for highly efficient, very common gas instantaneous system.

2.2.1.2.5 Assumed Temperature Difference Between Hot Water and Indoor Air

The Hotwater Module assumes a constant temperature difference of 40, between hot water and indoor air temperatures.

Review / recommendation: This assumption could be relatively accurate in older houses where hot water delivery temperature could be set to 60°C, however for all new houses, hot water delivery temperature is set no higher than 50°C to comply with requirements of AS/NZS 3500.4:2018 [52] to avoid scalding of vulnerable occupants. The aforementioned assumed temperature difference would therefore assume an indoor temperature of 10°C, which is unacceptably low. It should also be noted that, as discussed in section 2.2.1.2.6, the associated accuracy of this assumption is further compromised where a hot water delivery temperature control panel is utilised.

The value for assumed temperature difference between hot water and indoor air temperature should be reduced to a much lower value, e.g. 30°C, to account for the impact of legislated regulations associated with hot water delivery temperature.

2.2.1.2.6 Treatment of Hot Water Delivery Temperature Control Panels

As previously discussed, the Hotwater Module assumes a constant temperature difference of 40, between hot water and indoor air temperatures. This does not account for the use of hot water delivery temperature control panels, which facilitate the use of considerably lower hot water delivery temperatures in specific household zones.

Review / recommendation: It is generally accepted that considerable savings can be facilitated through the use of hot water delivery temperature control panels, specifically where water heaters can be set to deliver hot water to zones at temperatures of as low as 37°C. These types of systems tend to avoid heating water to unnecessarily high temperatures before reducing this temperature significantly at the faucet, which can otherwise result in considerable unnecessary heat loss.

Analogous to the way the Lighting Module treats the existence of dimmer switches, the Hotwater Module should treat the existence of hot water delivery temperature control panels, in terms of their potential to achieve water heating energy savings. This could be achieved through the incorporation of a factor that simply reduces the water heating energy attributable to any zone where such a controller exists.

2.2.1.2.7 Solar Hot Water System Energy Consumption

The Hotwater Module constitutes a methodology for evaluating the energy of various different types of hot water systems, including those incorporating solar collectors. In relation to solar water heaters, a number of assumptions are utilised in relation to significant installation characteristics such as collector azimuth (orientation), inclination (slope/altitude) and associated "collector non-ideal orientation factors" listed in Table 2-12 below.

Table 2-12: Solar Collector Non-ideal Factors

Azimuth°	**Inclination from the horizontal, K_{inclin}**					
(compass bearing)	**0°**	**20°**	**40°**	**60°**	**80°**	**90°**
270° (West)	0.85	0.85	0.80	0.72	0.60	0.53
300°	0.85	0.92	0.92	0.86	0.73	0.65
330°	0.85	0.98	0.99	0.93	0.80	0.71
0° (North)	0.85	0.97	1.00	0.94	0.80	0.70
30°	0.85	0.94	0.95	0.88	0.74	0.65
60°	0.85	0.88	0.86	0.77	0.63	0.57
90° (East)	0.85	0.80	0.73	0.64	0.52	0.46

Solar hot water system factors are also used by the Hotwater Module, which represent the solar fraction or amount of solar energy utilised for water heating. These factors are simply based on the collector type and method of circulation, as shown in Table 2-13 below.

Table 2-13: Solar hot water system type and assumed solar fraction

	Collector type	
Circulation type	Plate	Vacuum tube
Thermosiphon	0.475	0.57
Pump	0.45	0.54

All of the aforementioned assumptions are used to estimate the energy savings achieved through the use of solar collectors, using Equation 3:

Equation 3

$$SHW = K_{inclin} K_s A_c ASR$$

Review / recommendation:

Table 2-12 indicates that the available values for solar collector inclination (altitude) are 0°, 20°, 40°, 60°, 80° and 90°, which do not include many of the most common roof pitches and optimal inclinations of collectors in most Australian latitudes. Available values for solar collector azimuth range from 270° to 90°, which represent acceptable to optimal values and therefore do not account for sub-optimal orientation of solar collectors due to compromised solar access or inferior design and installation. Furthermore, some of the collector non-ideal orientation factors listed are questionable, especially the values associated with 90° inclination, which represent systems that absorb practically no solar radiation throughout the summer months.

The fixed value of solar fraction, listed in Table 2-13, which is dependent only on the systems collector and circulation type, omits the fact that all solar water heaters sold in Australia are required to achieve a solar fraction of at least 60% (0.6). Furthermore, there is a large variation in the solar fraction achieved by the various systems currently available in Australia, which are all listed in the CER list of solar water heaters, some of which achieve solar fractions of greater than 0.90.

The most critically important point about water heater energy rating is that solar hot water systems, including their conventional boosting hot water systems and components, are all tested and modelled using a well established system that is accepted as being acceptably accurate by the Australian Federal Government. This system is described in AS/NZS 4234:2008 and currently, all but a few solar hot water systems and a large proportion of conventional hot water systems and associated components have been tested and their energy consumption has been modelled for the purposes of this system.

It is recommended that the system for calculation of energy consumption of heated water systems described in AS/NZS 4234:2008 [53] replaces the existing Hotwater Module. This recommendation is based on the fact that this system is already in use for legislative purposes, its accuracy has been tested and accepted by the Australian Federal Government and it utilises far fewer questionable assumptions than the existing Hotwater Module, which is currently incorporated into AccuRate Sustainability.

The STC's for a given system (STC_{system}) can be easily converted to solar fraction, by dividing by the maximum achievable number of STC's for the given system type (see Equation 4).

Equation 4

$$Solar\ Fraction = \frac{STC_{system}}{STC_{\max achievable}}$$

It should be noted that $STC_{max\ achievable}$ is determined by the size of the system and relates to the energy consumed by a similarly sized reference system to which the solar hot water system is being compared for the sake of calculating associated energy savings (see AS/NZS 4234:2008). It should also be noted that the current version of the Hotwater Module utilises a significantly different reference system for the sake of comparison, which should also be brought into line with the methodology described in AS/NZS 4234:2008 [53].

Lastly, it must be mentioned that the assumed relationship between Solar Fraction and the SHW coefficient utilised in the existing Hotwater Module is as follows:

$$Solar\ Fraction = 1 - SHW$$

2.2.1.3 Space Heating Module

Significant assumptions utilised by the Space Heating Module will be discussed in this section, including emission factors, ducting losses and the way in which the module prioritises whether a given heating system services a given zone. A number of less significant assumptions have been identified but will not be discussed.

2.2.1.3.1 Ducting Loss Model

The Space Heating Module currently utilises some basic factors to estimate the delivery efficiency for a space heating system to account for ducting losses, i.e. energy lost, and therefore consumed by space heating systems, through the mechanism of heat delivery to heated zones.

Review / recommendation:

The very basic methodology for estimating delivery efficiency appears to ignore the complex nature of ducting losses. The option to utilise a much more complex methodology is mentioned in the AccuRate Sustainability (v.2.3.3.13) Software Manual (see Equation 5 below), however the complexity of this makes its use impractical for the vast majority of AccuRate users.

Equation 5

$$DE = \frac{a_s Q_e \rho_{in}}{E_{cap}} \left(\frac{E_{n,cap}}{Q_e \rho_{in}} + (1 - a_r)\left(h_{amb,r} - h_{in}\right) + a_r C_p (B_r - 1)\Delta t_r + C_p (B_s - 1)(t_{sp} - t_{amb,s}) \right)$$

It is recommended that a more comprehensive ducting loss model be incorporated into the Space Heating Module of AccuRate Sustainability, whereby a simple list of variables to be entered and selected is incorporated. Details are discussed in the NCCARF report [54].

2.2.1.3.2 Heating System Prioritisation

Where more than one space heating system is used to meet the heating requirements of all zones, the Space Heating Module prioritises the use of heaters by type for a given zone. One example of this is where often highly efficient “Electric Heat Pump (Air Source)” space heaters are given a secondary priority (level 2) beneath numerous other far less efficient system types, including systems utilising oil, natural gas and wood as fuel source.

Review / recommendation:

It appears that the prioritisation of older and inefficient oil, gas and wood fired space heating systems over highly efficient heat pumps is counterintuitive, therefore it is recommended that prioritisation is informed by the efficiency of all systems.

It is recommended that the Space Heating Module prioritises the use of appliances, based on their efficiency, where the highest efficiency appliances are given the highest priority for utilisation.

2.2.1.3.3 Emission Factors

Emission factors associated with the use of LPG and Oil as fuel source listed within the AccuRate Sustainability Software Manual (Version 2.3.3.13) for the Space Heating Module are different to those listed for the Hotwater Module. These differences are shown in Table 2-14 below, noting that each value is the same throughout all states of Australia.

Table 2-14: Contradictive Emission Factors

Module Type	**Emission Factors (kg CO_2-e/GJ) – All States**	
	LPG	Oil
Space Heating Module	67.6	78.4
Hotwater Module	64.8	74.3

Review / recommendation:

The emission factors associated with the burning of a given fuel in a given location should be identical.

These values must be aligned so that all modules utilise the same emission factor for the same fuel source and associated physical process (e.g. burning fuel to generate heat) in a given location.

2.2.1.3.4 Reverse Cycle Space Heating System Rated Efficiency

The rated efficiency for a given reverse cycle space heating system can be obtained from the energy rating website. This value is treated to be fixed within the Space Heating Module, regardless of the outdoor temperature.

Review / recommendation:

In practice, the efficiency of a reverse cycle space heating system is highly likely to vary as the outdoor temperature varies, in addition to variations according to age and other factors. The rated value will likely be correct at an outdoor temperature of approximately 7°C. The treatment of values of efficiency as being fixed is therefore, in most cases, an erroneous assumption and will most likely adversely affect the accuracy of associated calculations of the Space Heating Module.

It is recommended that the Space Heating Module varies the value of rated efficiency, obtained from the energy rating website, according to Figure 2-4 below.

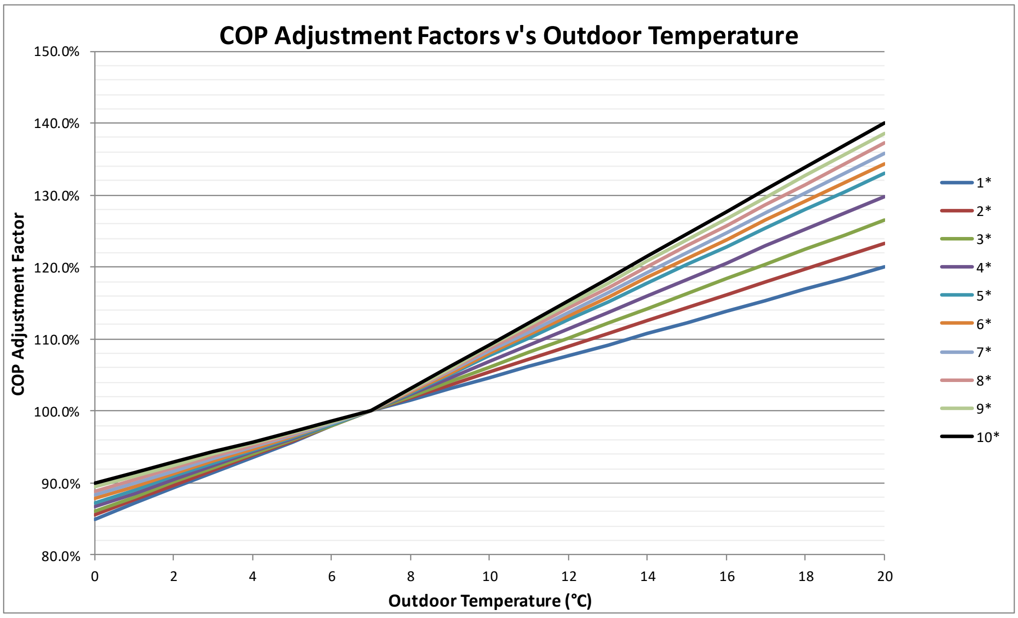


Figure 2-4: Recommended Outdoor Temperature Based, COP De-rating Scheme For Reverse Cycle Space Heating Systems

2.2.1.3.5 Space Heating Module Versus Existing MEPS Methodology

The Space Heating Module constitutes a methodology for evaluating the energy of various different types of space heating systems. An alternative system for evaluating the annual energy consumption of the majority of space heating appliances installed in households throughout Australia already exists within the Minimum Energy Performance Standards (MEPS) legislative instrument, described throughout all current parts of AS/NZS 3823 [55], including: AS/NZS 3823.1.1:2012; AS/NZS 3823.1.2:2012;. AS/NZS 3823.1.3: 2005(R2016); AS/NZS 3823.1.4:2012; AS/NZS 3823.1.5:2015; AS/NZS 3823.2:2013; AS/NZS 3823.3:2002(R2014); AS/NZS 3823.4.1:2014; AS/NZS 3823.4.2:2014; and AS/NZS 3823.4.3:2014.

Review / recommendation:

The MEPS legislative instrument represents a mature system that is used to evaluate critical aspects of the energy consumption of space heating appliances, which is currently accepted and utilised by the Australian federal government. Values for space heating energy, obtained using the MEPS system are known to be conservative estimates and almost always differ considerably to those obtained through use of AccuRate's Space Heating Module, for a number of reasons. Despite the variety of legitimate influences that contribute to this apparent discrepancy, such a discrepancy represents a source for users and the community to develop considerable mistrust of each separate system.

It is recommended that a thorough investigation is conducted into the ways in which the methodologies utilised within the MEPS instrument can be aligned to those used within the Space Heating Module of AccuRate Sustainability to avoid mistrust and synchronise the inputs and outputs of two potentially complementary systems.

2.2.1.4 Space Cooling Module

Significant assumptions utilised by the Space Cooling Module will be discussed in this section, including factors associated with the efficiency of a space cooling system and factors affecting this. Some less significant assumptions have been identified but will not be discussed.

2.2.1.4.1 Determining the Efficiency of a Space Cooling System

The default energy efficiency rating (EER) is stated to default to the associated systems minimum energy performance standard (MEPS), at the time of performing a rating. At present, this default value is assumed to be 2.9, which represents an outdated value. The Space Cooling Module contains a button, whose function is to facilitate access to characteristics of a specific space cooling system and to access the current MEPS value (e.g. 3.1 for a ducted system with less than 10kW capacity), using the Australian Governments 'Energy Rating' website [56]. It should also be noted that the terminology used on the Energy Rating website differs considerably to that used within AccuRate Sustainability.

Review / recommendation:

The aforementioned button, which is supposed to be linked to the relevant section of energy rating website, does not currently navigate to a suitable web page. Furthermore, the current default value of 2.9, which is listed and used by the Space Cooling Module, is applicable only to very large space cooling systems with capacity exceeding 39kW and is also therefore likely to be incorrect for the purposes of most users.

The inconsistent language between the Space Cooling Module text and that of the energy rating website introduces the potential to confuse the software user.

It is recommended that the energy rating website link associated with the button in the Space Cooling Module is updated to navigate to a page containing all information that is relevant to the performance of a specific space cooling system. This button should also allow determination of the relevant minimum energy performance requirements from the appropriate standard (i.e. currently AS/NZS 3823.2:2013, pg. 20).

2.2.1.4.2 Reverse Cycle Space Cooling System Rated Efficiency

The rated efficiency for a given reverse cycle space cooling system can be obtained from the energy rating website. This value is treated to be fixed within the Space Cooling Module, regardless of the outdoor temperature.

Review / recommendation:

In practice, the efficiency of a reverse cycle space cooling system is highly likely to vary as the outdoor temperature varies, in addition to variations according to age and other factors. The rated value will likely be correct at an outdoor temperature of approximately 35°C. The treatment of values of efficiency as being fixed is therefore, in most cases, an erroneous assumption and will most likely adversely affect the accuracy of associated calculations of the Space Cooling Module.

It is recommended that the Space Cooling Module varies the value of rated efficiency, obtained from the energy rating website, according to Figure 2-5 below.

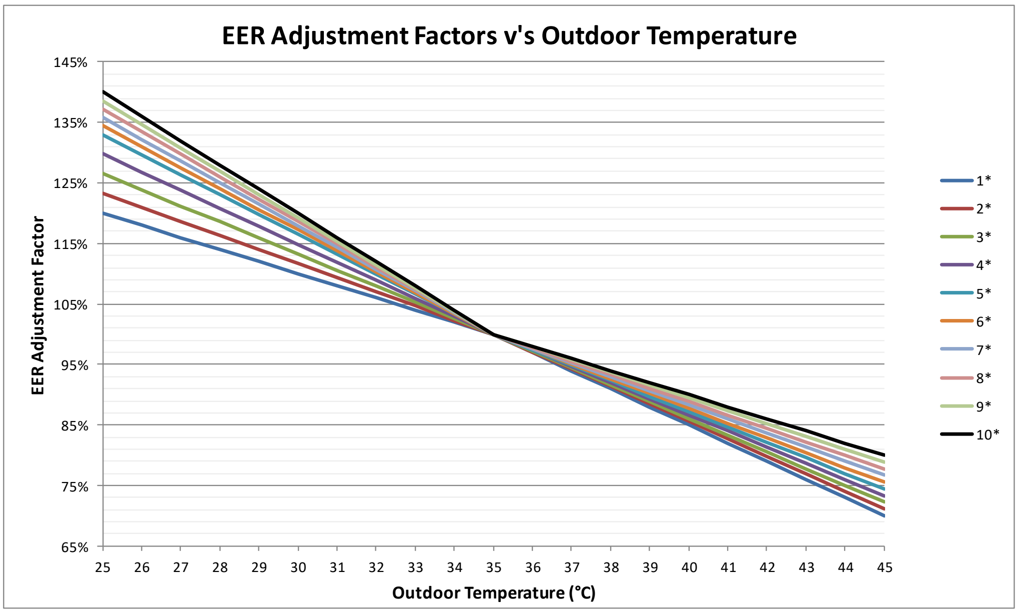


Figure 2-5: Recommended Outdoor Temperature Based, EER De-rating Scheme For Reverse Cycle Space Heating Systems

2.2.1.4.3 Performance of Evaporative Space Cooling Appliances

Direct evaporative cooling systems currently have a default fixed value for performance (EER) of 6.0, with higher fixed values also allowable. These values are utilised by the Space Cooling Module, regardless of the outdoor climate.

Review / recommendation:

The default value of performance for evaporative cooling systems is significantly high. This is most likely based on the relatively low energy consumption associated with the relatively high effective cooling capacity that can be achieved within an optimal range of combined outdoor temperatures and humidities. It must be noted however that, outside the optimal range of combined outdoor temperatures and humidities, most evaporative space cooling systems cannot effectively achieve thermal comfort within any zone during times where a space cooling load is present. Evaporative space cooling systems may not achieve thermal comfort for occupants where outdoor dry-bulb temperatures exceed 35°C, given that most standard systems do not achieve a temperature reduction of greater than 10°C in most climatic conditions experienced during the cooling season. Furthermore, as relative humidity increases above 50%, the ability of these systems to reduce indoor temperature and achieve thermal comfort for occupants diminishes considerably. For buildings where natural infiltration rates have been significantly reduced, the additional internal moisture load introduced by direct evaporative cooling systems is also a concern, in terms of the health and wellbeing of occupants and the impact on structural components of the house.

It should be noted that currently, an Australian Standard is currently being drafted to allow the performance of evaporative space cooling and similar appliances to be evaluated. This draft standard was scheduled to be implemented before the end of the year 2019, however due to significant industry objections, the future of this document is unknown and may result in it becoming an informative publication, rather than a legislative instrument.

It is recommended that, where possible, the rated efficiency of evaporative cooling systems is used within the space cooling module. Accordingly, it is also recommended that where a trend towards a common range of efficiencies for such systems is identified, then this should be used to modify the default value for evaporative space cooling systems, if significantly different to the existing default value.

2.2.1.4.4 Combination of Evaporative and Refrigerative Space Cooling Appliances

It is possible that a zone could be serviced by both a direct evaporative and a refrigerative space cooling system. It also appears to be possible, within the Space Cooling Module, for both systems to service a given zone at the same time.

Review / recommendation:

The modelling of both a direct evaporative and a refrigerative space cooling system operating concurrently in one or more zones would theoretically, according to the Module, constitute the availability of a very large cooling capacity, based on the way that the weighted EER is calculated for a given zone. It must be noted, however, that if operated within the same zone, each of these two different types of system would drastically reduce the performance of the other i.e. they would ‘fight’ each other. This relates to the incompatible mechanisms by which each type of system achieves a cooling effect, where evaporative systems maintain a constant large volume throughput of air with a high relative humidity whilst refrigerative systems maintain a relatively very low throughput of air with much lower levels of relative humidity, in comparison to that achieved by evaporative systems.

It is recommended that, where both evaporative and refrigerative type systems exist in a house, that the Space Cooling Module generates warnings associated with the potential negative impact of using such systems concurrently within the house. Furthermore, it is recommended that the cooling module does not allow modelling of the cooling effect of both systems concurrently, preferably within the entire house, but at least within each serviceable zone.

2.2.1.4.5 Age Based Performance Degradation

The Space Cooling Module refers to two age-related factors that can be used to inform the performance values that are used in calculations. Where the EER a system is unknown but its year of manufacture is known or can be estimated, then a value for default EER is determined using Equation 6:

Equation 6

$$EER = (YearOfManufacture \times 0.0293) - 39.28$$

Where a system is not new, it is stated that the rated EER is reduced by the values listed in Table 2-15, depending on the age of the system.

Table 2-15: Age-based EER reduction

Age (years)	EER Reduction (R)
5	0.10
10	0.14
15	0.18
Over 20	0.21

Review / recommendation:

It is unclear whether the two age-based performance reduction techniques for space cooling systems should be used consecutively or separately. If used separately, the accuracy of these systems is questionable, however when used together they appear to generate expected levels of efficiency, based on previous, in-house, research consultancy.

It is recommended that, where the rated performance of a system is unknown, all possible factors are applied in order to most accurately reflect the systems actual performance.

2.2.1.4.6 Space Cooling Module Versus Existing MEPS Methodology

The Space Cooling Module constitutes a methodology for evaluating the energy of various different types of space cooling systems. An alternative system for evaluating the annual energy consumption of the majority of space cooling appliances installed in households throughout Australia already exists within the Minimum Energy Performance Standards (MEPS) legislative instrument, described throughout all current parts of AS/NZS 3823 [55], including: AS/NZS 3823.1.1:2012; AS/NZS 3823.1.2:2012;. AS/NZS 3823.1.3: 2005(R2016); AS/NZS 3823.1.4:2012; AS/NZS 3823.1.5:2015; AS/NZS 3823.2:2013; AS/NZS 3823.3:2002(R2014); AS/NZS 3823.4.1:2014; AS/NZS 3823.4.2:2014; and AS/NZS 3823.4.3:2014.

Review / recommendation:

The MEPS legislative instrument represents a mature system that is used to evaluate critical aspects of the energy consumption of space cooling appliances, which is currently accepted and utilised by the Australian federal government. Values for space cooling energy, obtained using the MEPS system are known to be conservative estimates and almost always differ considerably to those obtained through use of AccuRates Space Cooling Module, for a number of reasons. Despite the variety of legitimate influences that contribute to this apparent discrepancy, such a discrepancy represents a source for users and the community to develop considerable mistrust of each separate system.

It is recommended that a thorough investigation is conducted into the ways in which the methodologies utilised within the MEPS instrument can be aligned to those used within the Space Cooling Module of AccuRate Sustainability to avoid mistrust and synchronise the inputs and outputs of two potentially complementary systems.

2.2.1.5 CO_2 Emissions Factor

A review of the existing emission factors used by AccuRate Sustainability, found that these were based on data those published by National Greenhouse Accounts (NGA) Factors in 2010. These emission factors were at the time the ‘latest estimates’ based on the full fuel cycle, (i.e. scope 2 + scope 3) for electricity consumed and purchased by end users. These purchased electricity emission factors are updated regularly, as summarised in Table 2-16 [57], for each State and Territory, as well as the Australian average.

Note that by definition [57]:

- scope 2 refers to: indirect emission factors that are physically produced by the burning of fuels (coal, natural gas, etc.) at the power station.
- scope 3 refers to: indirect emissions from the extraction, production and transport of fuel burned at generation and the indirect emissions attributable to the electricity lost in delivery in the transmission and distribution network.

Table 2-16: Purchased electricity emission factors (scope 2 + 3) for Australian States and Territories [57].

State / Territory	**Emission Factors (scope 2 + scope 3) [kg CO_2-e/GJ]**								
	AccuRate Sustainability	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**Latest Estimate**
ACT	298	278	277	276	271	269	266	262	256
NSW	298	278	277	276	271	269	266	262	256
NT	382	220	216	217	214	212	209	204	201
QLD	283	277	270	262	260	258	256	256	256
SA	236	221	212	201	192	180	174	173	170
TAS	257	92	78	66	51	35	39	49	61
VIC	96	376	371	371	361	343	325	322	323
WA	215	251	241	233	231	225	217	210	207
AUS (avg.)	288	283	278	274	267	261	254	253	251

Although the emission factors of the majority of Australia's States and Territories, seem to vary only slightly year to year, these are shown to have significantly reduced each year in SA. This is largely due to the continued integration of renewable energy technologies, but also due to the closure of a coal-fired power station (Northern Power station, Pt Augusta) in 2015.

Review / recommendation: As emissions factors are updated regularly, it is highly recommended that a mechanism be introduced to AccuRate Sustainability that allows the user / assessor to adjust CO_2 emission factors.

2.3 Discussion

Rating tools need to b periodically updated to match the types of houses that are currently being designed and constructed in accordance with our modem life styles. For example, nowadays houses contain many appliances and gadgets, which were not previously available including home office equipment. In addition occupancy behaviour may need to be readdressed, e.g. where people operate their houses differently due to pet ownership.

As buildings become more energy efficient, heat transmission will become less significant compared to internal loads, and as such, internal heat loads will increase and the assumptions that go into the calculations will require periodic updating. As air tightness increases, moisture and mechanical ventilation systems, including heat recovery, may become more of a focal point in the future. These systems, along with blower door test results, will need to be incorporated into the next version of the rating tool.

The next generation of the rating tool should be able to reward innovative design solutions including the benefit of natural light, instead of penalising a design by increasing the cooling load. In addition, building material libraries need to be expanded to include emerging, creative and unconventional building materials, which currently cannot be include in a building model.

It is recommended that the next generation rating tool should be linked to all relevant regulations and standards; e.g. there is no coordination between MEPS regulation, gas standards or NatHERS. The former, will allow an assessor to easily see the impact of a new regulation automatically once an update is mandated. The tool should also have the ability to easily reference international building standards and building simulation tools.

3 Interrogation of Available Empirical/Monitoring Evidence

The purpose of this chapter is to highlight how Accurate has successfully contributed to the reduction of household energy, through facilitating the manifestation of Government regulation, helping to take the rating of residential dwellings from four stars in 2003 to six stars and higher today. This chapter also aims to show how, by utilising measured data, AccuRate Sustainability can be further improved through the refinement of existing assumptions and the development of new assumptions. Section 3.1 and 3.2 of this chapter verify some of the current highly significant assumptions, and confirm that energy can be saved by utilising AccuRate in the design process to increase the star rating of a particular building design. The remaining sections of Chapter 3 investigate the need for refinement of existing assumptions and development of new assumptions, through analysis of measured household energy and associated climate data.

3.1 Temperature Data Analysis

A large volume of temperature data were obtained and analysed for the purposes of this report. These analyses are contained in the following section and mostly relate to testing the assumptions contained within AccuRate Sustainability and the associated Chenath engine. These data relate to several different studies conducted in different Australian cities, including: Brisbane, Queensland; Melbourne, Victoria; and Adelaide, South Australia. These analyses pay particular attention to the assumptions and how these relate to existing adaptive comfort models and whether this type of model is suitable for use within NatHERS software.

3.1.1 Adaptive Thermal Comfort Literature Review

In ASHRAE 55-2013 [35], thermal comfort is defined as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. Apart from cultural influences, thermal comfort depends upon environmental and personal factors. It is complicated to predict the range of temperatures for this comfort condition. Thermal comfort has been discussed since 1930s. Climate chamber tests and field studies are two approaches used in the field of thermal comfort. Steady-state models were developed from climate chamber tests, which were based on heat exchange processes of the body, such as the widely used Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) model [58]. Most of the steady-state models were developed prior to the field studies.

Field studies conducted in real buildings led to adaptive thermal comfort models, which were based on the adaptive principle that occupants are active and not passive (the PMV method) relating to their thermal environment, i.e., “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” [59]. To do that, occupants may change their clothing, posture, activity, etc. or change their surrounding environment using windows, blinds, fans and in certain conditions mechanical space heating or cooling. People may also move around to find a room with improved conditions. Under the hypothesis of adaptive thermal comfort where people gradually lessen the human response to repeated environmental stimulation through both behavioural and physiological as well as psychological adaptation, and the fact that past thermal history will modify the occupant’s thermal expectations and preferences, people in warm climates will prefer higher indoor temperatures than those living in cold climates [37]. A number of studies show that the range of comfort temperatures in naturally ventilated buildings or mixed-mode buildings is much wider than what PMV-PPD predict [60-63].

The adaptive method was developed from field studies in mainly naturally ventilated office buildings [37, 64-69] by relating indoor operative temperatures (acceptable ranges) to prevailing outdoor temperatures. The acceptable range is the comfort temperature band within which the great majority of people, described by the percentage of acceptability, are adequately comfortable. This acceptable temperature range is wider than 'ideal' conditions and would encompass feeling such as 'slightly cool', 'slightly warm' and 'neutral'. Thermal comfort is subjective and personal, and there may be no single condition that is comfortable for all the occupants at any given time. Furthermore, the heating and cooling capacities required would be prohibitive if the acceptable temperature range has to be met for 100% of the occupancy time, even during extreme weather conditions [70].

Thermal comfort studies in buildings have been recently reviewed [71-75]. These studies discussed the research on steady-state and adaptive thermal comfort, as well as thermal comfort standards for naturally ventilated, air-conditioned and mixed buildings. Field studies in educational, office, residential and other building types were also examined. A number of other studies [76-82], have focused on the investigation of thermal comfort and energy efficiency. As mentioned in [74], in general, these studies of the energy use implications of thermal comfort in built environment can be grouped into two areas: case studies (HVAC, heated or cooled buildings) and implications for thermal comfort standards.

Most of the case studies for heating and cooling of buildings focused on increasing the summer set point temperature (SST) or setting a variable indoor set point temperatures for different times of the day and different outdoor conditions. Two major types of control strategies were proposed. The first type involved diverse thermostat techniques through changing the setback period, set point temperature, and setback temperature [83]. To have a better understanding the trade-off between thermal comfort and energy consumption, attempts have also been made [84, 85] to correlate cooling energy consumption with corresponding thermostat operational mode. The second type of control strategy covered deals with the dynamic control of the set point temperature based on adaptive thermal comfort models [39, 86]. Case studies summarized in [74] show that substantial energy can be saved for both office and residential buildings, ranging from 6% reduction in HVAC electricity usage in Australian office buildings (by increasing 1 °C in the SST) [87] up to a 33.6% reduction in total energy cost in hot desert region in Riyadh [88].

To offer a uniform method for the building industry and the general public, many studies have been undertaken on the implications of thermal comfort standards since early 2000s, including the works by de Dear and Brager [63] for global general buildings; Van der Linder et al. [89] for office buildings in Netherlands; Ogbonna and Harris [90] for classroom, studio and residential buildings in Nigeria; Nicol and Humphreys [91] for global general buildings; Nicol and Humphreys [66] for office building in Europe; Roaf et al. [92] for global general buildings; Yao, Liu and Li [93] for university classroom buildings in China; Indraganti [94] for residential buildings in India; Panao, Camelo and Goncalves [95] for residential and "small service" buildings in Portugal; Cândido et al. [96] for non-domestic buildings in Brazil; Yun, Kong and Kim [97] for office buildings in South Korea; Liang, Lin and Hwang [98] for school buildings in Taiwan; and Li et al. [99] for two types of buildings (heated/cooled or free-running mode) in China.

Nowadays the international standards commonly used to evaluate the thermal environments are ISO 7730-2005 [100], ASHRAE 55-2013 [35] and EN 15251-2007 [101]. The Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) method, which was based on Fanger's theory [58], is the basis of ISO 7730-2005 and the Graphic and Analytical Comfort Zone methods in the ASHRAE 55-2013 standards. Both EN 15251-2007 and ASHRAE 55-2013 standards adopted the adaptive thermal comfort method for the evaluation of the indoor environment of naturally ventilated buildings. The ISO 7730-2005 standard does not incorporate the adaptive thermal comfort method, but specifies the thermal indoor environment to be within 70% of the acceptability limit for naturally ventilated buildings [70]. For naturally conditioned spaces, ASHRAE 55-2013 specifies the acceptability limit to be 80%. To meet high occupant expectations of thermal environments, the acceptability limit of 90% is specified in ASHRAE55-2013.

The PPD is the complement of the thermal acceptability. For the three acceptability limits mentioned above the PPD are 30%, 20% and 10% respectively. Most previous studies have been concentrated on non-residential buildings. Compared to non-residential buildings, occupants of residential houses generally have greater opportunities (subject to the capabilities of the building and its systems) to decide and create thermal comfort conditions themselves. Given the large overall energy consumption from the residential sector, increasing energy prices, and changing climate, there is an increasing interest in the study of impact of different thermal comfort models (standards) on residential energy consumption. For instance, Attia and Carlucci [102] conducted a simulation study to compare the impact of four models (Fanger's model in ISO 7730, the ASHRAE55 adaptive comfort model, the EN15251 adaptive model and Givoni's model) on energy consumption and thermal performance for a zero energy multi-residential building in hot climates. This study shows, that to meet the thermal comfort criteria according to ISO 7730 in comparison to EN1521, ASHRAE 55 or Givoni's model, the percentage of energy consumption difference varied up to 16%, 21% and 24.7%, respectively. Kim et al. [40] carried out a field study of air conditioning and thermal comfort in residential buildings in Sydney and Wollongong, Australia. They found that the comfort zone widths for 80% acceptability were 9 K in residential settings, which is 2 K wider than that expected by the adaptive model. Shiel et al. [103] presented a simulation case study to estimate the space heating and cooling energy of a one-bedroom residential building in a warm temperate climate (Adelaide, South Australia) with global warming using alternative Standard Effective Temperature (SET∗) comfort approaches. For the SET∗ comfort approaches, the acceptability limits of 90% and 80% were also evaluated. The results from their study showed that the SET∗80% approach with air movement, changed clothing and occupant acclimatization can save over 95% of the Nationwide House Energy Rating Scheme (NatHERS) residential heating and cooling energy. Shiel et al. [103] suggested that more research is needed for the inclusion in NatHERS.

A few studies [104-106] have investigated the potential energy saving of non-residential buildings through adaptive thermal comfort approaches under climate change conditions. Case studies made in [104] for school and office buildings in United Kingdom indicate that high mass buildings are capable of providing a high quality of indoor thermal comfort when all the principles of low-energy and sustainable design are applied considering current and future climates. Touhy et al. [105] investigated the impact of two adaptive thermal comfort approaches on comfort and energy demand of a London office building. Variables such as future climate, future building upgrades, internal heat gains, setback temperatures and ventilation were also explored. The study suggests that for a typical office building under 2005 and predicted 2080 London climates, the building could achieve close to zero energy demand for space heating and cooling by a combination of strategies. Wan et al. [106] developed regression models to predict energy consumption of office building air conditioning for five typical climate regions in China under different climate change scenarios. An increasing trend of cooling load and a decreasing of heating load due to climate change in future years were predicted. As mentioned in [74], more work is required to analyse how, and to what extent future global warming impacts the applicability of adaptive thermal comfort models already developed and used in different regions worldwide.

Nicol [107] collected information from dwellings in a range of climates and buildings and found a very wide range of indoor temperatures in dwellings, which may be naturally ventilated or mechanically heated or cooled. The evidence from Nicol [107] suggests that the adaptive behaviours of building occupants occur when buildings are mechanically heated or cooled as well as when they are naturally ventilated and free-running. It is debatable how realistically these ranges can be acceptable in residential buildings and how different the ranges achieved by adaptive measures in houses can be [70].

3.1.2 Living Room Air-Conditioner Set Temperature for Houses in Study of Adelaide, Melbourne and Brisbane Houses

To understand air conditioning (A/C) operation behaviours, the indoor and outdoor thermal environment in the winter and summer, when air conditioning is operated regularly, is analysed in houses located in some of Australia's most dense population centres. The main data considered are the indoor and outdoor air temperatures, when air conditioners turn on and off, whilst the houses are occupied. The data collection and analysis methods are described below.

3.1.2.1 Data source

To investigate the impact of NatHERS house energy efficiency regulation on Australian residential buildings, the Australian Government commissioned CSIRO to do a survey and monitoring study in Brisbane, Adelaide and Melbourne in 2012. This study is commonly known as the Residential Building Energy Efficiency Study (RBEES). These three cities have different climates: Brisbane (warm humid summer, mild winter), Adelaide (warm temperate) and Melbourne (mild temperate). Half-hour electricity consumption data was collected using direct monitoring of electricity at the switchboard for 64, 66 and 59 houses in Brisbane, Adelaide and Melbourne respectively for 9 months from the beginning of June 2012 to the end of February 2013. The monitoring was continued after February 2013 to allow follow-up studies. Temperature measurements at the living areas were also taken at 30-minute intervals using Thermochron temperature sensor/data loggers, which have an accuracy of ±1°C within the temperature range from -30 °C to +70 °C. The temperature sensors were installed at locations where direct sunlight was avoided.

All the houses were built between 2001 and 2011. Among these monitored houses, 129 houses (21 in Melbourne, 49 in Adelaide and 59 in Brisbane), which have at least one reverse cycle air conditioner (A/C) installed, were chosen for this study, because these 129 houses have dedicated electric circuits for air conditioners. Between June 2012 and August 2014, a total of 1.86 million sets of half hour measurements were collected on A/C electricity consumption and living room air temperature for the 129 houses. The majority of these measurements were taken between the beginning of June 2012 to the end of February 2013. For each house, the air temperatures of the nearest Bureau of Meteorology (BoM) weather station were obtained as the outdoor air temperature. For details of the monitoring methodology, please refer to Ambrose et al. [50].

3.1.2.2 A/C switch on temperatures

The A/C power consumption measurements were analysed to find the A/C switch on and switch off temperature. A/C switch on is determined by a power consumption jump from zero or a low standby power consumption, while A/C switch off is judged by a power consumption drop to zero or a low standby power consumption. The indoor temperature at the beginning of the power jump is taken as the A/C switch on indoor temperature, T_{switchon}. Similarly, the A/C switch off indoor temperature, T_{off} was taken at the beginning of a power consumption drop. The indoor temperatures between the A/C switch on and switch off is the indoor temperature when A/C is in operation, i.e., $T_{\text{operation}}$.

When A/C is switched on, it means that the occupants would like to change the current indoor thermal condition which is most likely unsatisfactory. Figure 3-1 shows the probability of A/C switch on when the houses are at different indoor air temperatures. This probability is calculated as the number of A/C switch on at one specified indoor temperature divided by the total number of half hour records when the house is at this specified indoor temperature. Figure 3-1 does not include the lowest and the highest indoor temperatures experienced in the houses in each city, because switch on events for these extreme indoor temperatures are too low (less than 10). It is seen that A/C is most unlikely to be switched on at around 20-22.5°C, 21.5-24°C and 23.5-26°C indoor temperatures in Melbourne, Adelaide and Brisbane, respectively. The temperature range around 20°C to 26°C is arguably the most preferred temperature range or the easiest temperature range for thermal adaption by the majority of the populations in buildings with heating and cooling [68]. These preferred temperature ranges increase with the average outdoor temperatures, which suggests thermal adaptation to the local climate.

It is noted that many low indoor temperatures occur during sleeping hours, this period has the lowest probability of A/C operation. This may explain that the switch on curve at low indoor temperatures in Figure 3-1 is not as decisive as the curve at high indoor temperatures which often occur during late afternoon and evening when occupants are awake and active. The probability of A/C switch on increases rapidly at high indoor temperatures above the preferred ranges.

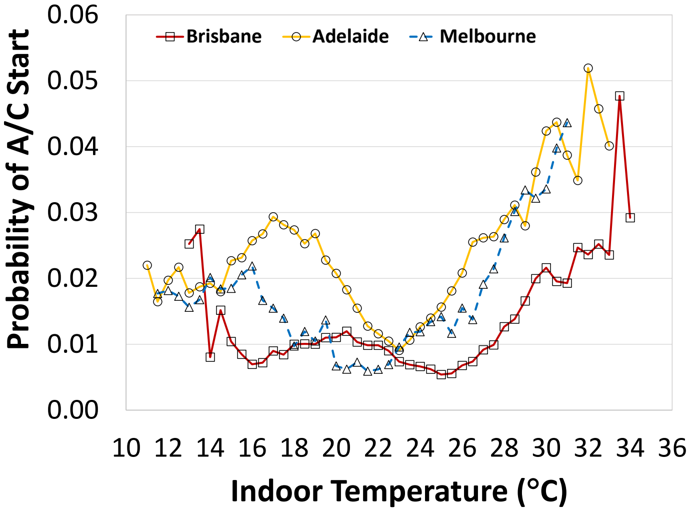


Figure 3-1: A/C "switch on" probability at different indoor air temperature in Brisbane, Adelaide and Melbourne

Figure 3-2 shows the relationship between the indoor air temperatures when A/C is switched on, (i.e. T_{switchon}) and the running average outdoor temperature ($T_{\text{runningaverage}}$) in Brisbane, Adelaide and Melbourne respectively. Here, the running average outdoor temperature $T_{\text{runningaverage}}$ is the mean temperature for the previous seven days. For each city, the left side plot shows the correlation including all the data points in the whole range of the running average outdoor temperature (referred to as single range plot hereafter). The right side plot shows the correlations if the running average outdoor temperature is divided into three ranges, the low range, the shoulder range and the high range (referred to as three range plot hereafter). These ranges are 10.1 - 15.5°C, 15.6 - 22.8°C, 22.9 - 27.5°C for Brisbane; 4.9 - 12.7°C, 12.8 - 22.0°C, 22.1 - 30.4°C for Adelaide; and 7.0 - 12.8°C, 12.9 - 19.5°C, 19.6 - 27.2°C for Melbourne respectively.

It was found that for the single range plot, the correlation slopes between T_{switchon} and $T_{\text{runningaverage}}$ are between 0.63 and 0.74 for the three cities. However, for the three range plot, the correlation slopes between T_{switchon} and $T_{\mathrm{runningaverage}}$ are between 0.02 and 0.37 for the three cities for the low and the high ranges. For Adelaide and Melbourne, the correlation slopes are all below 0.28 for the low and the high ranges. For the shoulder ranges, the correlation slopes are high at around 1.0 for the three cities. Figure 3-2 suggests that occupants are not very tolerant at the low and the high $T_{\mathrm{runningaverage}}$ ranges, while they are more adaptive with the shoulder $T_{\mathrm{runningaverage}}$ range which is a transition from relatively cold to hot outdoor air temperatures. This low tolerance at the low and the high $T_{\mathrm{runningaverage}}$ range can be more clearly seen by the flat median (50-percentile) T_{switchon} values at the low and the high $T_{\mathrm{runningaverage}}$ ranges in the single range plots in Figure 3-2.

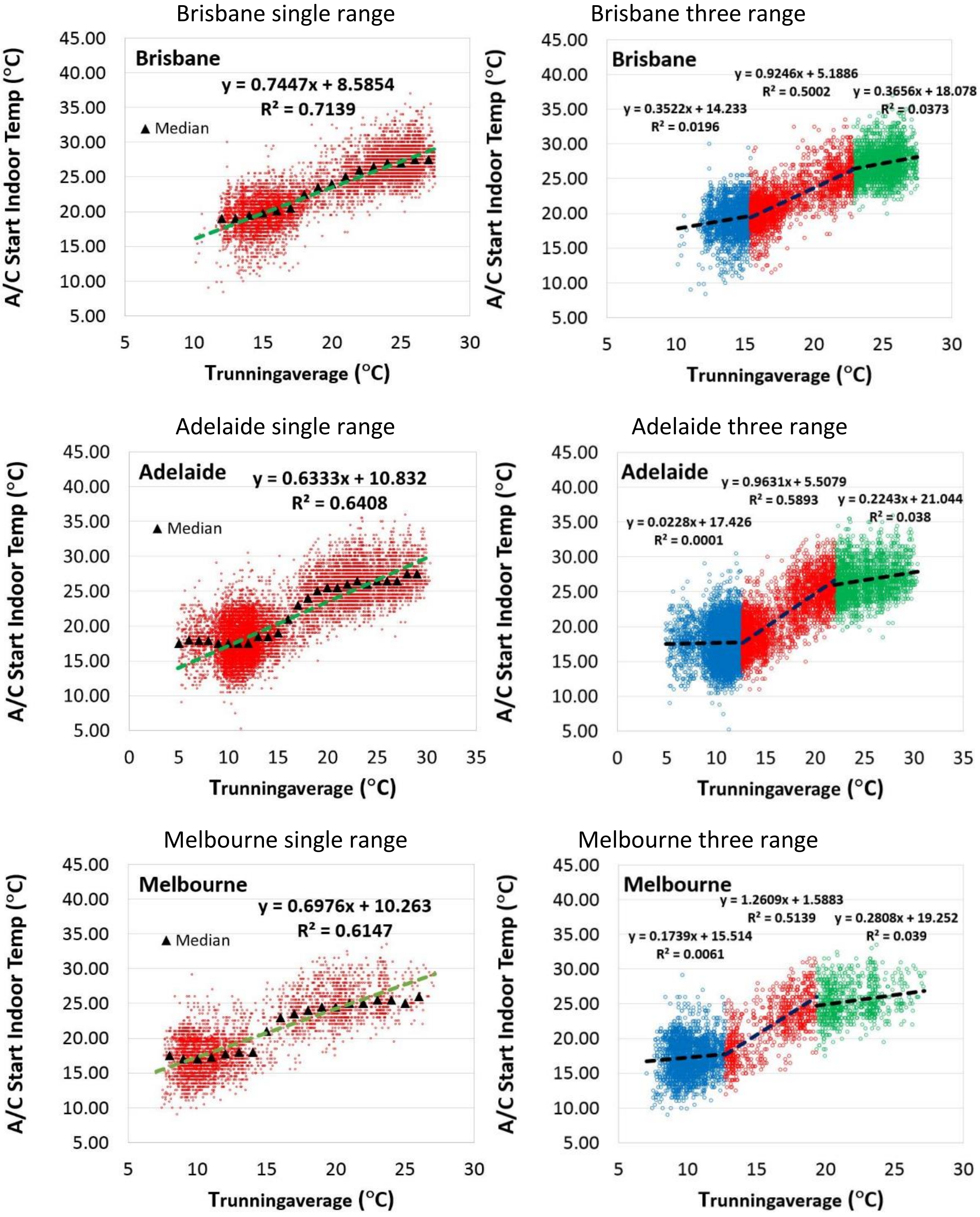
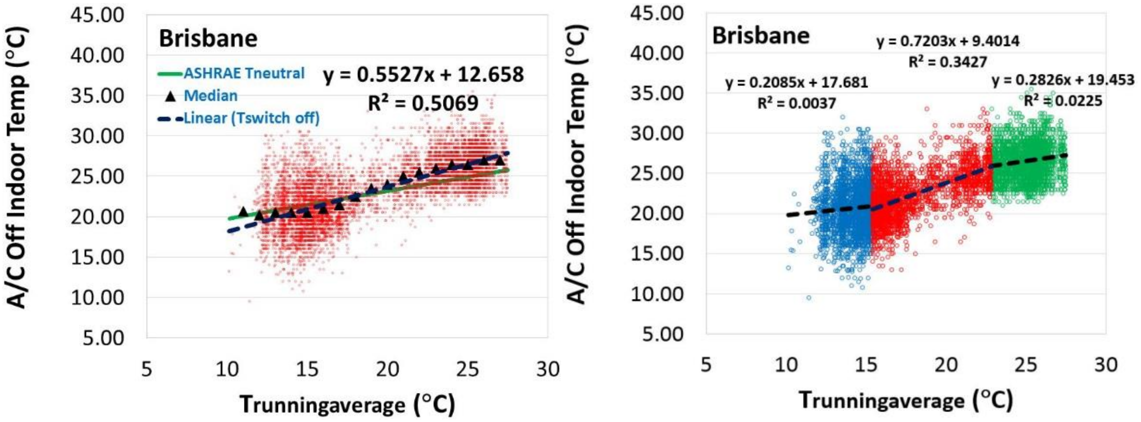


Figure 3-2: A/C "switch on" indoor air temperature at different running outdoor average temperature in Brisbane, Adelaide and Melbourne

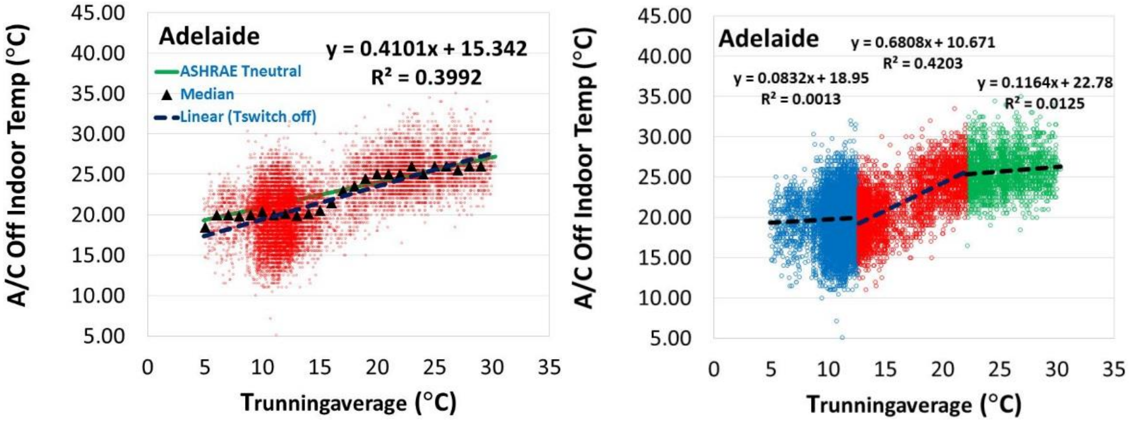
3.1.2.3 A/C switch off temperatures

A/C may be switched off when the occupants judge the indoor environment can maintain comfortable without A/C running, or when the occupants leave the air-conditioned space or the house. Kim et al. [40] discussed the A/C switch off indoor temperature (T_{off}) and considered that it may be a good approximation of occupants' comfort temperature. Figure 3-3 shows the relationship between Toff and $T_{\text{runningaverage}}$ for Brisbane, Adelaide and Melbourne respectively. The left side shows the single range plot and the right side shows the three range plot. The single range plots also include the neutral temperature T_{neutral} calculated using Eq. (1) by replacing T_m with $T_{\text{runningaverage}}$.



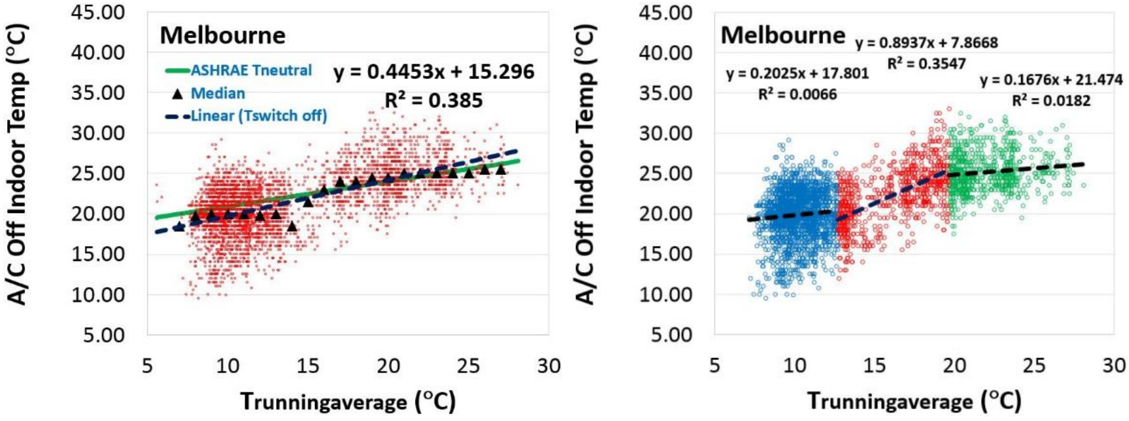
Brisbane single range

Brisbane three range



Adelaide single range

Adelaide three range



Melbourne single range

Melbourne three range

Figure 3-3: A/C "switch off" indoor air temperature at different running outdoor average temperature in Brisbane, Adelaide and Melbourne

In general, the correlations for the three cities are not far from the neutral temperature predicted by the ASHRAE adaptive thermal comfort model. The slightly higher correlation slopes from the measured T_{off} in comparison with $T_{neutral}$ may be due to several factors, i.e.:

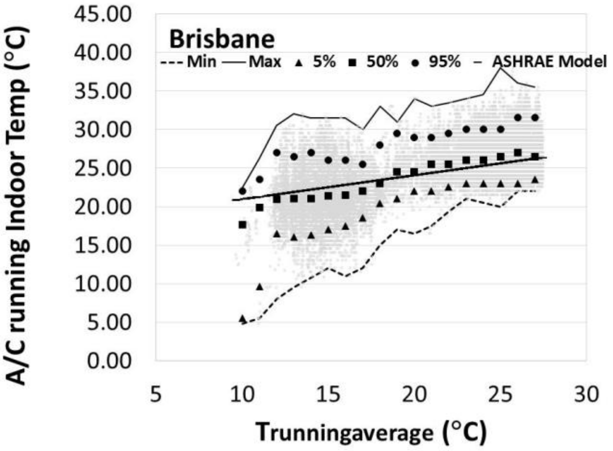
- Occupants do not heat or cool the living room to the neutral temperature since slightly cold (during heating) and slightly warm (during cooling) are acceptable.
- The A/C capacity is insufficient to heat or cool the living room to the neutral temperature.
- Due to the cost of running A/C at high capacity, and so on.

Similar to A/C switch on, Figure 3-3 again shows the existence of three $T_{runningaverage}$ ranges: a low, a shoulder and a high range for each climate. At the low and the high ranges, the occupants have less tolerance to the thermal environment, while the occupants are more adaptive in the shoulder range.

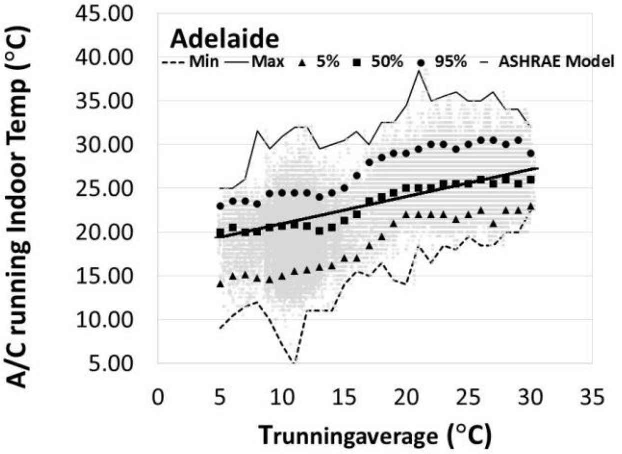
3.1.2.4 A/C operation indoor temperatures

Figure 3-4 shows the living room temperature when A/C is running as a function of $T_{runningaverage}$: minimum, maximum, 95-, 50-, and 5-percentiles for the houses in the three cities. It is seen that except those low $T_{runningaverage}$ where the measurements are sparse and the shoulder $T_{runningaverage}$ range, the median (50%) indoor temperature are relatively flat for cooling and heating. This trend is similar to that reported by Peeters et al. [39] for Belgian dwellings. Figure 3-4 also includes the neutral temperature line for the ASHRAE adaptive model, i.e. Eq. (1) by replacing T_m with $T_{runningaverage}$. It is interesting to see that the median indoor temperatures when A/C is in operation for the three cities are spread around the ASHRAE adaptive model line, except that the median indoor temperatures flatten out at the low and high $T_{runningaverage}$ ranges. Combining the findings above for T_{off}, the indoor temperature clouds during A/C operation may suggest that occupants' thermal comfort in the heated and cooled houses in these three cities may be not far from the ASHRAE adaptive model, however, there are obviously limits existing at the low and high $T_{runningaverage}$ ranges.

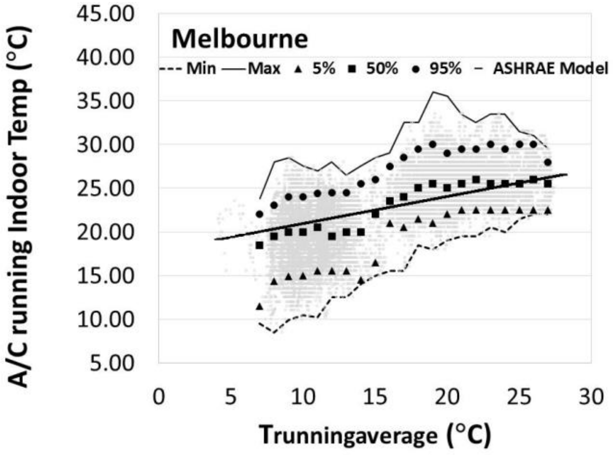
Table 3-1 lists the average median indoor temperature when A/C is in operation, the 80-percentile (from 10-percentile to 90-percentile) and the 90-percentile temperature (from 5-percentile to 95-percentile) bands for the three cities for heating and cooling respectively. In the brackets in Table 3-1, the positive value is the upper band and the negative value is the lower band. It is seen that the median heating indoor temperatures are between 19.3 and 20.9°C. In general, the temperature band for heating is wider than that for cooling. This is in agreement with that reported by Peeters et al. [39] for Belgian dwellings. In average, the 80-percentile indoor air temperature bands are 7.3°C and 6.2°C for heating and cooling respectively. The 90-percentile indoor air temperature bands are 9.3°C and 7.8°C for heating and cooling respectively which is within the ranges reported by Nicol [107] for residential buildings.



(a) Brisbane



(b) Adelaide



(c) Melbourne

Figure 3-4: Living room temperature when A/C in running as a function of $T_{runningaverage}$: minimum, maximum, 95-, 50-, and 5-percentiles

Table 3-1: Average median indoor temperature and 80-, 90-percentile temperature bands when A/C runs

Location	Average Median Temperature [ºC]		Average 80% percentile band [ºC]		Average 90% percentile band [ºC]	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
Brisbane	20.9	27.4	7.7(4.1,-3.6)	6.2(2.9,-3.3)	9.8(5.2,-4.6)	7.8(4.0,-3.8)
Adelaide	20.0	26.1	7.1(2.8,-4.3)	6.1(3.4,-2.7)	9.0(3.7,-5.3)	7.8(4.4,-3.4)
Melbourne	19.3	26.2	7.0(3.2,-3.8)	6.2(3.2,-3.0)	9.0(4.0,-5.0)	7.9(4.1,-3.8)

3.1.2.5 The relationship between A/C switch on and A/C operation indoor temperatures

Figure 3-5 and Figure 3-6 show the relationship between the average $T_{switchon}$ and the average A/C operation indoor temperature $T_{operation}$ for each house in winter and summer in Brisbane, Adelaide and Melbourne respectively. It is seen that for each city, occupants operate houses in significantly wide ranges of average heating and cooling indoor temperatures. For heating, this was from 13 to 23 °C. For cooling, it was from 22 to 31°C. It is also seen that the average $T_{switchon}$ and the average $T_{operation}$ are well correlated. It means that occupants who switch on A/C at low indoor temperatures prefer running A/C at low indoor temperatures. The opposite is true that occupants who switch on A/C at high indoor temperatures prefer running A/C at high indoor temperatures.

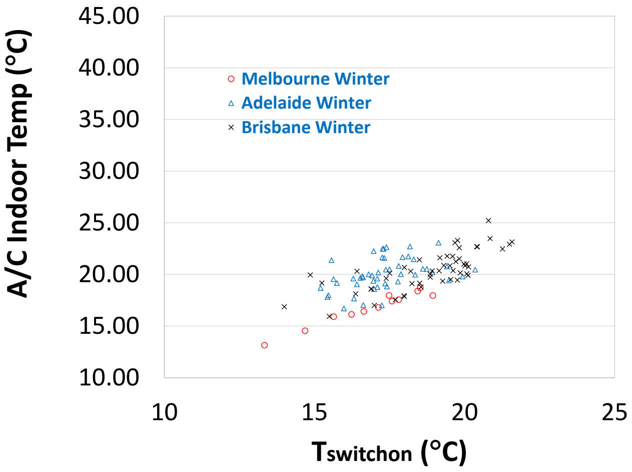


Figure 3-5: Relationship between the average A/C switch on indoor temperature and the average A/C operation indoor air temperature for each house in winter and summer

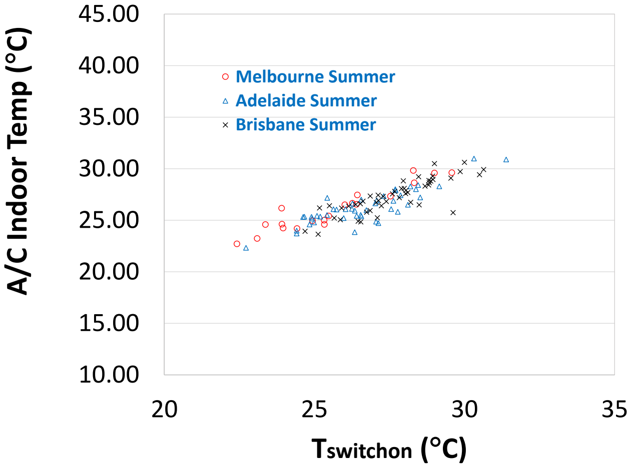


Figure 3-6: Relationship between the average A/C switch on indoor temperature and the average A/C operation indoor air temperature for each house in winter and summer

3.1.2.6 *Implications for energy efficient building regulations*

The findings of the current study may have several implications for the improvement on the thermostat settings and A/C operation assumptions for house energy rating in Australia. It is very likely that the existing static thermostat setting approach will continue to be used in the AccuRate software for house energy rating in Australia for the foreseeable three to five years. The findings in this study the $T_{switchon}$, $T_{operation}$, Toff are relatively flat at the low and high $T_{runningaverage}$ ranges do support such simplifications before a more reliable dynamic thermostat setting approach can be established.

Table 3-2 lists the average median $T_{switchon}$, $T_{operation}$, T_{off} for heating and cooling for the three cities. In the brackets are the existing assumed thermostat settings in AccuRate for house energy rating calculations. For heating, the thermostat of 20°C in the living room appears reasonable for Adelaide, but is about 0.7°C higher and 0.9°C lower for Melbourne and Brisbane respectively. However, the heating switch on temperatures in Adelaide and in Melbourne in the existing AccuRate software for living room is too high and a switch on indoor temperature of around 17.0°C may be more adequate. For cooling, the average median cooling switch on temperature are around 0.5°C lower than the currently assumed values for the three cities. However, the median indoor temperatures, when A/C is running which may be considered as the real thermostat set point, are about 1.5°C above the currently assumed values for the three cities. It may be arguable whether it is adequate to use the average median $T_{switchon}$ and $T_{operation}$ for setting the A/C triggering indoor temperature and the thermostat set point temperature. Further research is needed.

It is noted that the current research only provides one angle of the understanding of thermal comfort and occupants' A/C operation behaviours in houses. The study has at least the following limitations:

- The number of houses investigated are limited;
- Measurements were only taken for air temperatures in the living room. Indoor relative humidity mean radiant temperatures and air movement velocity were not measured. Further, indoor temperatures in bedrooms are likely different from those in living rooms;
- Thermal comfort surveys were not carried out during the monitoring period.

Considering the importance of thermal comfort and A/C operation in house energy efficiency regulation development, further research is needed to validate and improve the understanding in both occupants' thermal comfort and A/C operation behaviours in Australian residential houses.

Table 3-2: Average median $T_{switchon}$, $T_{operation}$, T_{off} for heating and cooling for the three cities (In the brackets are the existing assumed thermostat settings in AccuRate for house energy rating calculations)

Location	**Average Median $T_{switchon}$ [ºC]**		**Average Median $T_{operation}$ [ºC]**		**Average Median T_{off} [ºC]**	
	Heating	**Cooling**	**Heating**	**Cooling**	**Heating**	**Cooling**
Brisbane	19.5(20.0)	27.7(28.0)	20.9(20.0)	27.4(25.5)	20.4(20.0)	26.6(25.5)
Adelaide	17.3(20.0)	26.9(27.5)	20.0(20.0)	26.1(25.0)	20.5(20.0)	25.7(25.0)
Melbourne	16.6(20.0)	26.1(26.5)	19.3(20.0)	26.2(24.0)	20.2(20.0)	25.6(24.0)

3.1.3 House Living Room Temperature and Humidity Trends in RBEES Data

Investigating internal temperature and humidity conditions inside houses as compared to external conditions helps to understand how a house is performing thermally and when conditioning may be required and/or is in operation. Data collected as part of a CSIRO study [50] provides some insights it how houses are performing in three Australian cities (Adelaide, Brisbane and Melbourne). The following charts are from data gathered as a follow up investigation to the main research project and allowed researchers to upgrade temperature sensors to ones that also recorded relative humidity.

Data was gathered in all three cities from June 2015 until November 2017 from 58, 42 and 62 houses in Adelaide, Brisbane and Melbourne respectively.

The first series of charts show the average monthly temperature and relative humidity data for four times of the day (morning, afternoon, evening and night). For Adelaide and Melbourne, it shows the evening heating occurring during the winter months that is maintaining internal temperatures at around 19.5°C. Average night time temperatures in winter in Adelaide and Melbourne do not drop below 16.5°C. In summer, average afternoon and evening temperatures track very closely to each other in Adelaide and Melbourne as do the morning and night average temperatures. In Brisbane, temperature profiles are more evenly spread across the day, especially during the summer months.

Average monthly relative humidity data shows that Adelaide houses experience low humidity during the summer months and higher over the winter months. This is in line with the Adelaide climatic conditions. Melbourne houses have a mainly stable relative humidity throughout the year, averaging around 53.5%. Brisbane follows the climatic conditions of its sub-tropical environment with high humidity during summer and lower over winter. Evening and afternoon humidity during summer is lower than night and morning humidity suggesting that conditioning is being used at these times to keep houses comfortable.

Maximum and minimum temperatures recorded for each month for each city are also displayed as box and whisker graphs that show the average maximum and minimum temperatures being experienced as well as the extremes. In summer months some houses in all cities experienced internal temperatures in excess of 35°C, with several temperatures in excess of 40°C recorded in Melbourne houses. On average, houses had average maximum temperatures in summer of over 30°C which is well outside accepted comfort ranges. In winter some houses in Adelaide and Melbourne recorded temperatures below 8°C, while most winter recordings in Brisbane remained above 10°C. On average most houses experienced winter minimums of around 12°C.

The second series of charts show average hourly temperature and relative humidity readings for both the summer and winter periods. The average external temperature and relative humidity readings are also displayed as recorded by the closest Bureau of Meteorology station. In summer peak average internal temperature is achieved at 4pm, 3pm and 6pm in Adelaide, Brisbane and Melbourne respectively which is around three hours after the external peak temperatures is achieved in each city. In all three cities houses remain warmer than the external temperature during the summer evening and night time periods indicating that they are not taking advantage of night purging opportunities.

In winter, evening heating is evident in both Adelaide and Melbourne houses with temperatures not starting to drop until 10pm indicating that heating systems are switched off or thermostats reduced at this time. Brisbane houses show little evidence of winter evening heating with houses starting to cool down from a peak at 4pm, but still maintaining an average internal temperature of 20°C.

Internal relative humidity during winter is very even across the day in all three cities averaging around 55% in all locations. In summer this level of relative humidity is maintained in Melbourne, but in Brisbane daily average RH increases to 62% and peaks in the early morning at 67% at 7am, similar in time to the external peak at 85% at 5am. Adelaide summer RH is similar for both internal and external locations at a low 48% reflecting Adelaide’s dry and hot summer averages.

3.1.3.1 Average monthly temperature and humidity

3.1.3.1.1 Adelaide monthly

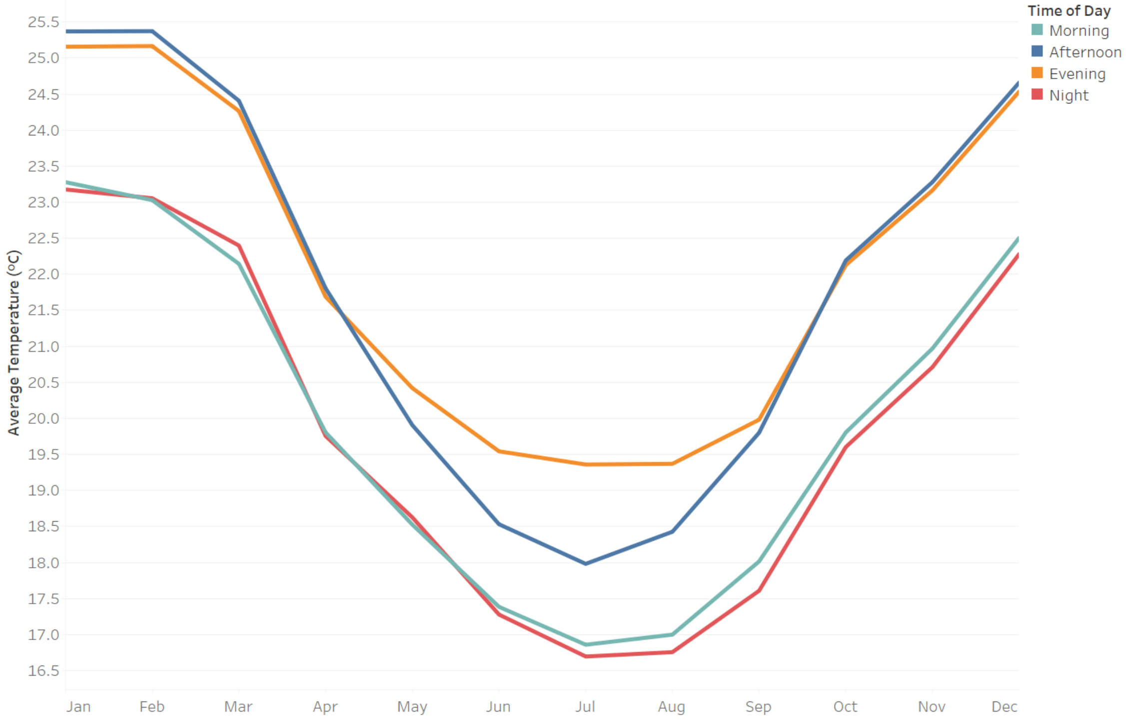


Figure 3-7: Average monthly living room temperatures by time of day for Adelaide houses

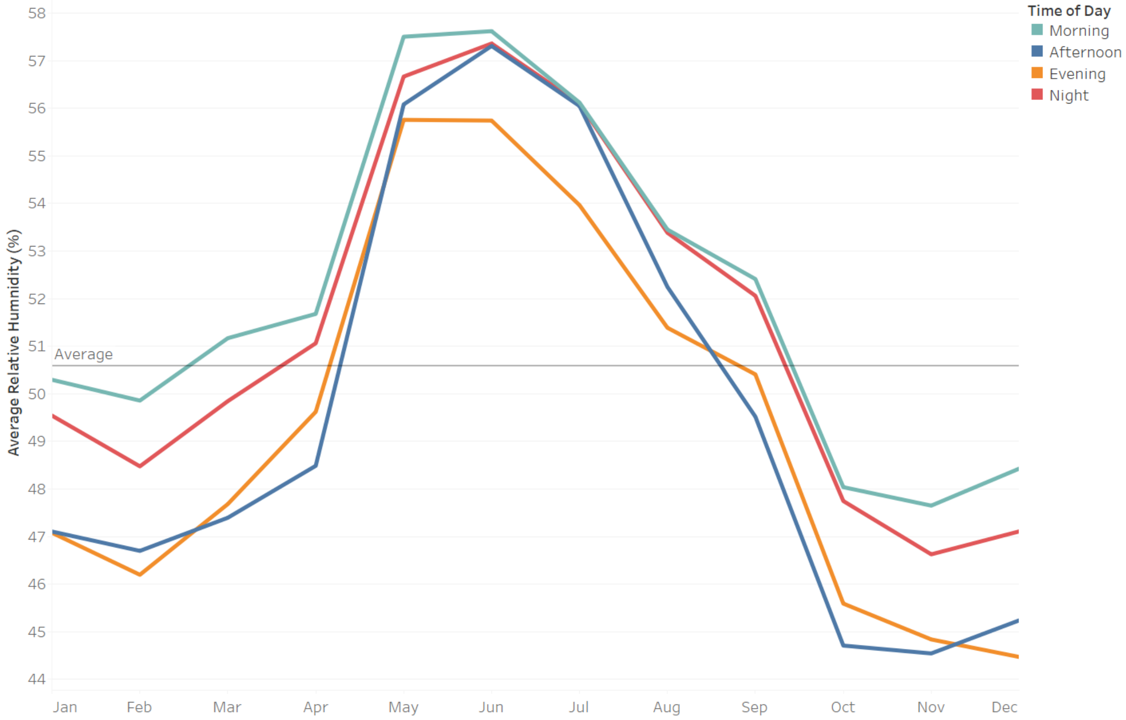


Figure 3-8: Average monthly living room relative humidity by time of day for Adelaide houses

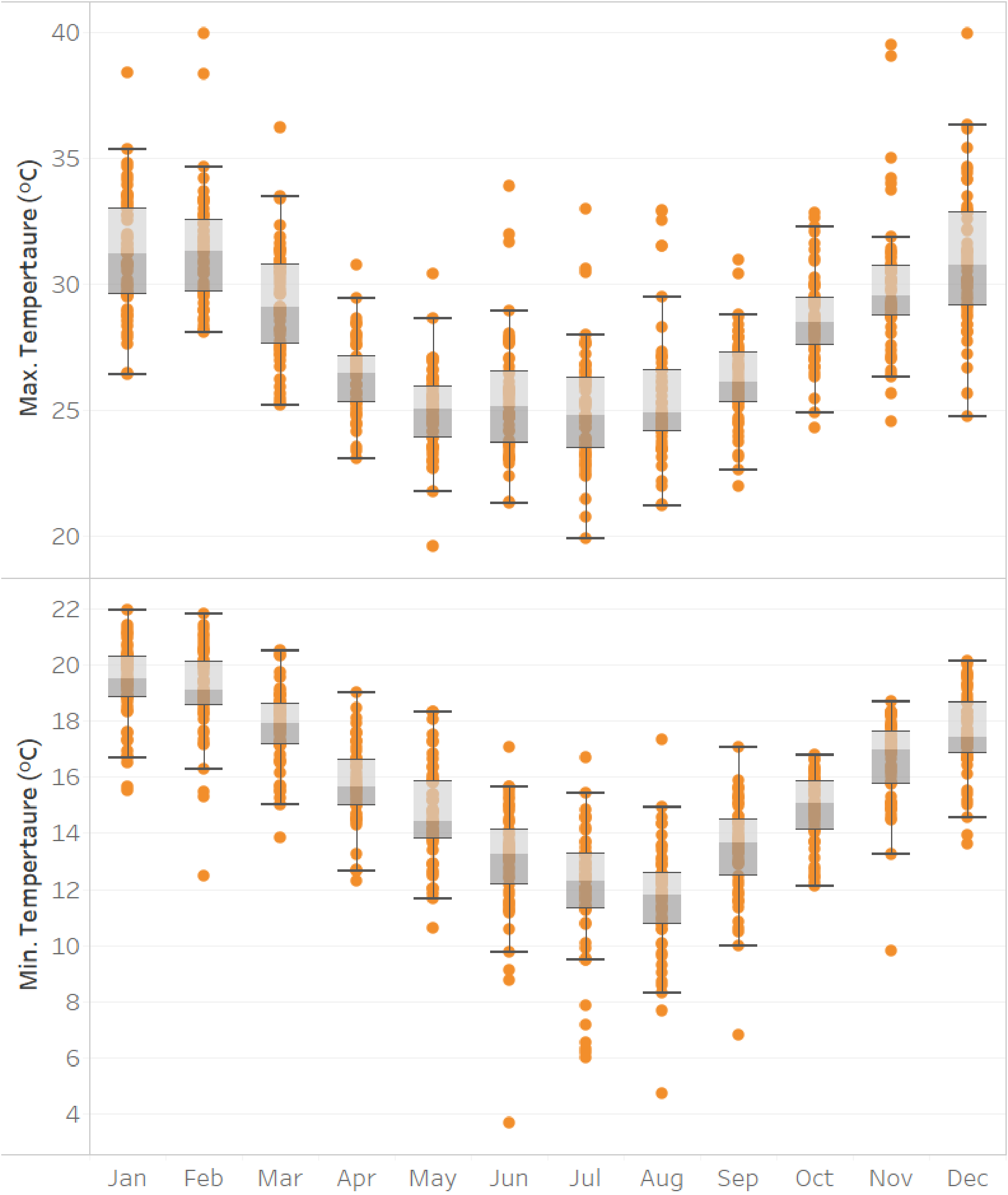


Figure 3-9: Maximum and minimum internal living room temperatures for Adelaide houses

3.1.3.1.2 Brisbane monthly

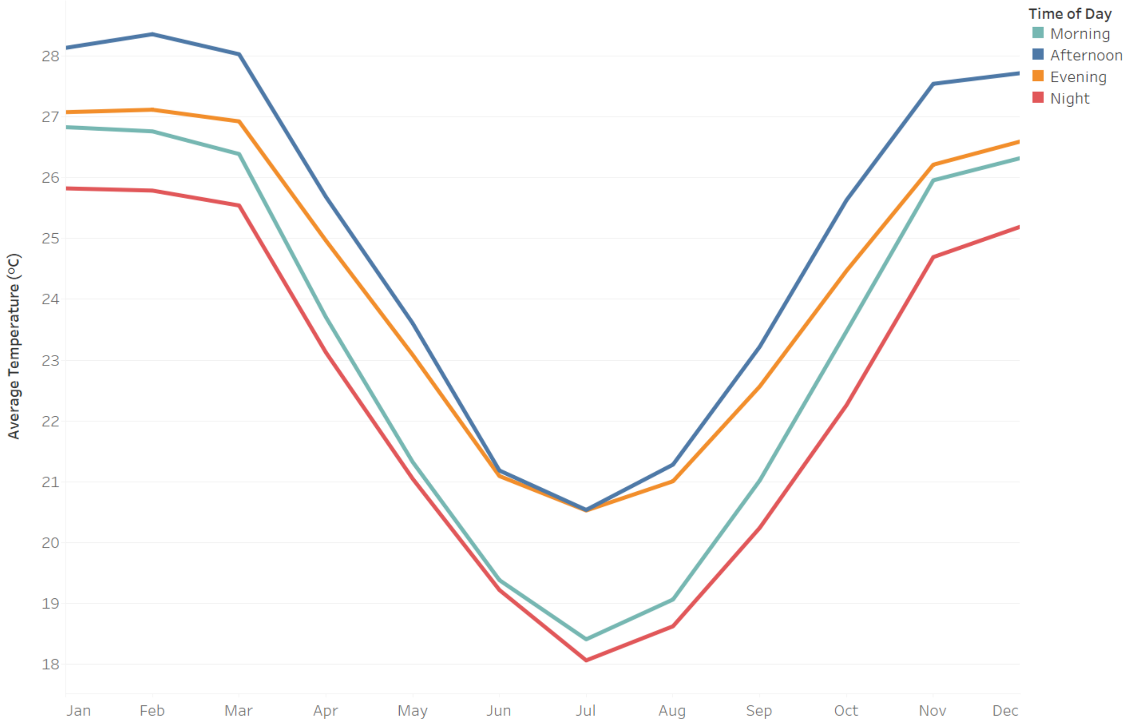


Figure 3-10: Average monthly living room temperatures by time of day for Brisbane houses

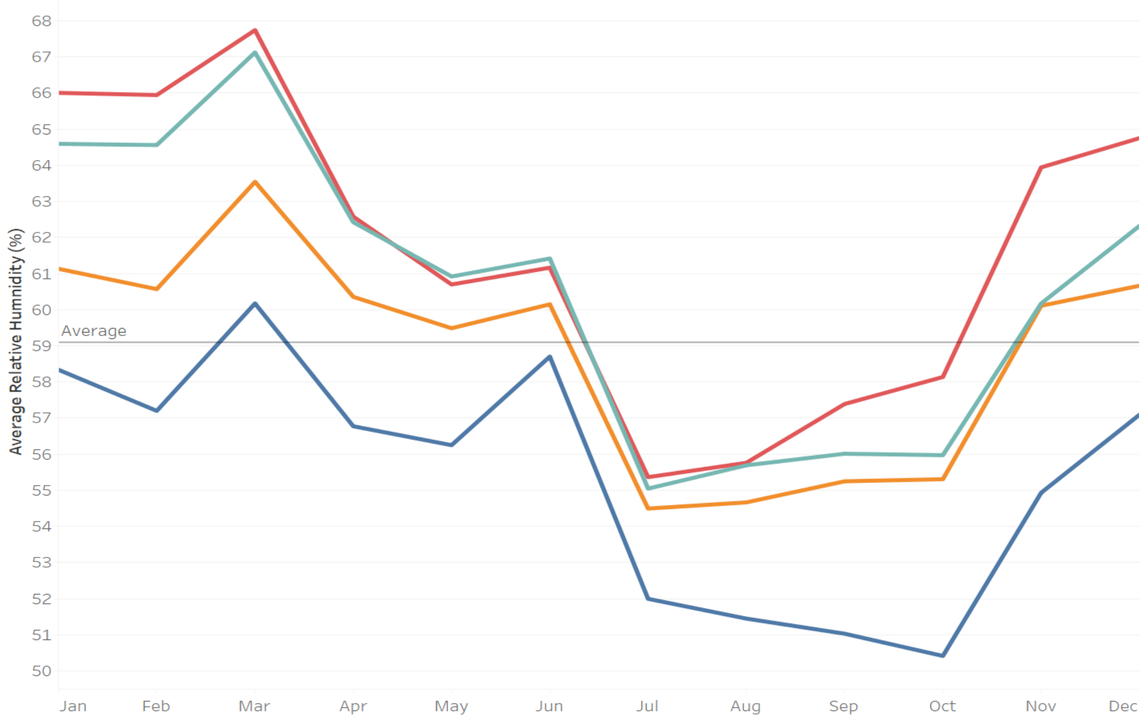


Figure 3-11: Average monthly living room relative humidity by time of day for Brisbane houses

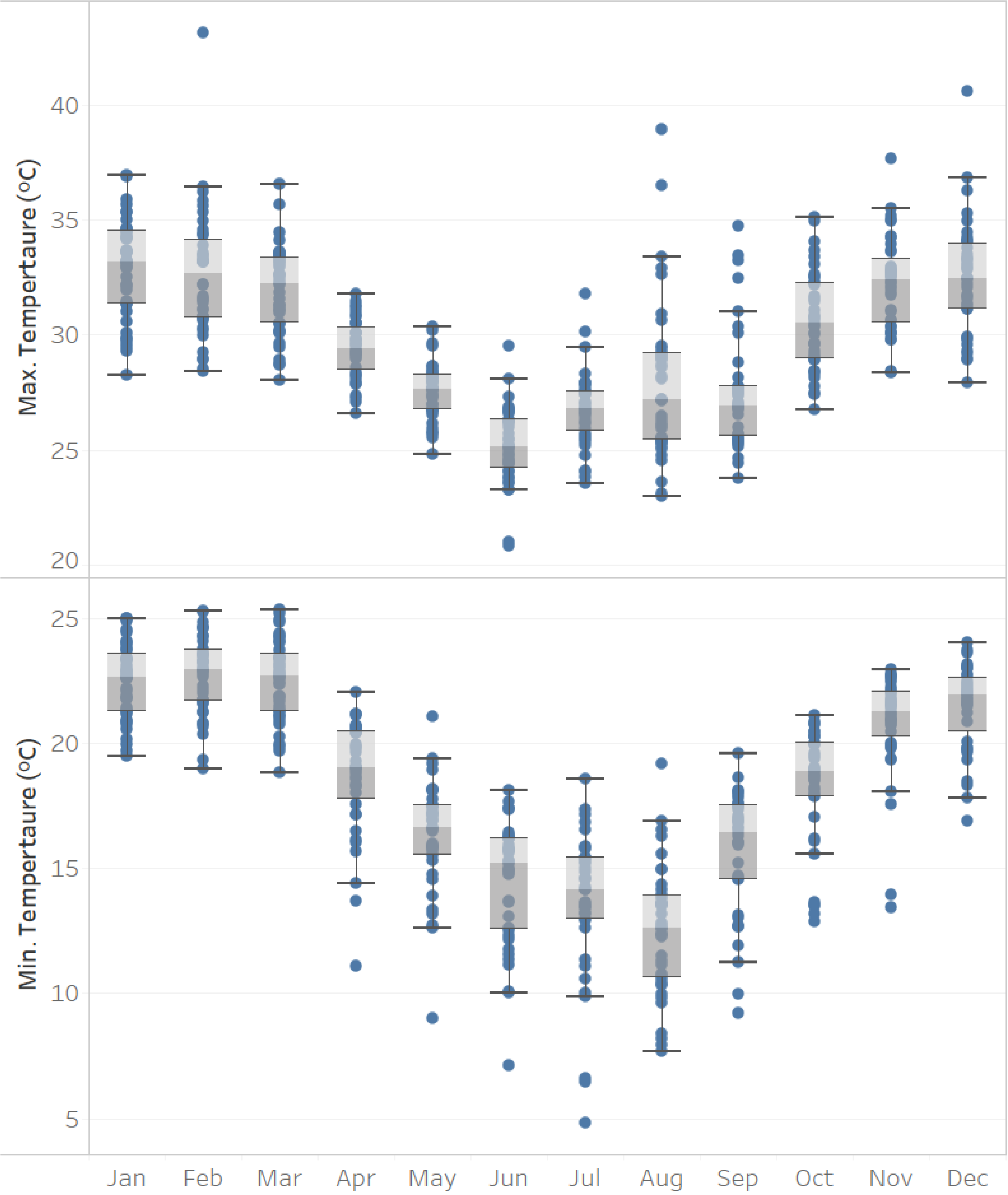


Figure 3-12: Maximum and minimum internal living room temperatures for Brisbane houses

3.1.3.1.3 Melbourne monthly

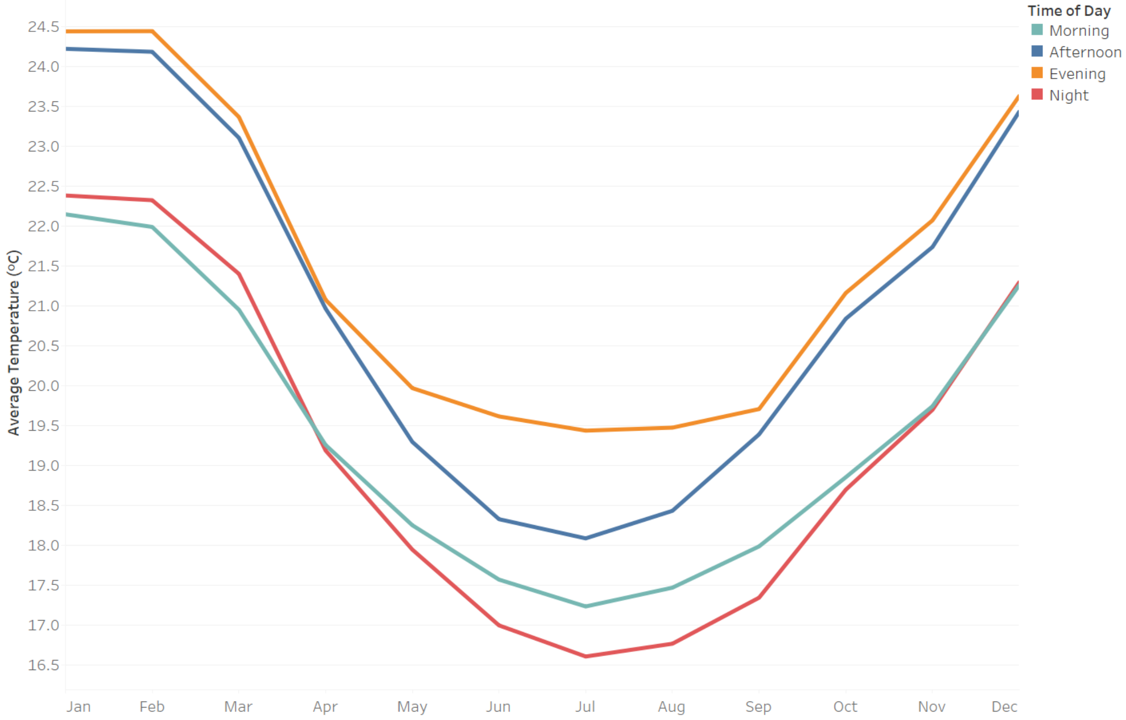


Figure 3-13: Average monthly living room temperatures by time of day for Melbourne houses

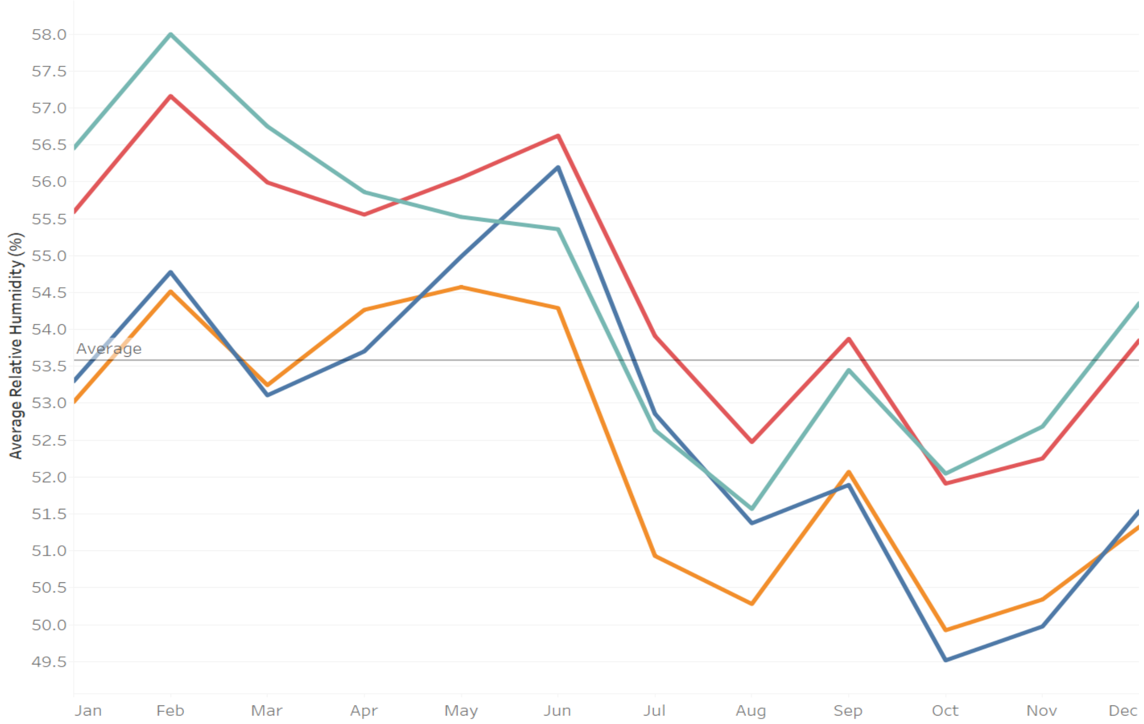


Figure 3-14: Average monthly living room relative humidity by time of day for Melbourne houses

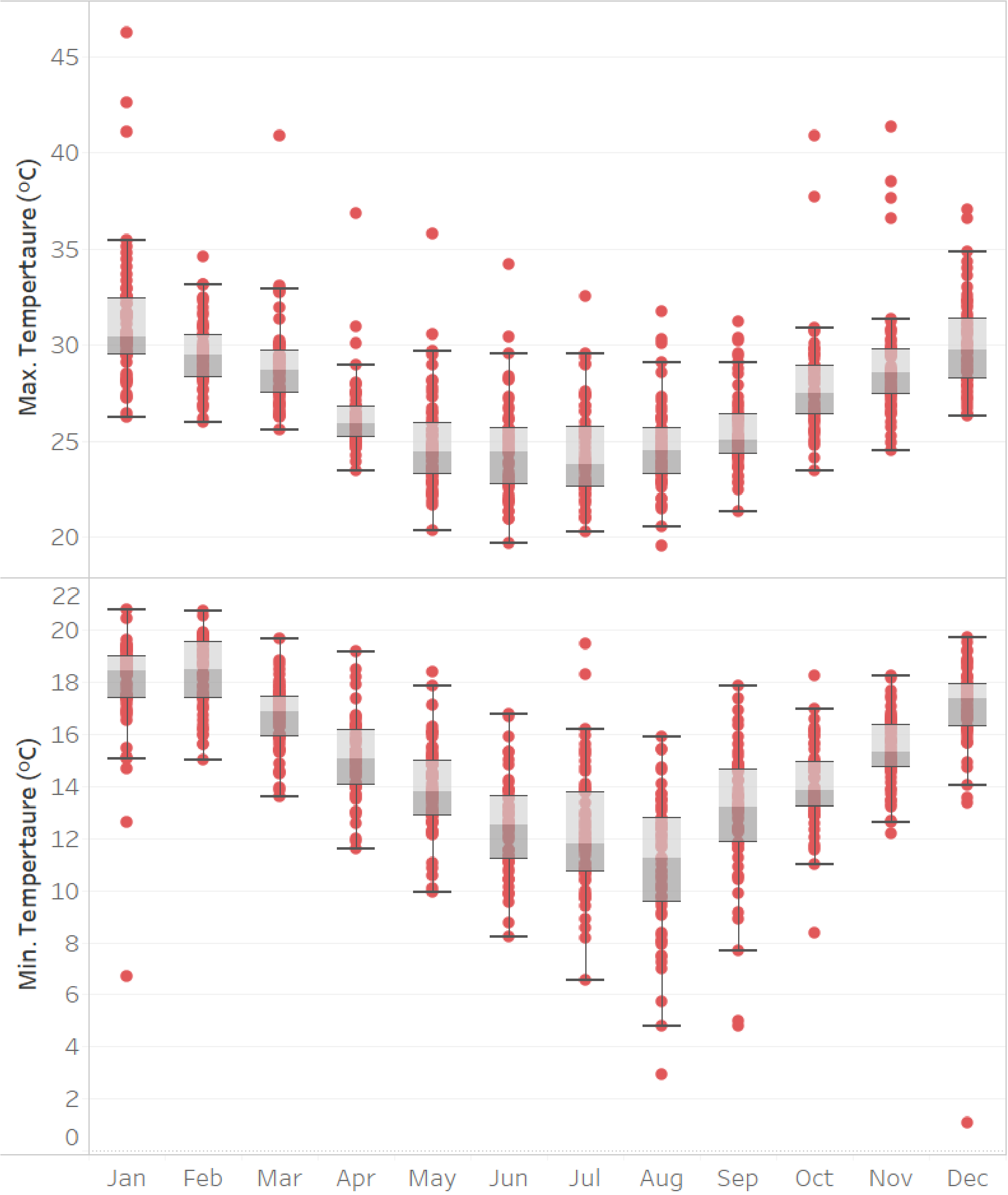


Figure 3-15: Maximum and minimum internal living room temperatures for Melbourne houses

3.1.3.2 Average hourly temperatures and humidity

3.1.3.2.1 Adelaide hourly

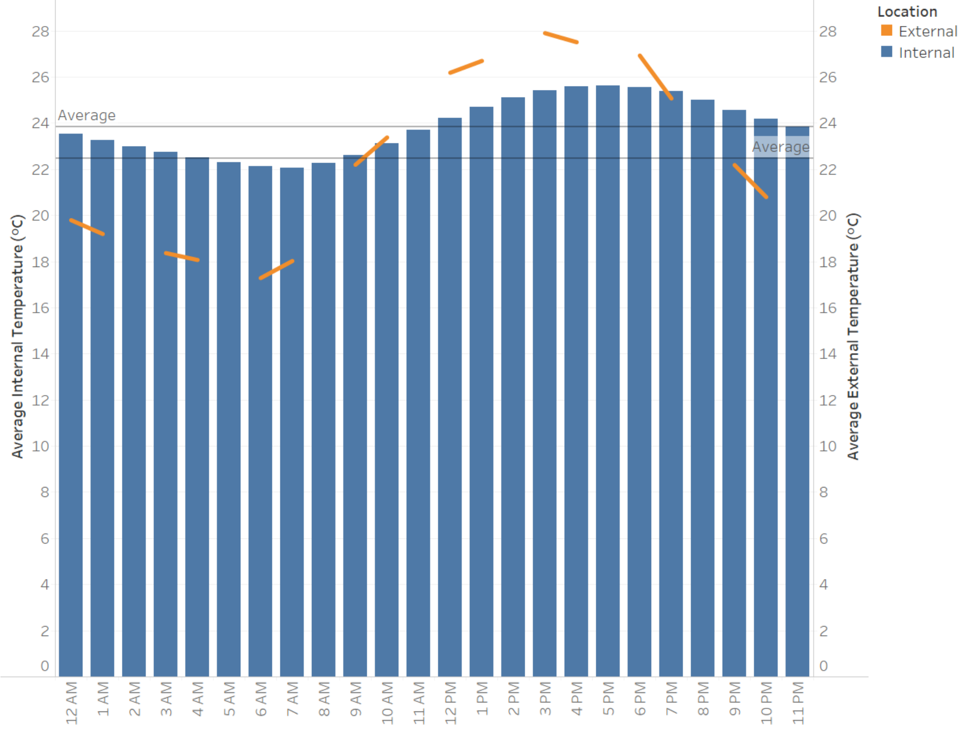


Figure 3-16: Average hourly internal and external temperatures for summer months in Adelaide

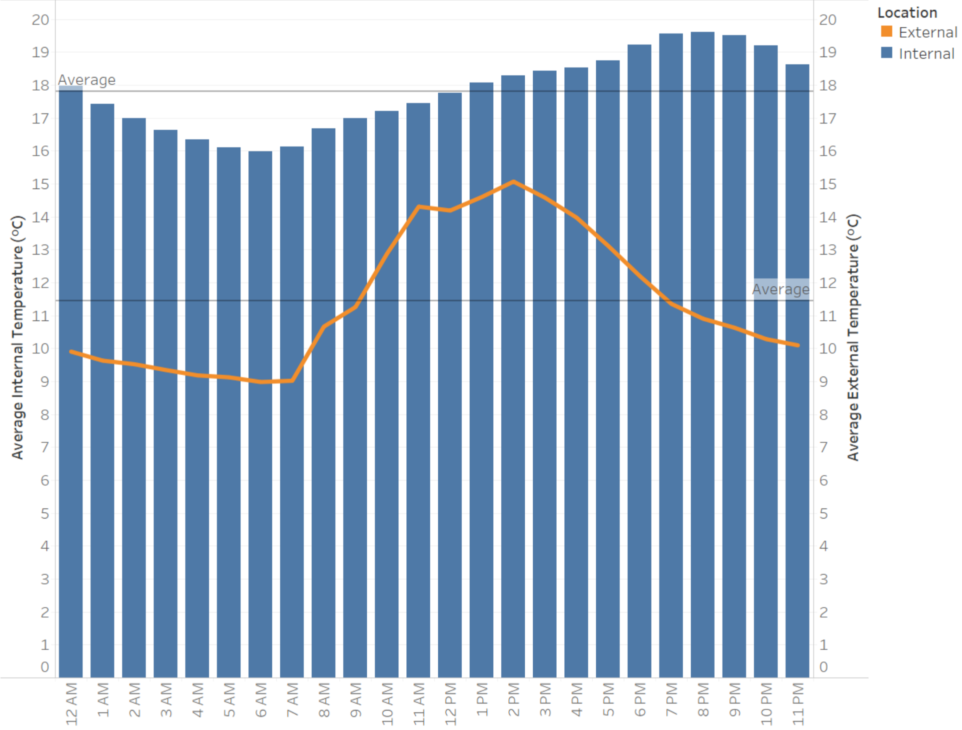


Figure 3-17: Average hourly internal and external temperatures for winter months in Adelaide

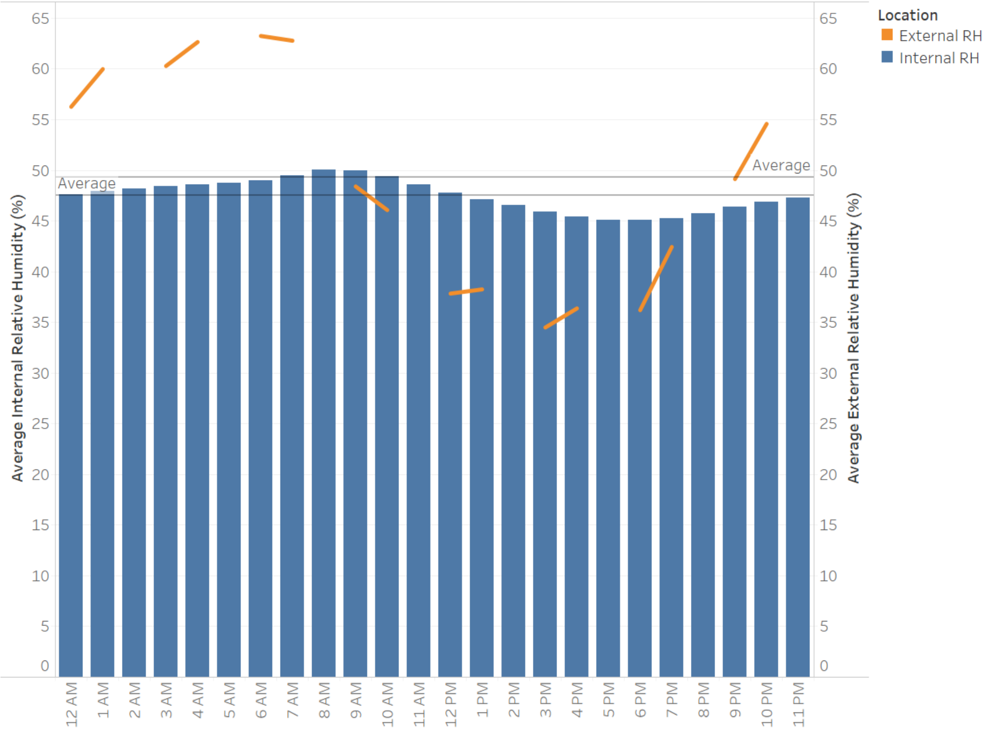


Figure 3-18: Average hourly internal and external relative humidity for summer months in Adelaide

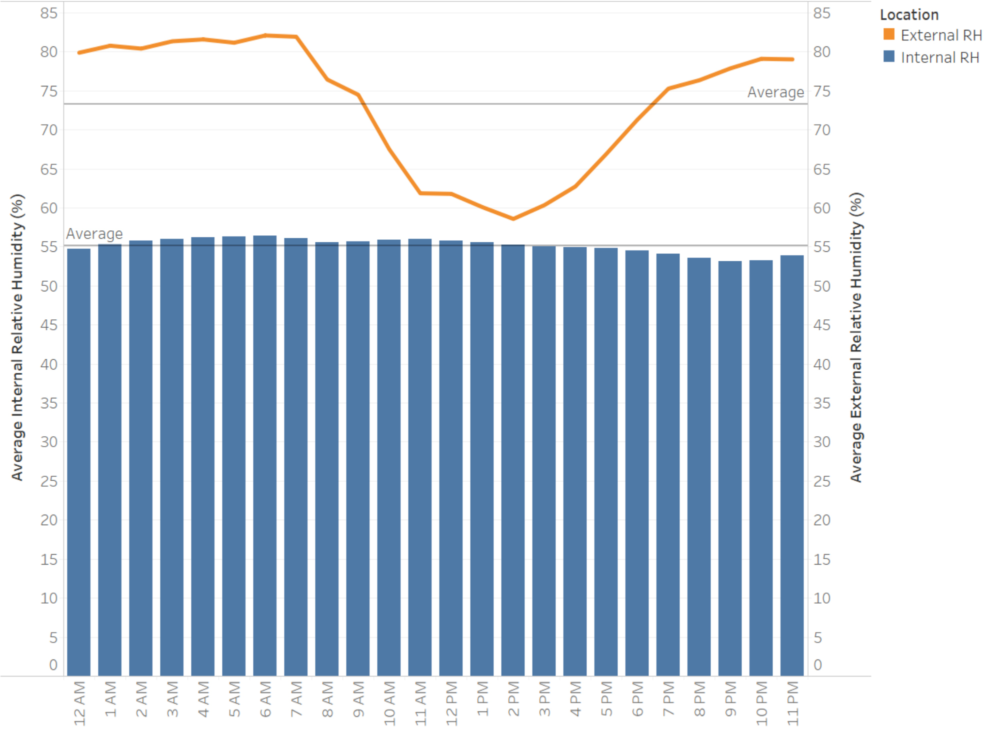


Figure 3-19: Average hourly internal and external relative humidity for winter months in Adelaide

3.1.3.2.2 Brisbane hourly

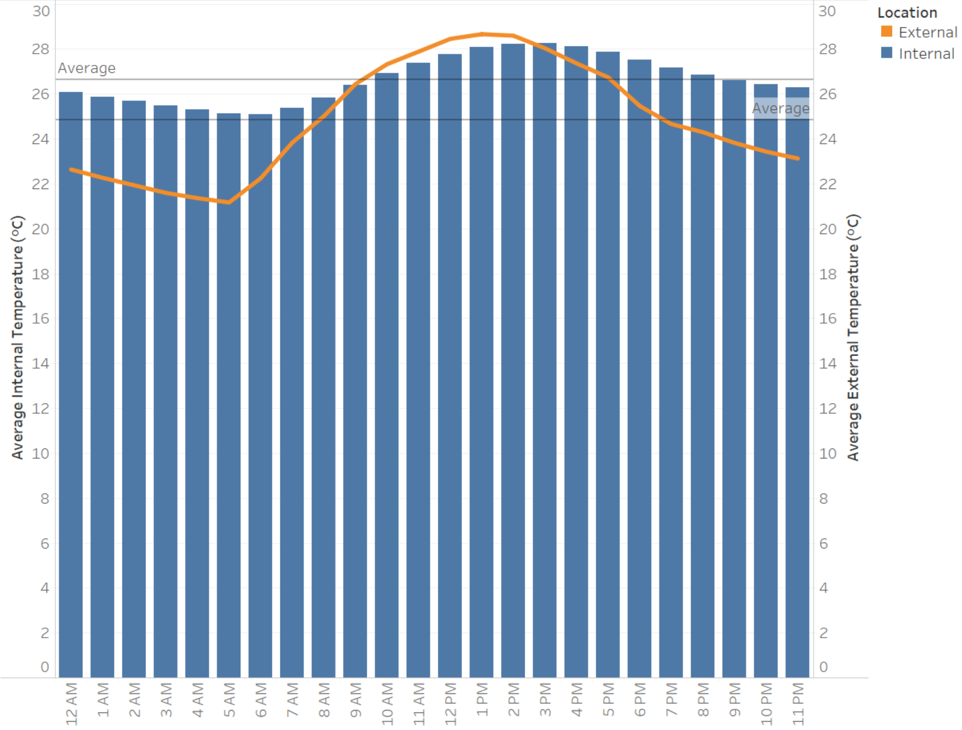


Figure 3-20: Average hourly internal and external temperatures for summer months in Brisbane

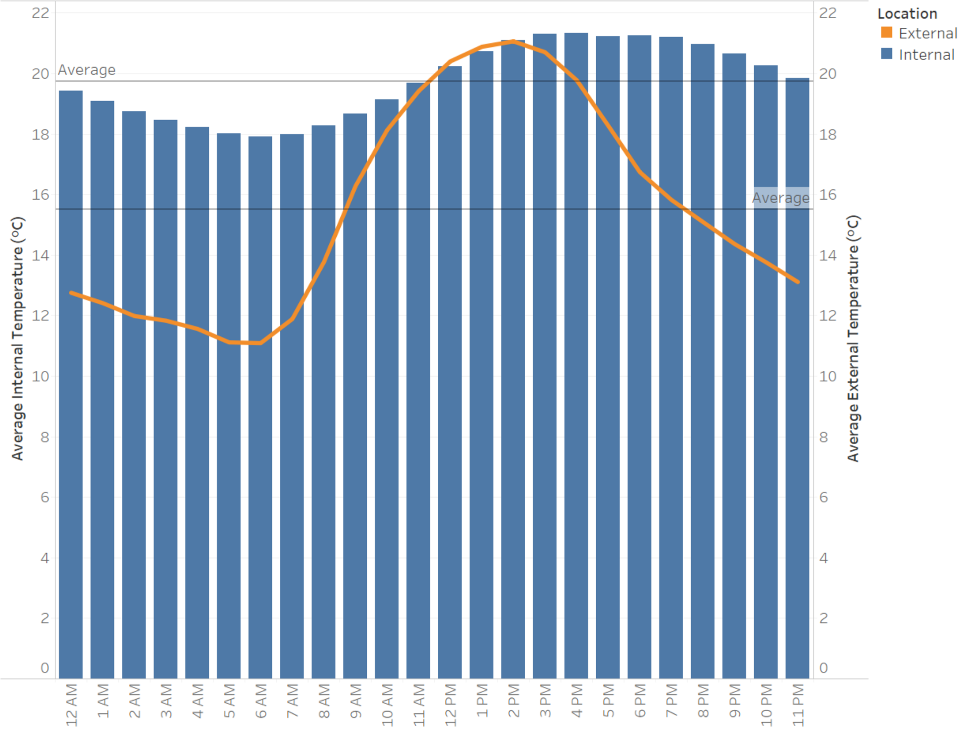


Figure 3-21: Average hourly internal and external temperatures for winter months in Brisbane

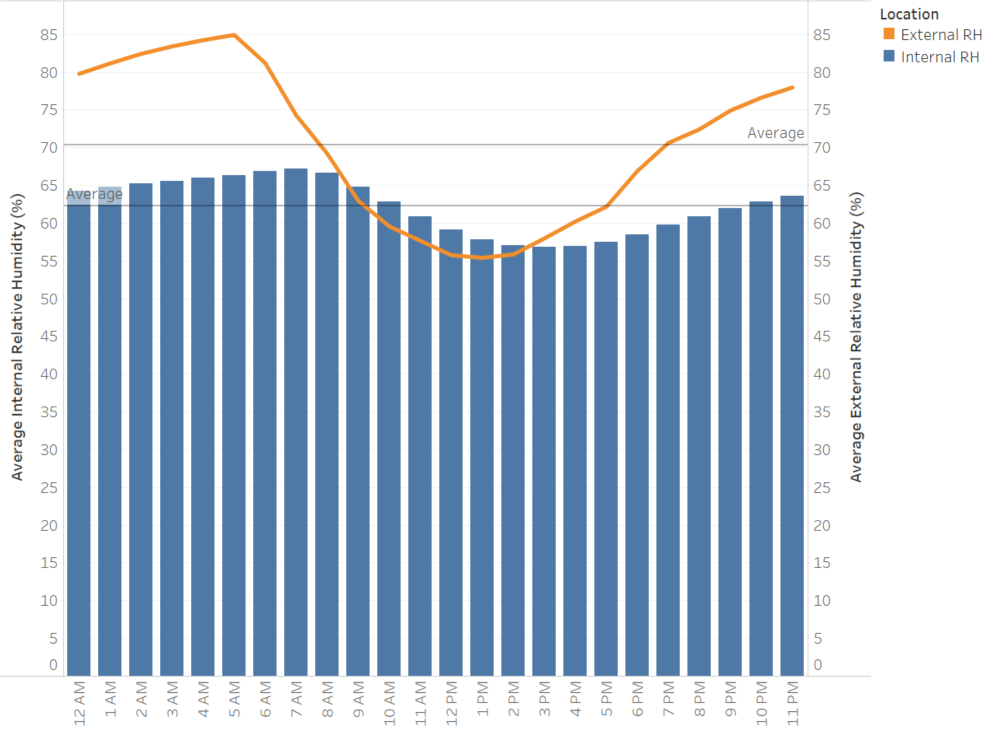


Figure 3-22: Average hourly internal and external relative humidity for summer months in Brisbane

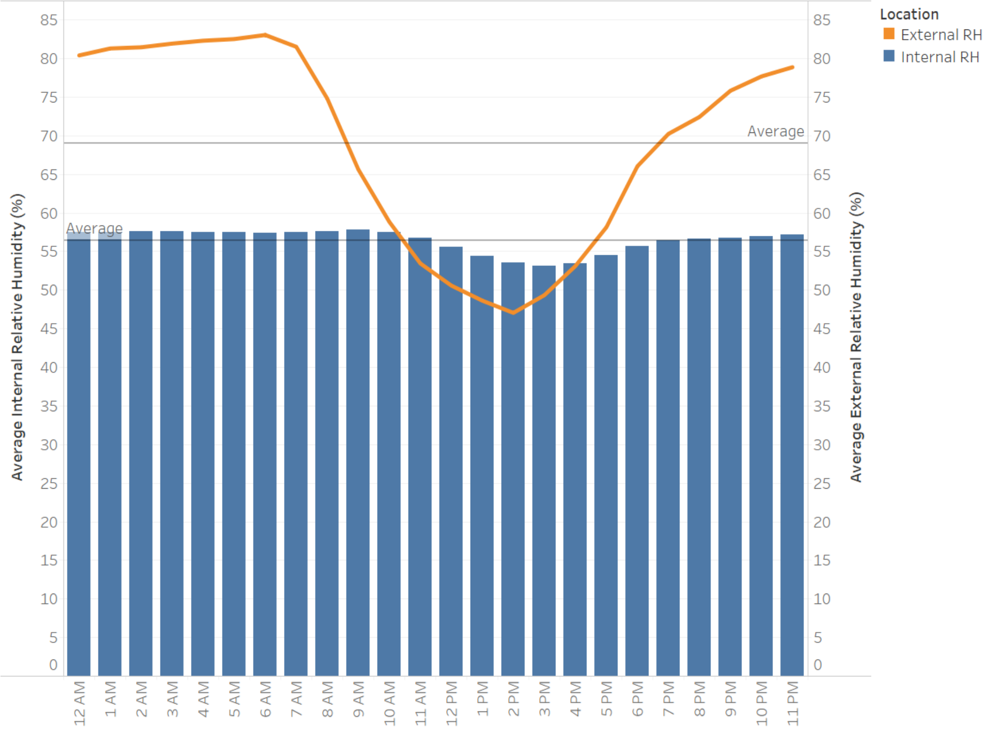


Figure 3-23: Average hourly internal and external relative humidity for winter months in Brisbane

3.1.3.2.3 Melbourne hourly

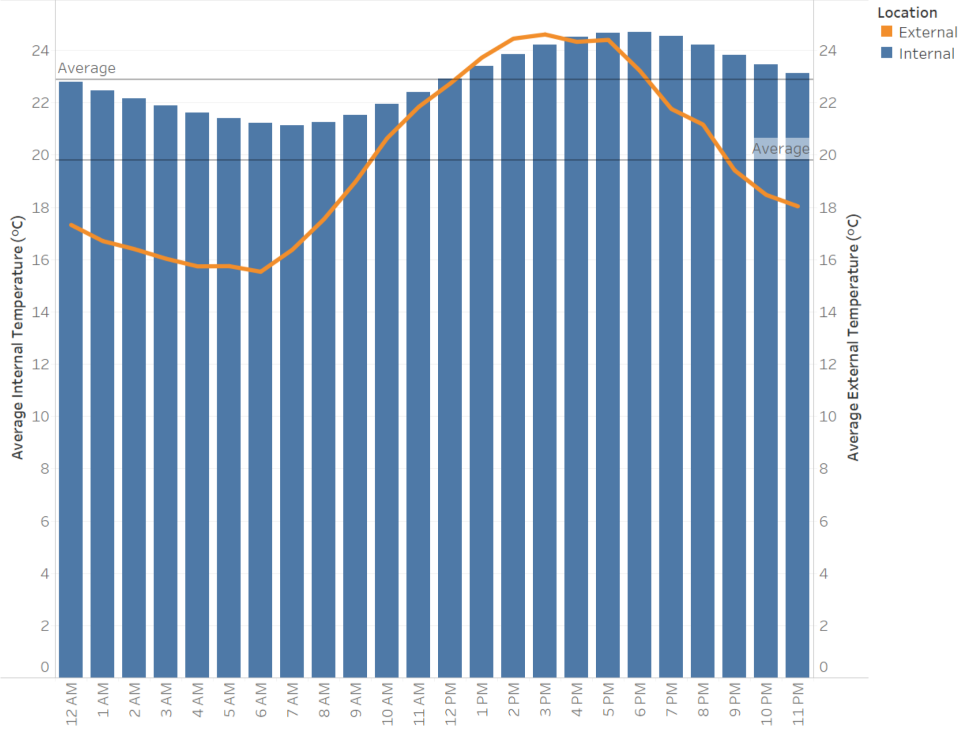


Figure 3-24: Average hourly internal and external temperatures for summer months in Melbourne

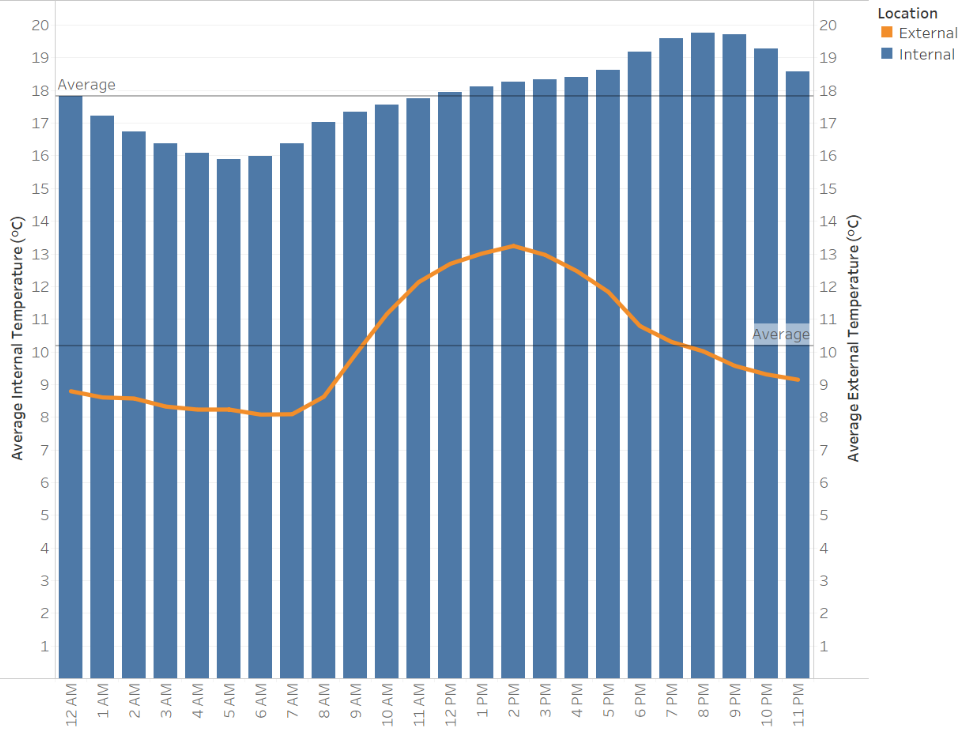


Figure 3-25: Average hourly internal and external temperatures for winter months in Melbourne

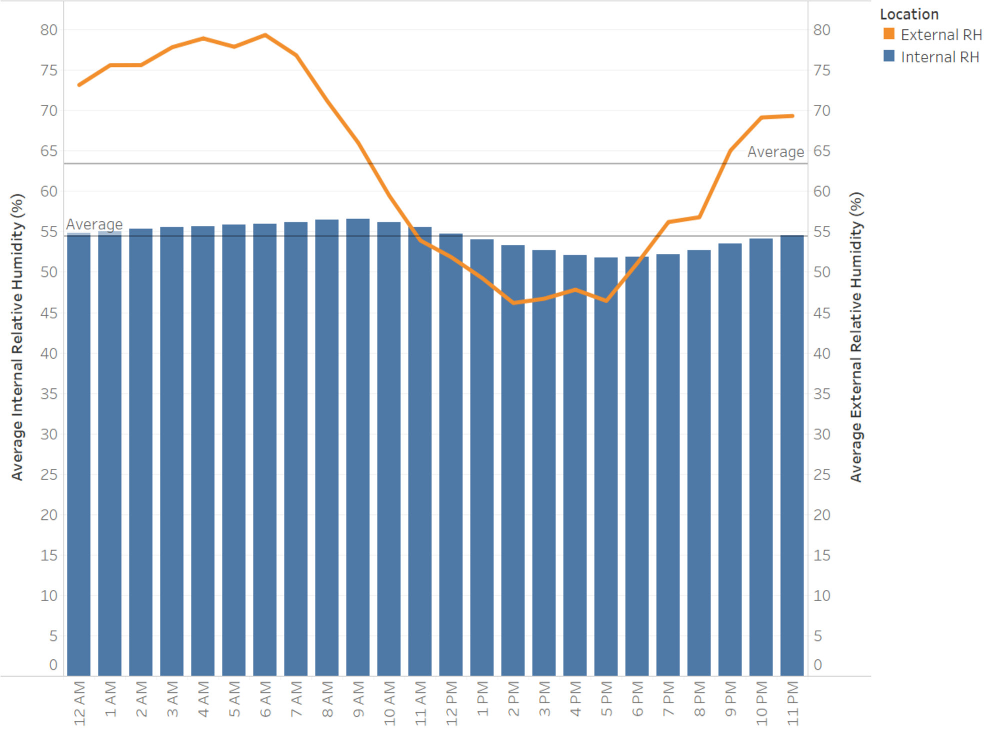


Figure 3-26: Average hourly internal and external relative humidity for summer months in Melbourne

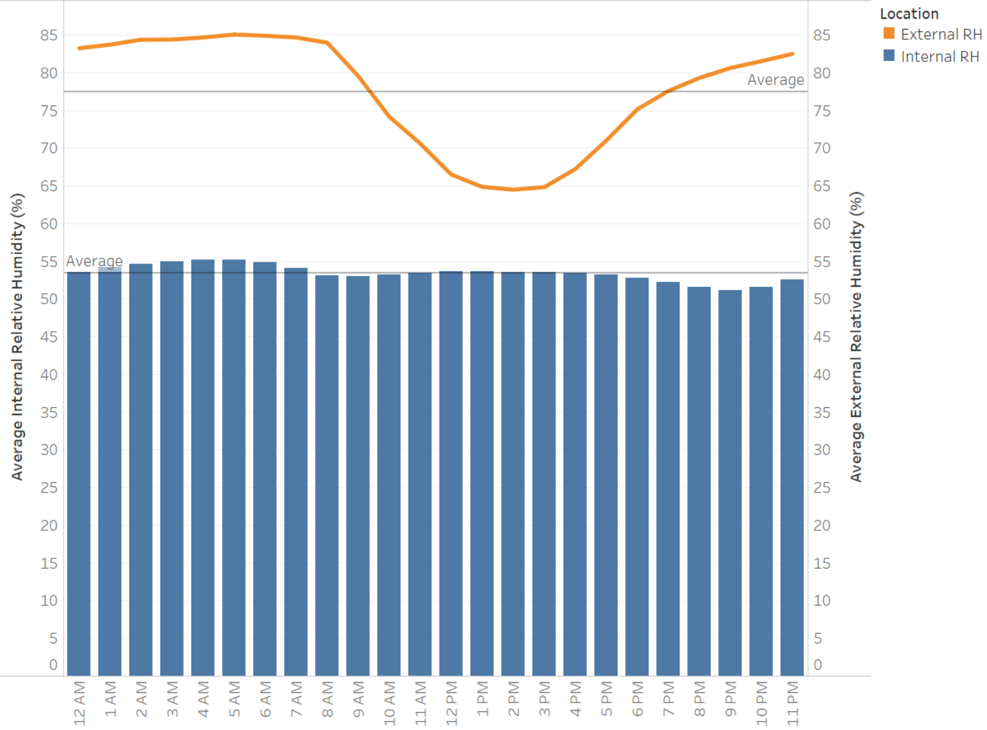


Figure 3-27: Average hourly internal and external relative humidity for winter months in Melbourne

3.1.4 Bedroom Temperature Adaptive Thermal Comfort Analysis

For all Lochiel Park houses, where recorded bedroom temperature data were available, an analysis was conducted to obtain summer and winter bedroom temperature data sets, for times when people were home, and separating data for when they were and were not using air-conditioners during hours where they were assumed to be inhabiting bedroom zones. In order to determine the summer data set of bedroom temperatures when the air-conditioner was on, bedroom temperatures for each individual household were correlated with when their air-conditioner energy was significantly greater than the standby load. These data were then charted against the corresponding seven day running mean outdoor air temperature (see Figure 3-28). On this same chart, the ASHRAE 80% and 90% acceptability limit was also charted to show whether thermal comfort was likely to have been achieved. Over 77% of the bedroom temperatures fell within the 90% limit, whilst over 90% fell within the 80% limit.

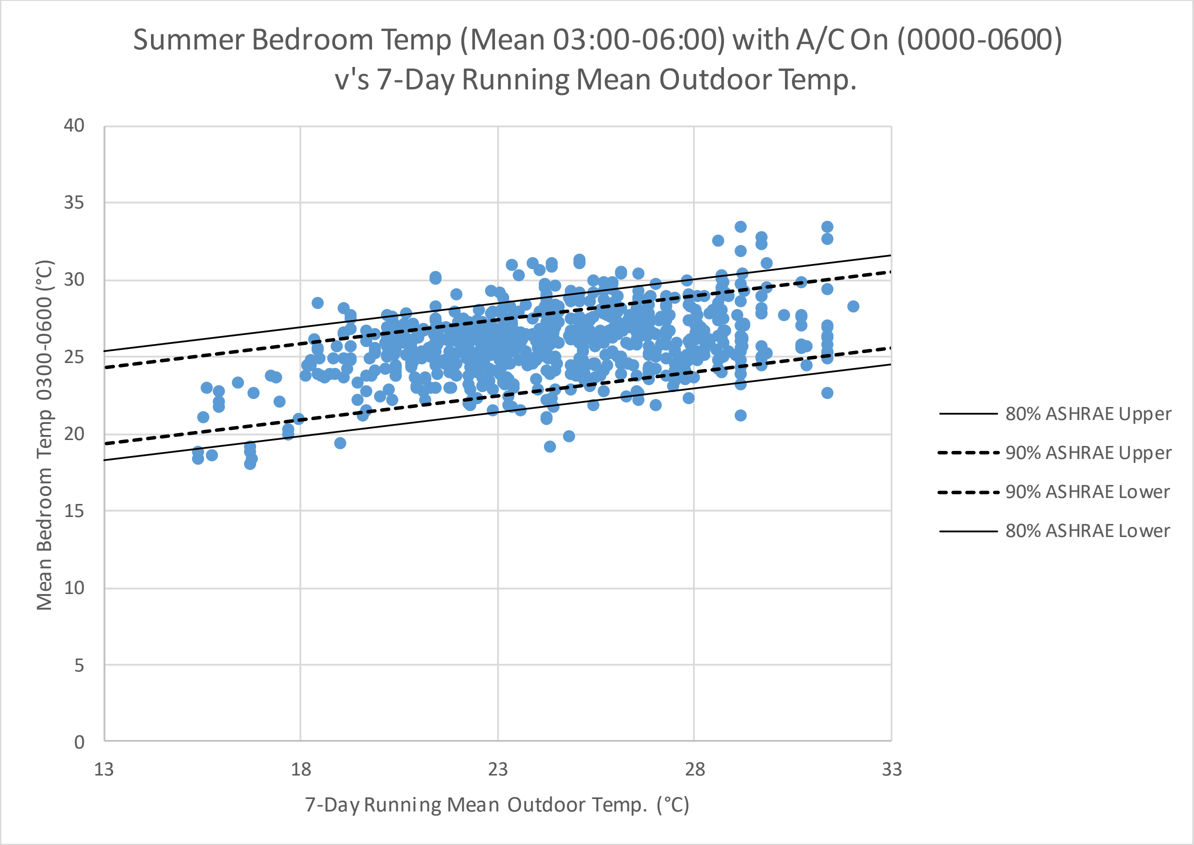


Figure 3-28: Summer bedroom temperatures versus seven day running mean outdoor temperature when A/C is activated (Lochiel Park houses, 2011-2016)

The frequency of bedroom temperatures, in 0.25°C intervals, was also charted in the histogram shown in Figure 3-29. This shows that the most common bedroom temperature was 26.5°C.

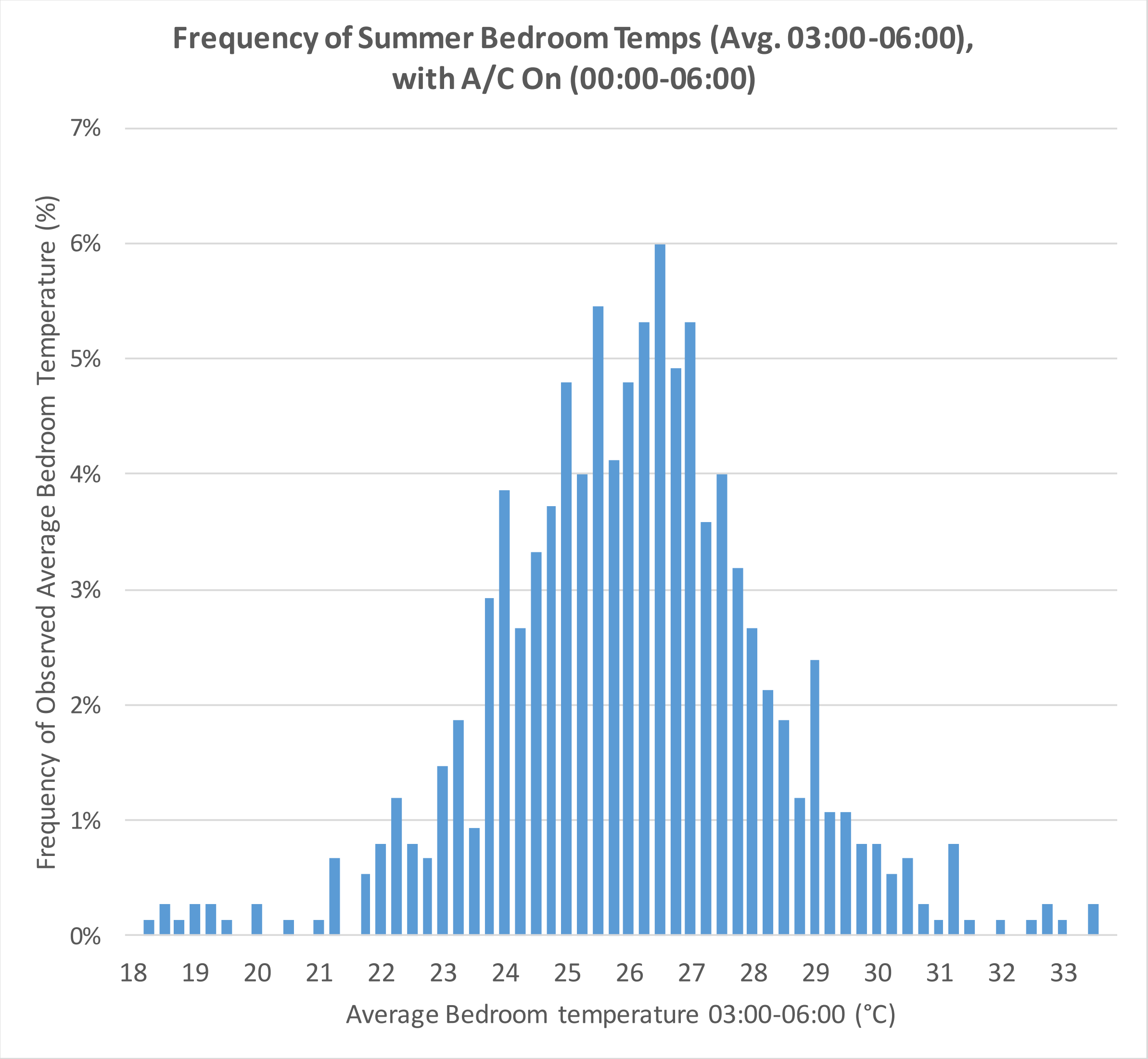


Figure 3-29: Frequency of Summer bedroom temperatures, with A/C activated, in 0.25C intervals (Lochiel Park houses, 2011-2016)

In order to determine the summer data set of bedroom temperatures when the air-conditioner was not in use, the mean bedroom temperature between 03:00AM and 06:00AM for each individual household was recorded only when both air-conditioner energy between the hours of 00:00AM and 06:00AM was equivalent to the standby load, and hot water was used between the hours of 18:30PM and 7:00AM, for the same associated night. These data were then charted against the corresponding seven day running mean outdoor air temperature (see Figure 3-30). On this same chart, the ASHRAE 80% and 90% acceptability limit was also charted to show whether thermal comfort was likely to have been achieved. In an almost identical manner as when the air-conditioner was on, over 77% of the bedroom temperatures fell within the 90% limit, whilst over 90% fell within the 80% limit, when the air-conditioner was off.

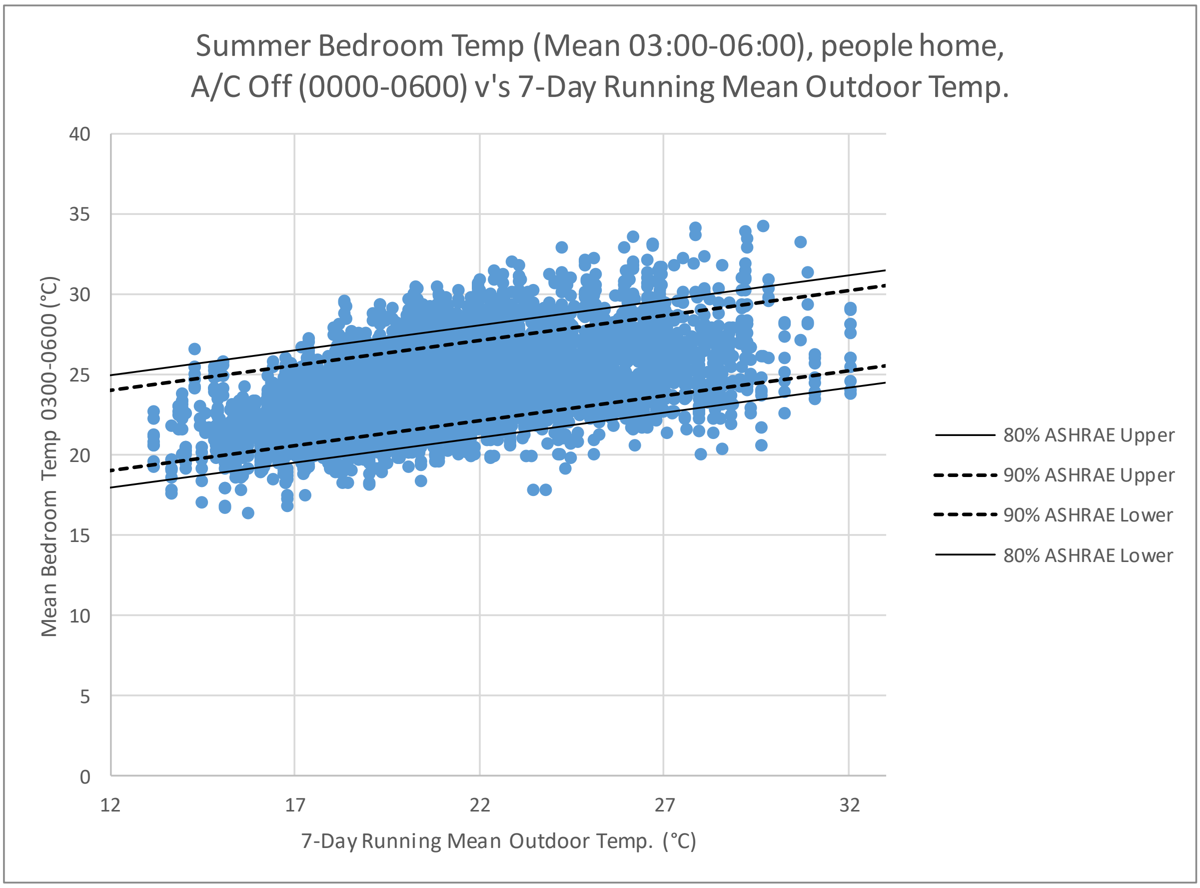


Figure 3-30: Summer bedroom temperatures versus seven day running mean outdoor temperature when A/C is inactive (Lochiel Park houses, 2011-2016)

The frequency of bedroom temperatures, in 0.25°C intervals, was also charted in the histogram shown in Figure 3-31. This shows that the most common bedroom temperature was 24.25°C.

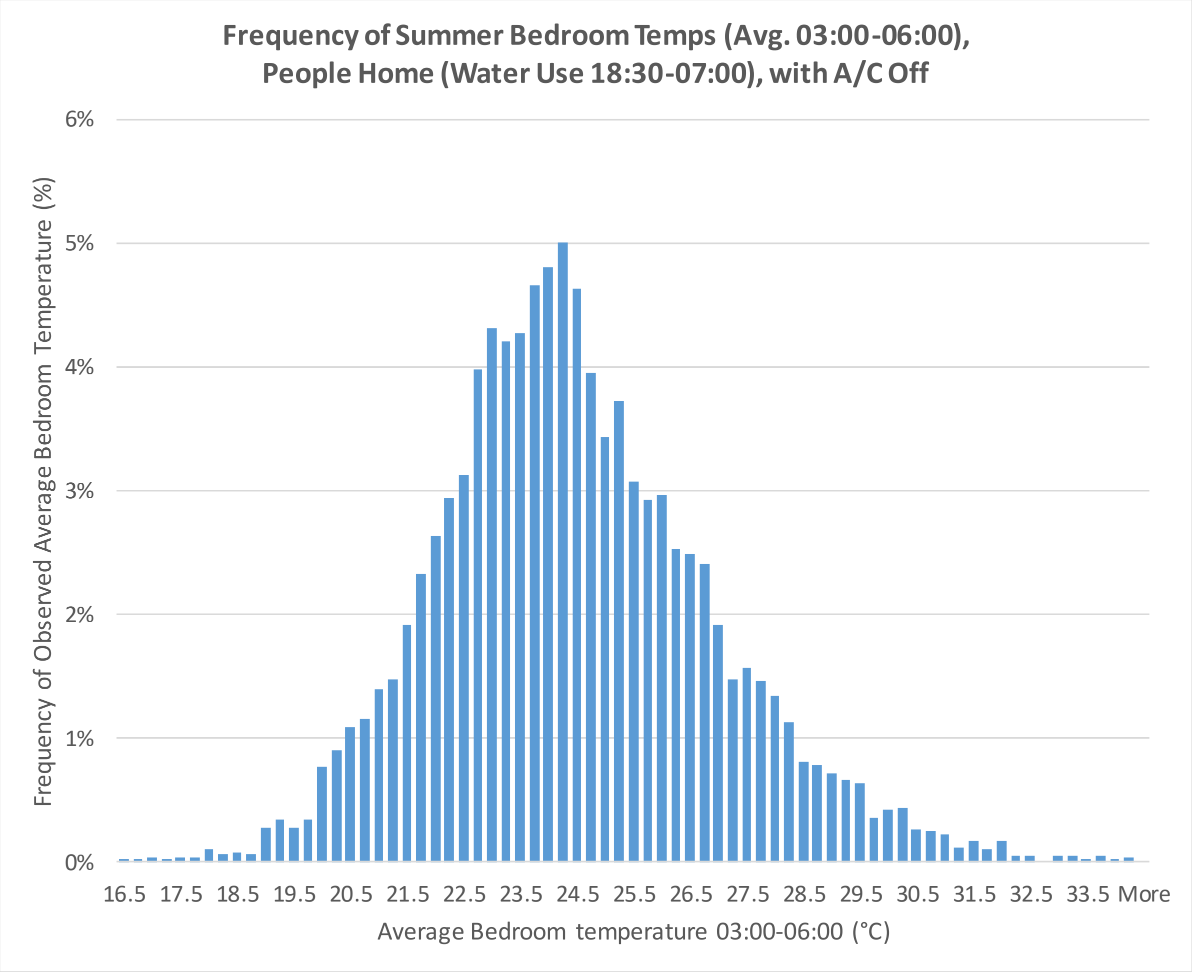


Figure 3-31: Frequency of Summer bedroom temperatures, with A/C inactive, in 0.25C intervals (Lochiel Park houses, 2011-2016)

With a very high percentage of Summer bedroom temperature falling within the ASHRAE 90% acceptability limits, it can be seen especially from Figure 3-28, and also from Figure 3-30 to a lesser extent, that summer cooling results are consistent and that the impact of air-conditioner use is negligible.

In order to determine the winter data set of bedroom temperatures when the air-conditioner was on, bedroom temperatures for each individual household were correlated with when their air-conditioner energy was significantly greater than the standby load. These data were then charted against the corresponding seven day running mean outdoor air temperature (see Figure 3-32). On this same chart, the ASHRAE 80% and 90% acceptability limit was also charted to show whether thermal comfort was likely to have been achieved. Only 22.4% of the bedroom temperatures fell within the 90% limit, whilst 58.1% fell within the 80% limit.

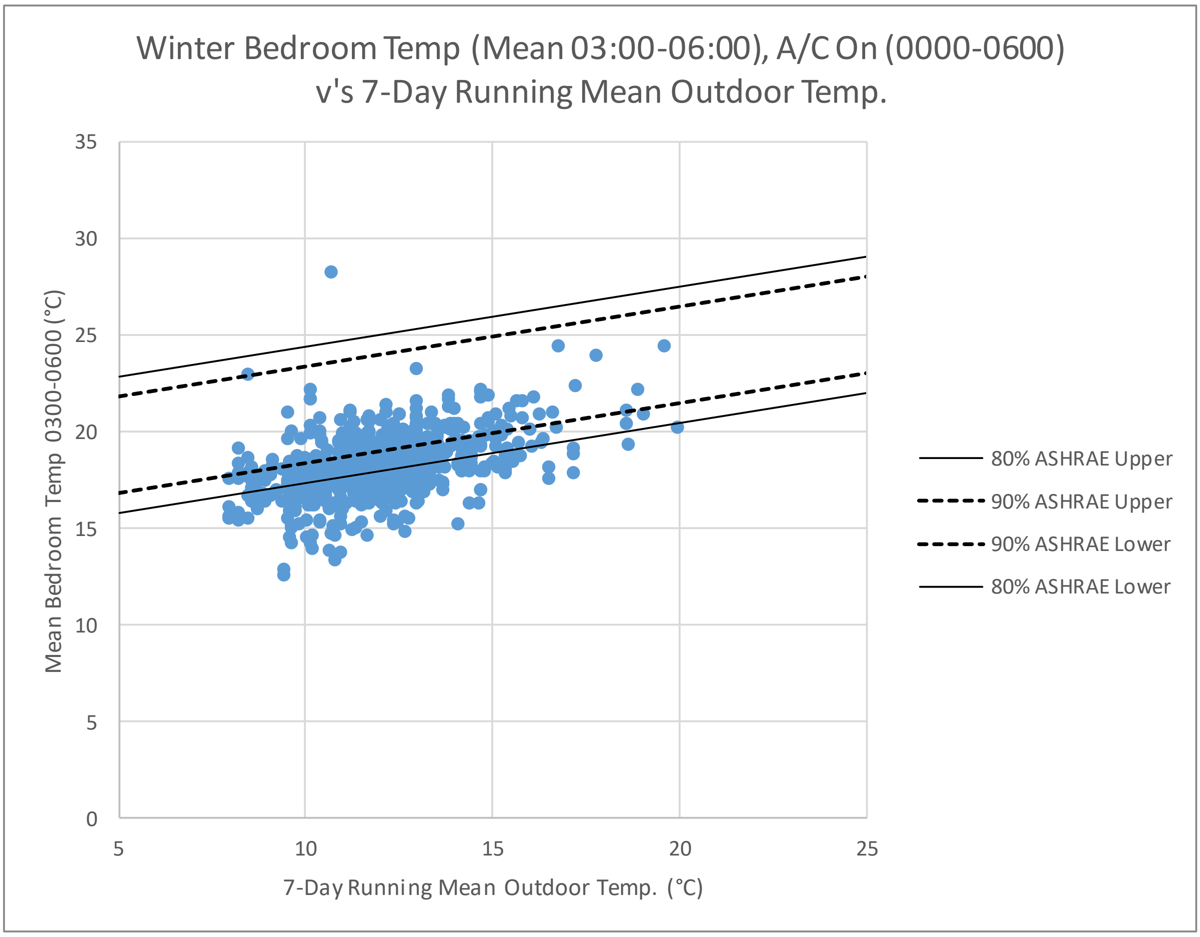


Figure 3-32 Winter bedroom temperatures versus seven day running mean outdoor temperature when A/C is activated (Lochiel Park houses, 2011-2016)

The frequency of bedroom temperatures, in 0.25°C intervals, was also charted in the histogram shown in Figure 3-33. This shows that the most common bedroom temperature was jointly 18°C and 18.5°C.

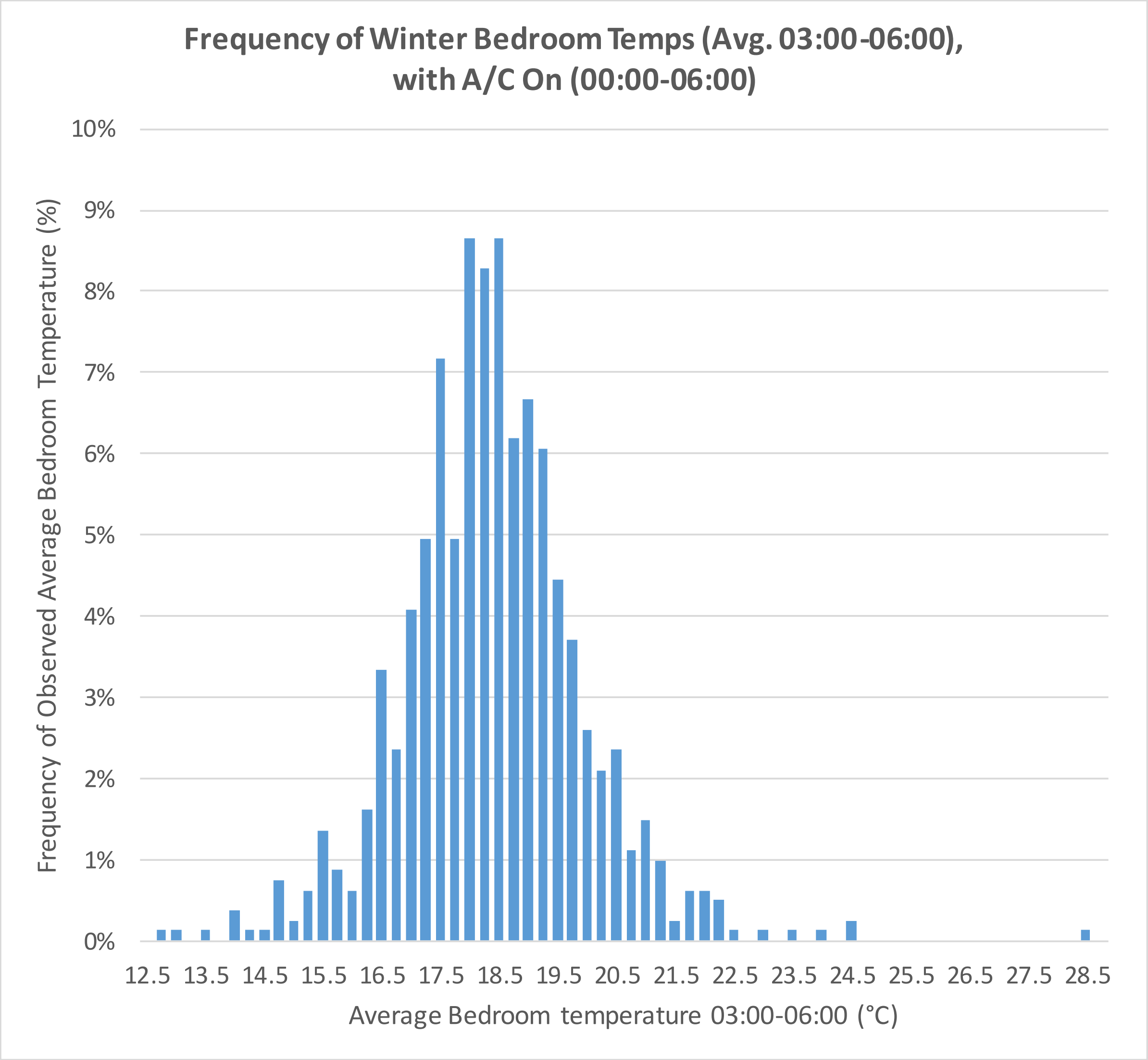


Figure 3-33 Frequency of Winter bedroom temperatures, with A/C activated, in 0.25C intervals (Lochiel Park houses, 2011-2016)

In order to determine the winter data set of bedroom temperatures when the air-conditioner was not in use, bedroom temperatures for each individual household were correlated with when their air-conditioner energy was approximately equal the standby load, provided that hot water was used between the hours of 18:30PM and 7:00AM, for the same associated night. These data were then charted against the corresponding seven day running mean outdoor air temperature (see Figure 3-34). On this same chart, the ASHRAE 80% and 90% acceptability limit was also charted to show whether thermal comfort was likely to have been achieved. As is highlighted by the chart, only 41.6% of the bedroom temperatures fell within the 90% limit, whilst 64% fell within the 80% limit.

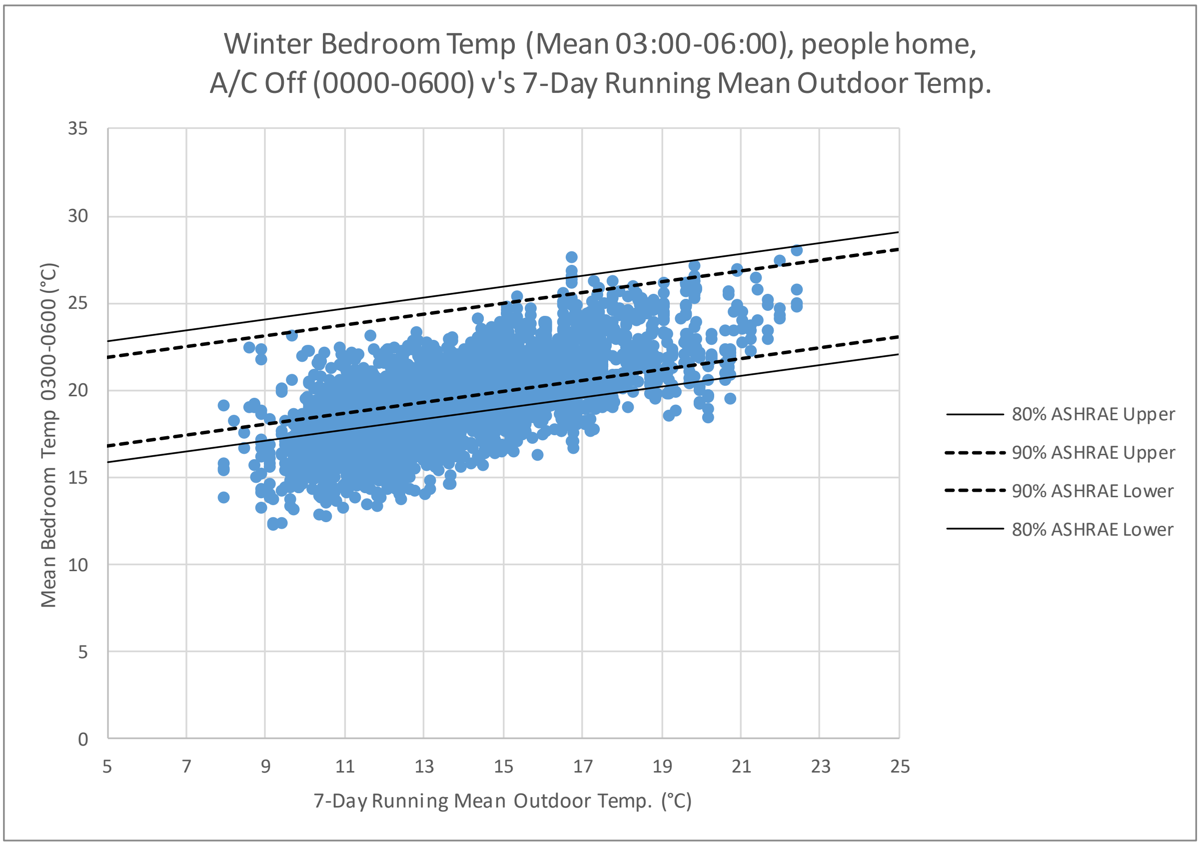


Figure 3-34: Winter bedroom temperatures versus seven day running mean outdoor temperature when A/C is inactive (Lochiel Park houses, 2011-2016)

The frequency of bedroom temperatures, in 0.25°C intervals, was also charted in the histogram shown in Figure 3-35. This shows that the most common bedroom temperature was 18.75°C.

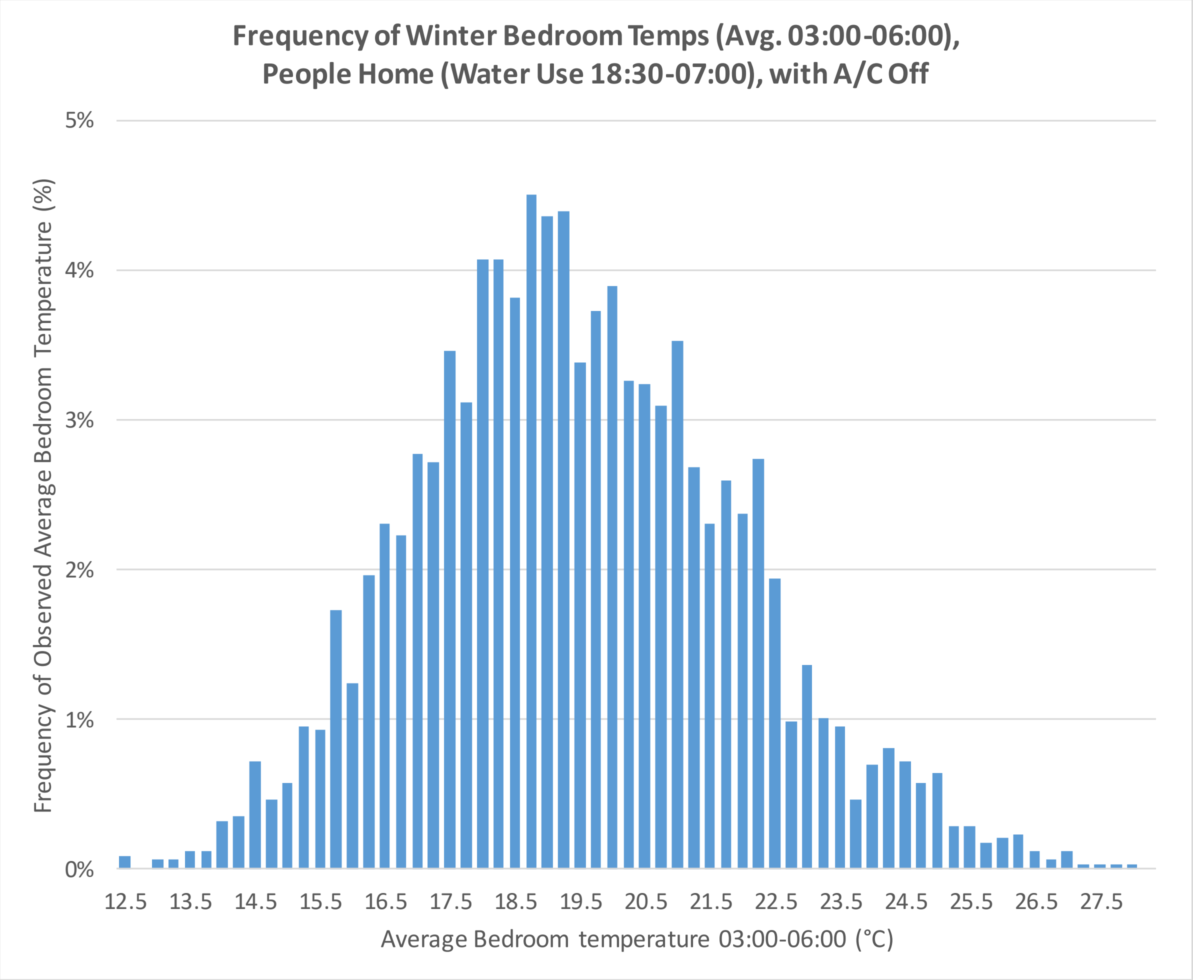


Figure 3-35: Frequency of Winter bedroom temperatures, with A/C inactive, in 0.25C intervals (Lochiel Park houses, 2011-2016)

With a relatively low percentage of winter bedroom temperatures falling within either the ASHRAE 80% or 90% acceptability limits, it can be seen from both Figure 3-32 and Figure 3-34, that winter heating results are inconsistent with the adaptive thermal comfort model. It should also be noted that the impact of air-conditioner use also appears to be negligible.

3.2 AccuRate Modelled Versus Measured Household Heating and Cooling

As part of a previous project, a large volume of household appliance energy consumption and climatic data was collected from 11 households in the Adelaide suburb of Lochiel Park, South Australia. One-minute interval electrical energy consumption data was recorded for all electrical end-uses that were supplied from a separate circuit on the switchboard, and corresponding values of temperature and relative humidity were recorded in 3 rooms for each house, using a specialised monitoring system for 11 Lochiel Park houses between 2010 and 2016. The temperature sensors were installed at locations where direct sunlight was avoided.

All the houses were built between 2009 and 2012. Only seven houses had at least one reverse cycle air conditioner installed. For all co-located houses, the outdoor air temperatures of the nearest Bureau of Meteorology (BoM) weather station at Kent Town, SA, were also obtained and utilised as the ambient air temperature.

For the purpose of data analysis, the heating season was assumed to encapsulate all monitored air-conditioning data recorded from 16th April to 15th October, inclusive and the cooling season was assumed to encapsulate all monitored air-conditioning data recorded from 16th October to 15th April, inclusive. Measured air-conditioning energy data were then converted to estimated load, based on an assumed constant rated value of air-conditioner efficiency, COP_{rated} for heating energy and EER_{rated} for cooling energy. Estimated heating and cooling load, based on measured heating and cooling energy, has been compared to predicted data, obtained using AccuRate Sustainability models for the same house designs, operating over the same period, utilising actual observed weather data from the Australian Bureau of Meteorology (BOM) inserted into AccuRates' Weather Data Library in RMY format. In order to improve the accuracy of this comparison, all measured energy that was consumed by the air-conditioner in standby mode was removed, prior to conversion of measured energy to estimated load.

Measured monthly total heating loads for seven Lochiel Park houses were combined to single monthly values, using available associated data, and plotted against corresponding combined total monthly heating load, as predicted by AccuRate Sustainability, in Figure 3-36.

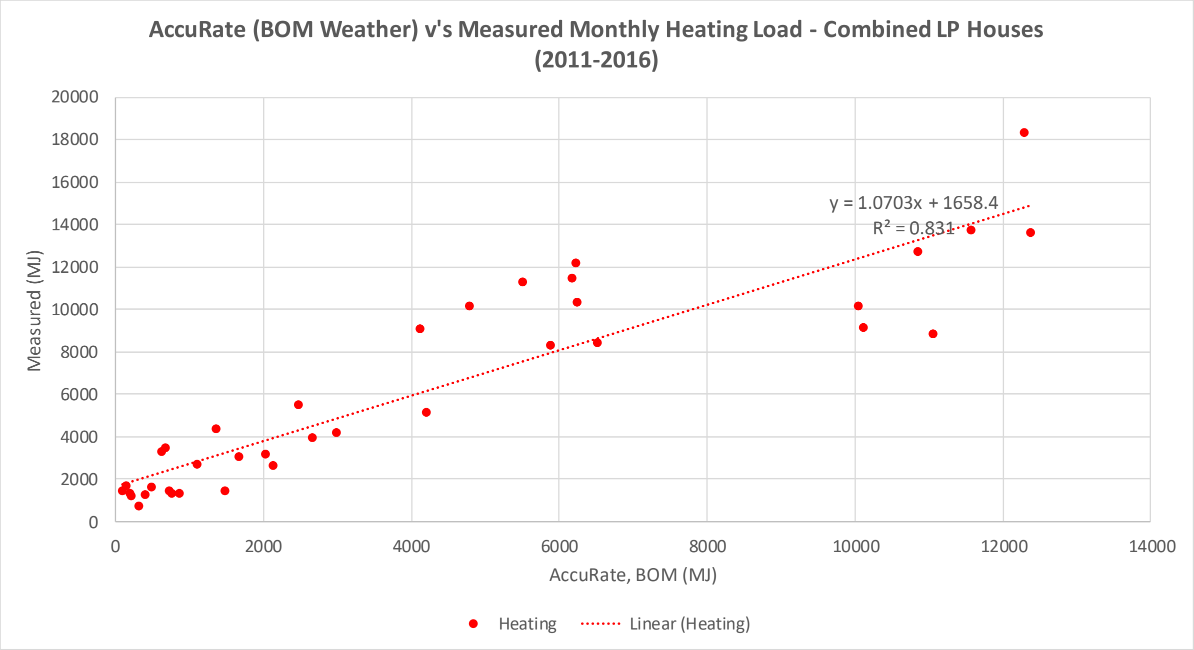


Figure 3-36: AccuRate versus Measured monthly combined heating load for 7 Lochiel Park houses (2011-2016)

Figure 3-36 shows an acceptable level of agreement between measured and modelled heating load, especially given that the line of best fit has a slope close to one. The houses, to which these data relate, all had similarly high AccuRate based star ratings, ranging from approximately 7 to 8 stars, at the time of construction. Despite removing the standby load from data, this figure still shows a trend for AccuRate to underestimate the heating load, which is known to be relatively dominant in terms of air-conditioning energy use in Adelaide.

Measured monthly total heating load was plotted against corresponding total monthly heating load, as predicted by AccuRate Sustainability, in Figure 3-37, for approximately 44 of the houses included in CSIRO's Residential Building Energy Efficiency Study (RBEES). The selection of these particular houses was based on CSIRO deeming associated data to be sufficiently clean and reliable for analysis. It should be noted that data pairs containing zeroes were removed from this data set and standby load was not removed from these data, because it was found that this tended to create unacceptably high inaccuracies in the resulting measured data, based primarily on the fact that data were recorded at half hourly intervals, rather than the ten-minute interval data obtained for Lochiel Park houses. The markers for each of these values in Figure 3-37 are distinguished by climate zone, however the line of best fit relates to all data points. This figure shows a far less acceptable level of agreement between measured and modelled individual monthly heating loads with an apparent tendency for AccuRate to overestimate heating load for houses in all climate zones, despite the inclusion of standby load.

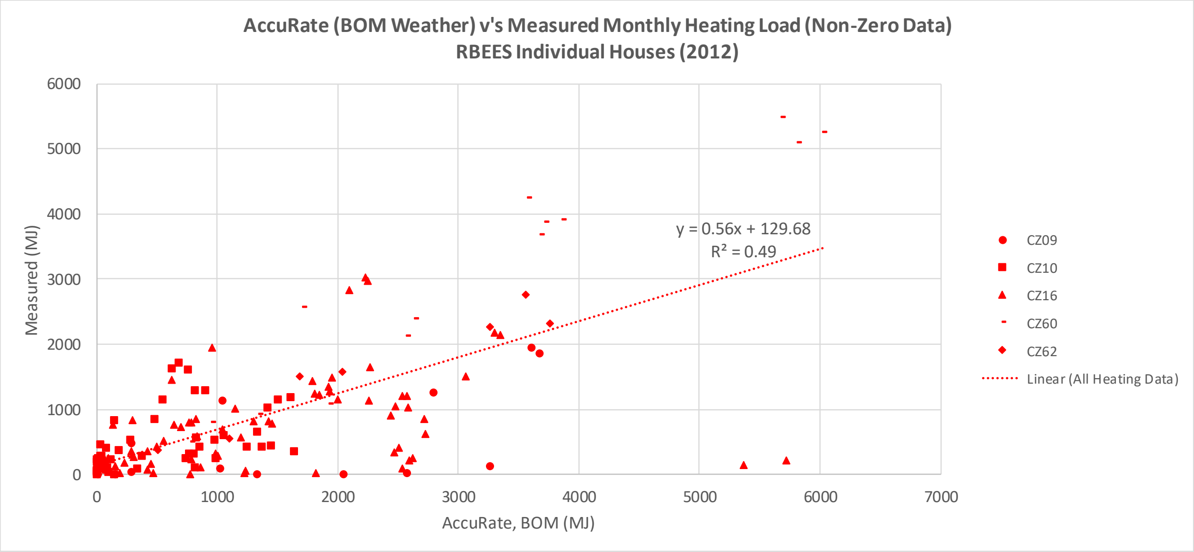


Figure 3-37: AccuRate versus Measured monthly heating load for RBEES houses (2012)

The monthly values from Figure 3-37 were combined into annual values for Figure 3-38. In a similar fashion to Figure 3-37, significant disagreement between the measured and AccuRate modelled heating load existed between annual totals for RBEES houses is seen in Figure 3-38, as one would expect.

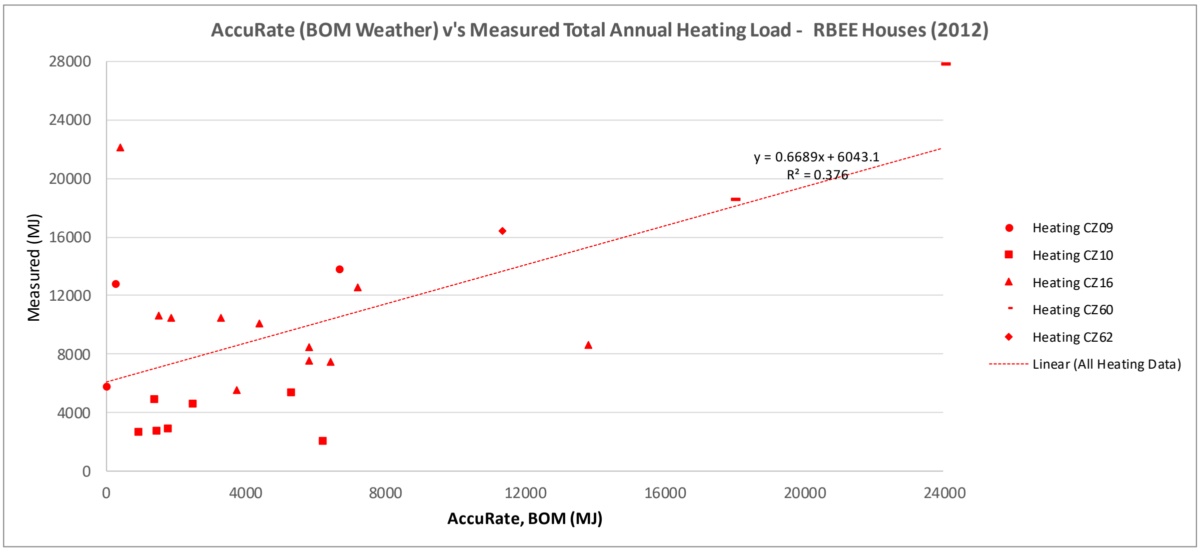


Figure 3-38: AccuRate versus Measured annual heating load for RBEES houses (2012)

Using the same methodology that was used to generate Figure 3-36 for heating data, each measured monthly total cooling load value for each Lochiel Park house for a given month was combined into a single point for the month, with available associated data, and plotted against corresponding combined total monthly cooling load, as predicted by AccuRate Sustainability, in Figure 3-39.

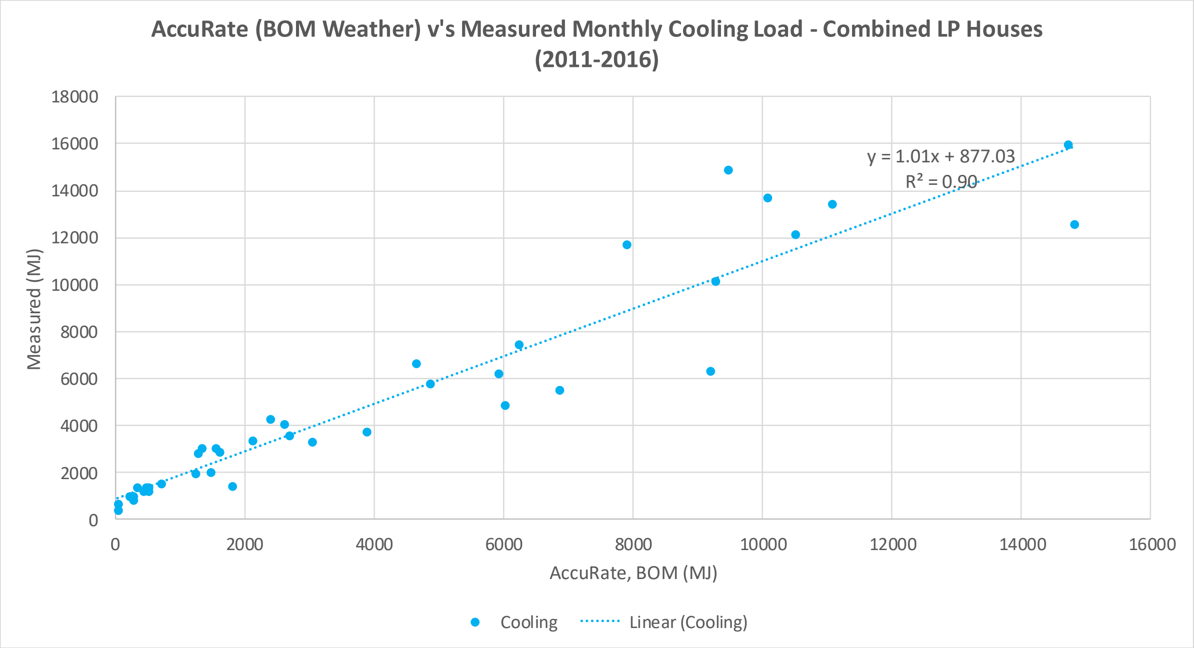


Figure 3-39: AccuRate versus Measured monthly combined cooling load for 7 Lochiel Park houses (2011-2016)

Figure 3-39 shows a relatively good level of agreement between measured and modelled monthly cooling load with all houses combined, especially given that the line of best fit once again has a slope close to one. Although less marked than for heating, this figure still shows a trend for AccuRate to underestimate the cooling load for Lochiel Park houses, which is not surprising given that cooling is less dominant, in terms of air-conditioning energy use for Adelaide.

Measured monthly total cooling load was plotted against corresponding total monthly cooling load, as predicted by AccuRate Sustainability, in Figure 3-40, for the 44 RBEES houses previously mentioned. The markers for each of these values in Figure 3-40 are distinguished by climate zone, however the line of best fit relates to all data. This figure shows a far less acceptable level of agreement between measured and modelled individual monthly heating loads with an apparent tendency for AccuRate to overestimate heating load for houses in all climate zones.

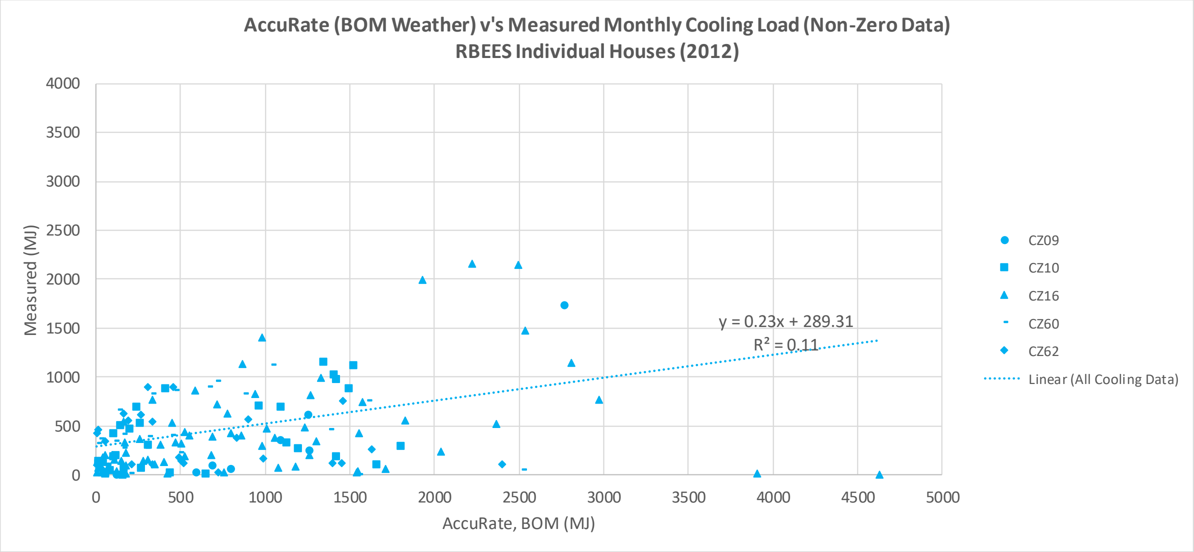


Figure 3-40: AccuRate versus Measured monthly cooling load for RBEES houses (2012)

The monthly values from Figure 3-40 were combined into annual values for Figure 3-41. In a similar fashion to Figure 3-40, significant disagreement between the measured and AccuRate modelled heating load existed between annual totals for RBEES houses is seen in Figure 3-41, as one would expect.

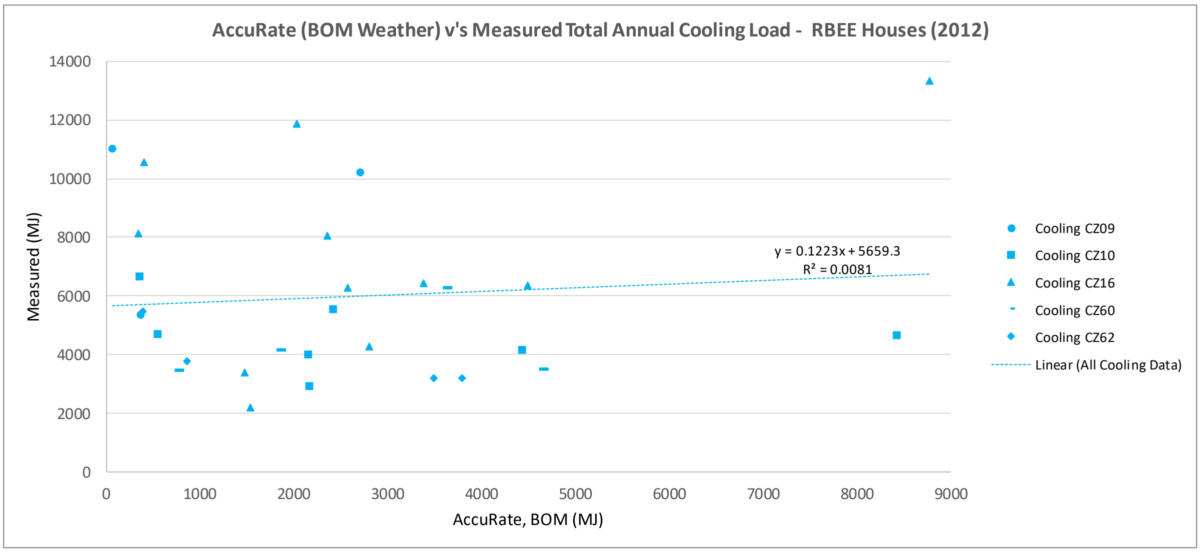


Figure 3-41: AccuRate versus Measured annual cooling load for RBEES houses (2012)

Where possible, data from the previously described comparative data sets for Lochiel Park, which were used to generated Figure 3-36 and Figure 3-39, were combined to plot for total space heating and cooling load (see Figure 3-42). Figure 3-42 also shows a relatively good level of agreement between measured and modelled total heating and cooling load for the group of houses located at Lochiel Park, South Australia.

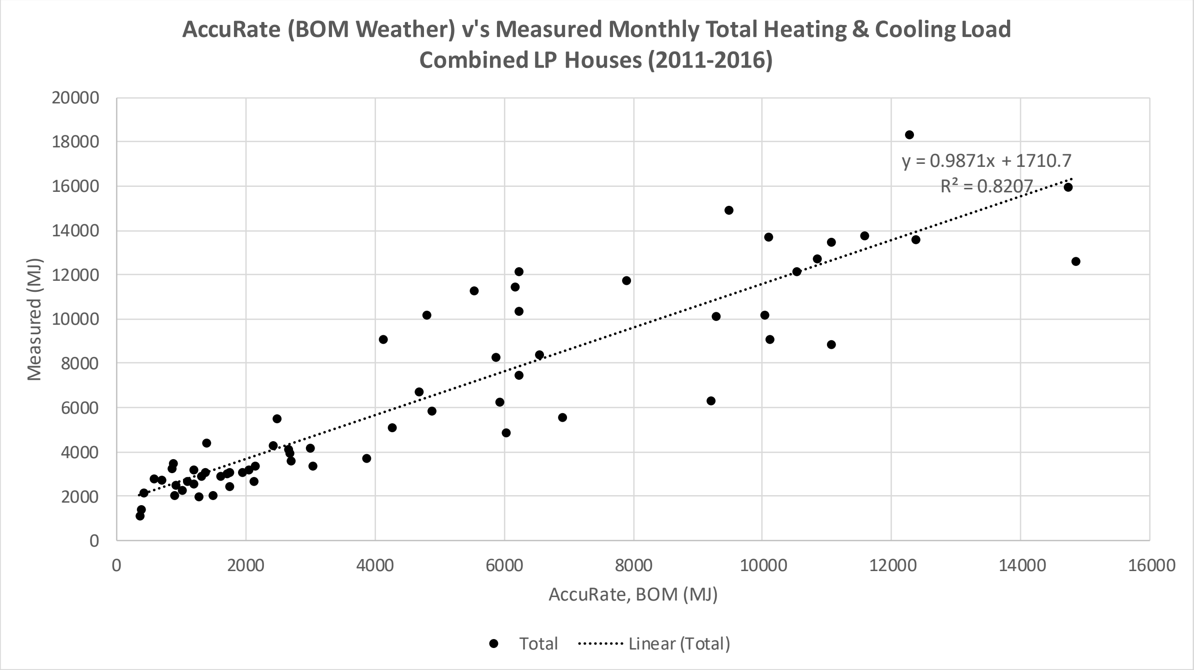


Figure 3-42: AccuRate v's Measured monthly combined household total heating and cooling load for 7 LP houses (2011-2016)

The Lochiel Park measured heating and cooling load data that were seen in other charts throughout this section were combined, for comparative purposes, into single mean monthly values for all seven houses, over the monitoring period. These data were compared to three groups of corresponding AccuRate data, in whose generation were used: actual BOM weather data in conventional mode; actual BOM weather data with windows closed; and standard RMY weather data in standard AccuRate rating mode. These data were charted in a series of separate bar charts, with the three charts for heating data contained in Table 3-3 and the three charts for cooling data contained in Table 3-4.

Apart from columns relating to AccuRate using standard RMY weather, for all charts shown in Table 3-3 and Table 3-4, the minima and maxima bars shown on all columns demonstrate a high range of variability for both measured and modelled data. It should, however be noted that the level of variability seen with all AccuRate data was considerably higher than that seen for measured data.

As expected, in a similar manner to Figure 3-36, Figure 3-43 shows close agreement between the mean monthly values of measured data versus data for Accurate using actual BOM weather data. For months with the highest heating loads, this level of agreement improves when the same AccuRate models are simulated with windows closed (see Figure 3-44). Figure 3-45 demonstrates the tendency for the standard AccuRate weather data to underestimate actual average heating load in the Adelaide climate zone, although a reasonable level of agreement between AccuRate and the measured data can also be seen.

In a similar manner to Figure 3-39, Figure 3-46 shows relatively close agreement between the mean monthly values of measured data versus data for Accurate using actual BOM weather data. For all cooling months, this level of agreement drops drastically when the same AccuRate models are simulated with windows closed (see Figure 3-47). Figure 3-48 shows a surprisingly good, and in fact the best level of agreement between the AccuRate using standard RMY weather data and measured data.

Table 3-3: Comparison between AccuRate and Measured mean monthly heating load, averaged over 5-6 years of data, for different AccuRate modelling strategies

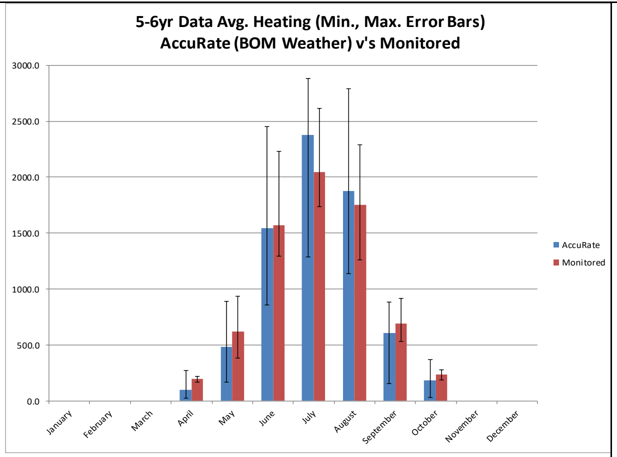


Figure 3-43: Measured v's AccuRate (actual BOM weather) mean monthly heating load

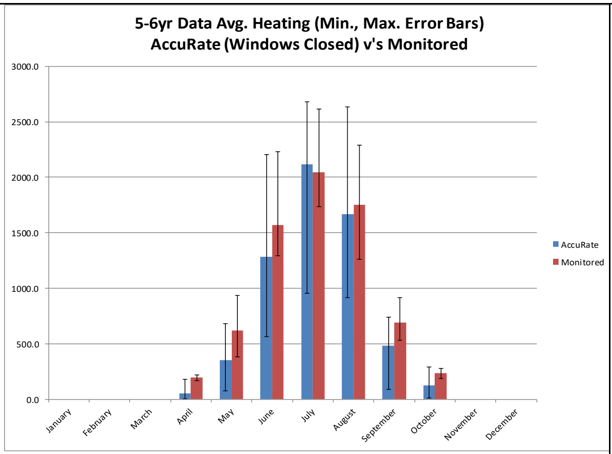


Figure 3-44: Measured v's AccuRate (actual BOM weather & windows closed) mean monthly heating load

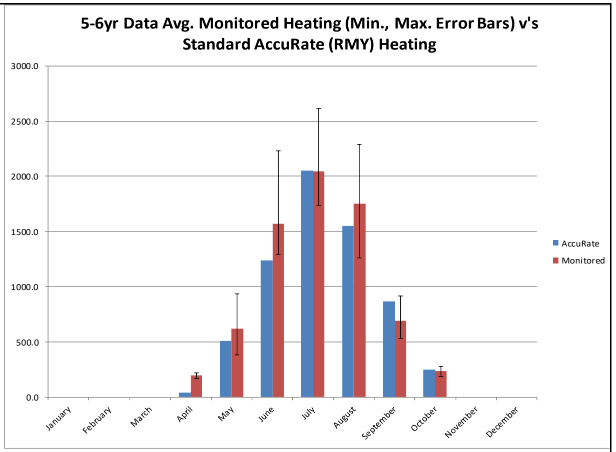


Figure 3-45: Measured mean monthly heating load v's AccuRate (standard RMY weather) monthly heating load

Table 3-4: Comparison between AccuRate and Measured mean monthly cooling load, averaged over 5-6 years of data, for different AccuRate modelling strategies

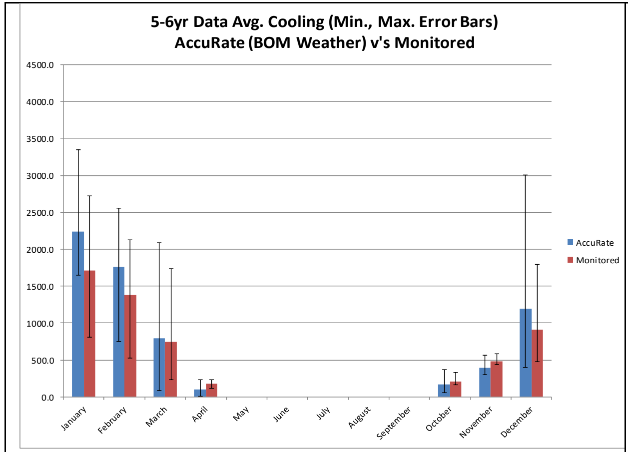


Figure 3-46: Measured v's AccuRate (actual BOM weather) mean monthly cooling load

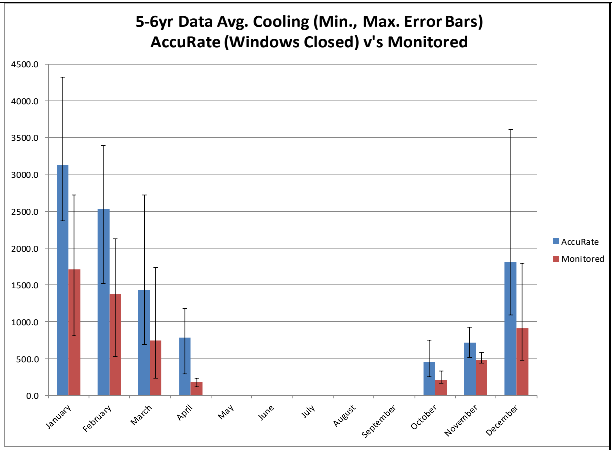


Figure 3-47: Measured v's AccuRate (actual BOM weather & windows closed) mean monthly cooling load

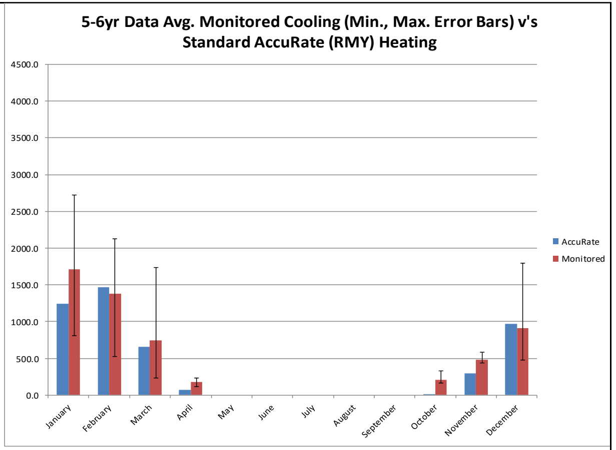


Figure 3-48: Measured mean monthly cooling load v's AccuRate (standard RMY weather) monthly cooling load

All heating data types for all Lochiel Park houses shown in Table 3-3 were then combined into a single mean annual value for comparative purposes (see Figure 3-49). Similarly to the monthly data discussed previously, it can be seen that on an annual basis, measured annual heating load ('Monitored') most closely resembles that predicted by AccuRate, using actual BOM weather data. It should be noted, however, that the degree of variability shown by the minima and maxima error bars is much greater for the loads predicted by Accurate, in comparison to measure data.

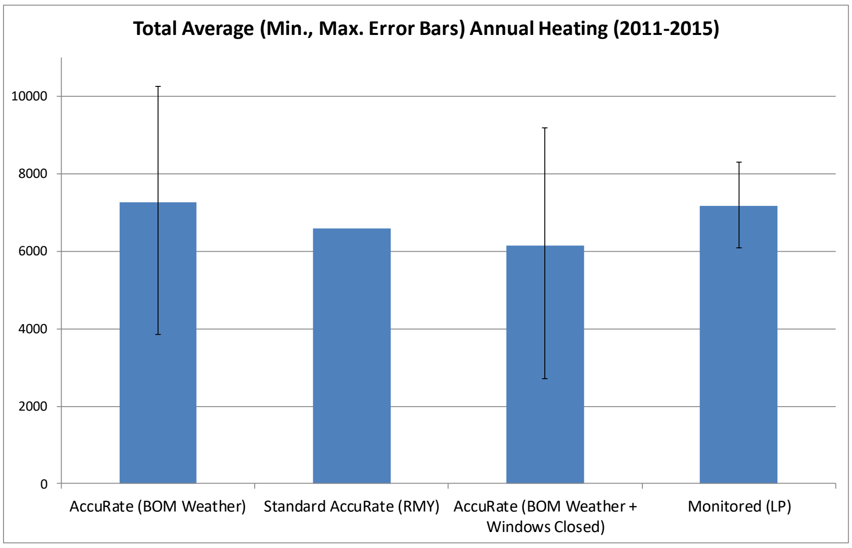


Figure 3-49: Comparison between annual standard AccuRate heating load and mean annual heating load for AccuRate (BOM), AccuRate (BOM with windows closed) and measured data

In the same manner as for Figure 3-49, all cooling data types for all Lochiel Park houses shown in Table 3-4 were then combined into a single mean annual value, shown in Figure 3-50, for comparative purposes. In some contrast to the monthly data discussed previously, though with the trend seen in Figure 3-49, Figure 3-50 shows that measured annual cooling load ('Monitored') most closely resembles that predicted by AccuRate, using actual BOM weather data. Unlike the heating data discussed for Figure 3-49, the minima and maxima error bars show that the measured and AccuRate (BOM) data demonstrate a similar level of variability

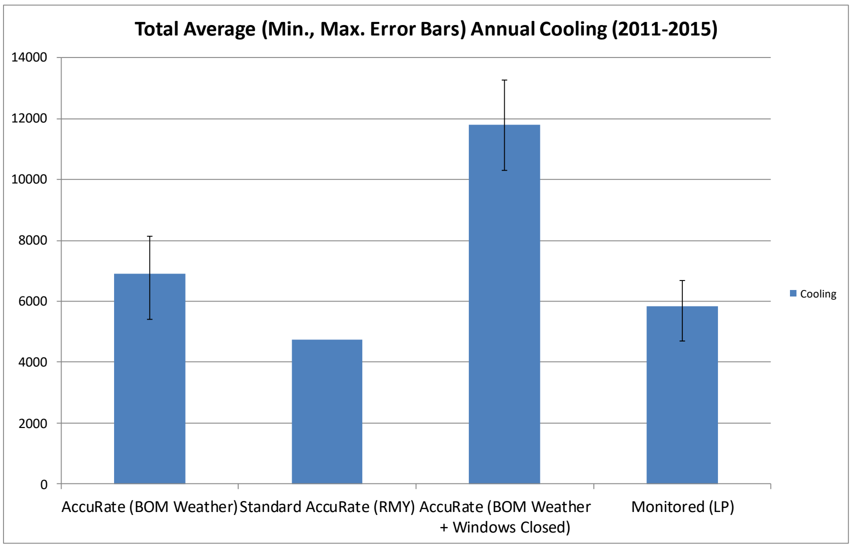


Figure 3-50: Comparison between annual standard AccuRate cooling load and mean annual cooling load for AccuRate (BOM), AccuRate (BOM with windows closed) and measured data

3.3 Degree Day Analysis

The data that were used to generate Figure 3-36 were used to calculate the ratio of measured to modelled heating load, for each individual household, for each month of the assumed heating season, where data were available. These values are plotted in Figure 3-51 below, against the heating degree months for the associated month, where degree months are the sum of degree days for a given month.

Each discrete degree month value, which relates to a specific month, has corresponding data for up to seven houses, which explains the apparent 'vertical bands' of data that can be seen in Figure 3-51 at discrete degree month values. The majority (64%) of 'heating ratio' values seen in this figure are below one, which could indicate a number of things, including: a tendency for AccuRate to overestimate actual heating load; a tendency for households to tolerate lower temperatures than expected; or a combination of these and other unidentified factors. Figure 3-36 demonstrated a tendency for AccuRate to underestimate the heating load, therefore it seems more likely that the aforementioned observation relates, at least in part, to a tendency for households to tolerate elevated temperatures, which is supported by winter bedroom temperature data contained in Figure 3-32, Figure 3-33, Figure 3-34 and Figure 3-35 of Section 3.1.4.

Figure 3-51 also shows a trend towards increased values of heating ratio with increasing degree days. This observation relates to much greater increases in the value of measured heating load, in comparison to predicted heating load, as outdoor temperature decreases. This suggests a tendency towards more extreme space heating behaviour during the coldest weather, at least in some households, than that predicted by AccuRate Sustainability, which is as one would expect.

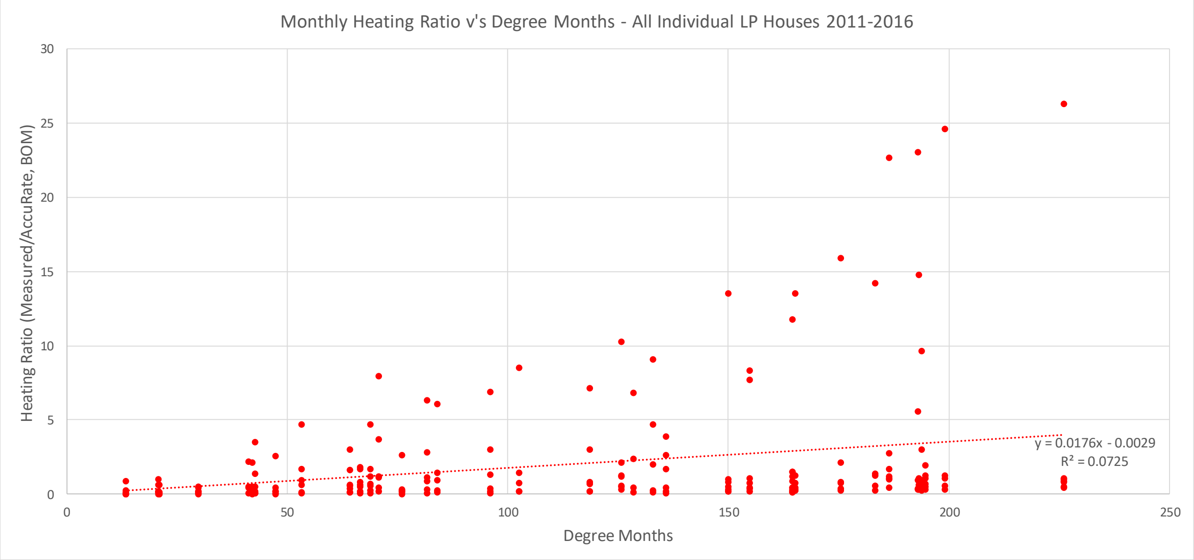


Figure 3-51: Ratio of Measured to Modelled monthly individual household heating load versus degree months, 7 LP houses (2011-2016)

The data that were used to generate Figure 3-39 were used to calculate the ratio of measured to modelled cooling load, for each individual household, for each month of the assumed cooling season, where data were available. These values are plotted in Figure 3-52 below, against the cooling degree months for the associated month, where degree months are the sum of degree days for a given month.

Each discrete degree month value, which relates to a specific month, has corresponding data for up to seven houses, which explains the apparent 'bands' of data that can be seen in Figure 3-52 at constant values of degree month. The majority (64%) of 'cooling ratio' values seen in this figure are below one, which could indicate a number of things, including: a tendency for AccuRate to overestimate actual cooling load; a tendency for households to tolerate elevated temperatures; or a combination of these and other factors.

Figure 3-52 also shows a slight trend towards increased values of cooling ratio with increasing degree days. This observation relates to greater increases in the value of measured cooling load, in comparison to predicted heating load, in some cases, as outdoor temperature increases. This suggests a tendency towards more extreme behaviour during the hottest weather, at least in some households, than that predicted by AccuRate Sustainability, which is as one would expect.

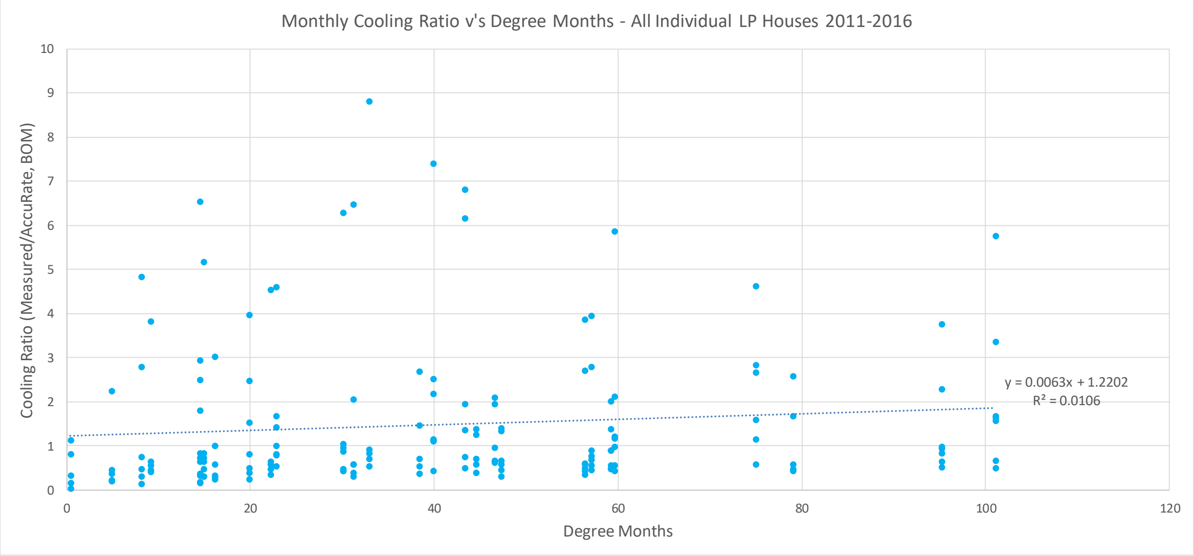


Figure 3-52: Ratio of Measured to Modelled monthly individual household cooling load versus degree months, 7 LP houses (2011-2016)

The individual household data that were used to generate Figure 3-51 were then combined, to represent an average household, in Figure 3-53. There is a distinct trend towards a ratio of one, whereby modelled equals predicted heating load, as degree month values increase. On average, this suggests a tendency for AccuRate Sustainability to be more accurate at predicting heating load at lower, or more extreme, outdoor temperatures.

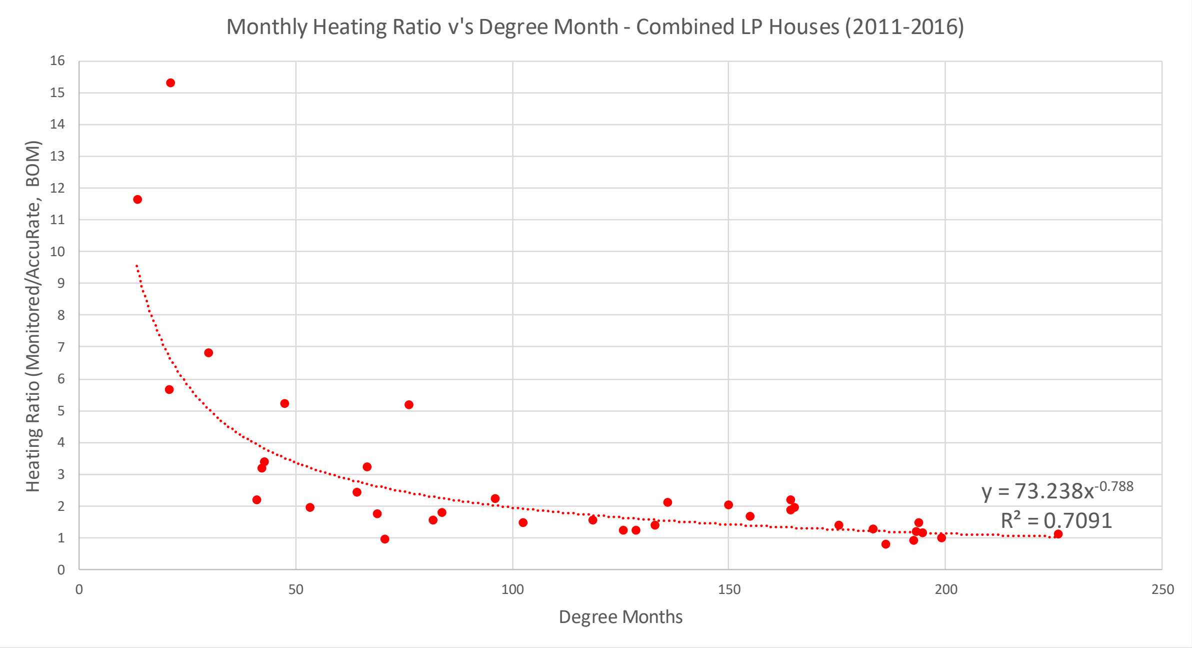


Figure 3-53: Ratio of Measured to Modelled monthly heating load versus degree months for seven Lochiel Park households combined (2011-2016)

A similar chart to Figure 3-53 has been generated using the data for RBEES houses (see Figure 3-54). This figure indicates a slight, but much less pronounced, trend towards a constant heating ratio between zero and one, as degree month values increase. This implies a tendency for the accuracy of AccuRate to improve at predicting heating load, as outdoor temperatures drop, however this trend appears to move towards an eventual over-estimation of the heating load at the most extreme winter temperatures.

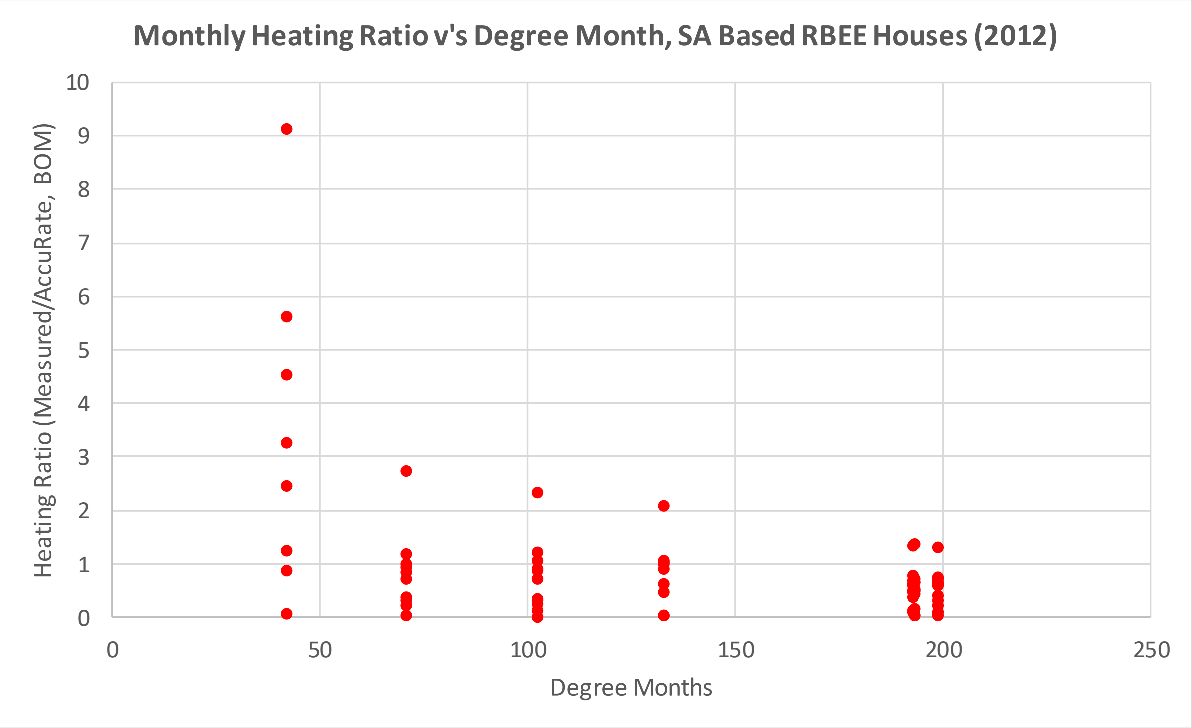


Figure 3-54: Ratio of Measured to Modelled monthly heating load versus degree months for individual RBEES households (2012)

The individual household data that were used to generate Figure 3-52 were then combined, to represent an average household, in Figure 3-55. Again, as with the heating data for Figure 3-53, there appears to be a trend towards a ratio of approximately one, whereby modelled equals predicted cooling load, as degree month values increase. On average, this suggests a tendency for AccuRate Sustainability to be more accurate at predicting cooling load at higher, or more extreme, outdoor temperatures. This implies that, for the warm temperate Adelaide climate zone, AccuRate would most likely correctly predict the performance of a building during heatwaves, should weather data files be updated to reflect the expected impact of climate change.

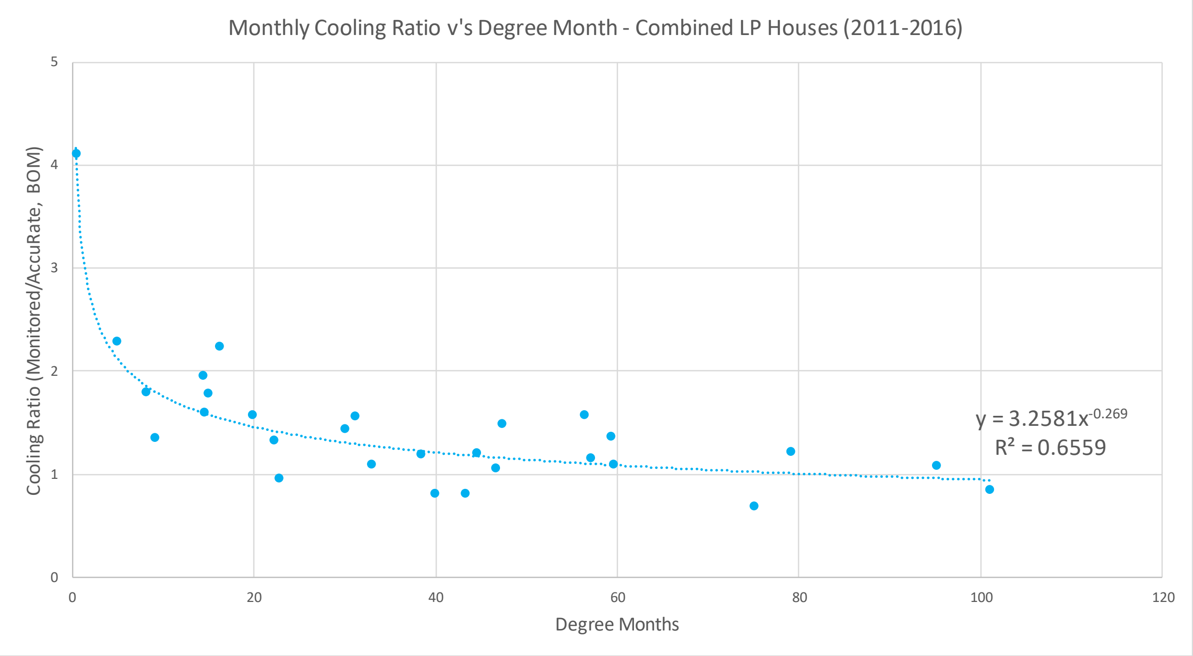


Figure 3-55: Ratio of Measured to Modelled monthly cooling load versus degree months for seven households combined (2011-2016)

A similar chart to Figure 3-55 has been generated using the data for RBEES houses (see Figure 3-56). This figure indicates a slight, though much less pronounced than Figure 3-55, trend towards a constant cooling ratio, as degree month values increase. This implies a tendency for the accuracy of AccuRate to improve at predicting cooling load, as outdoor temperatures drop, however this trend appears to move towards an eventual slight over-estimation of the cooling load at the most extreme summer temperatures.

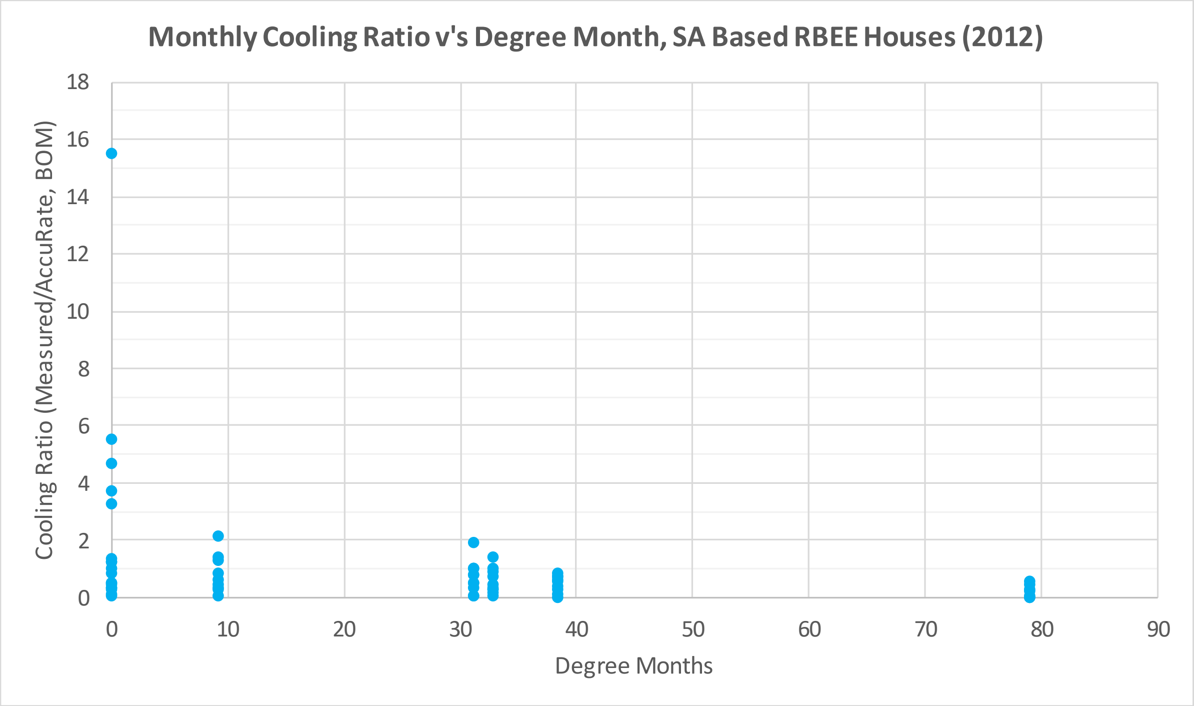


Figure 3-56: Ratio of Measured to Modelled monthly cooling load versus degree months for individual RBEES households (2012)

3.4 Comparison Between Household Air-Conditioning Energy (Both Measured and Modelled) in Two Different Groups of South Australian Houses

This section investigates the relationship between measured household energy use for thermal comfort purposes and the modelled thermal energy calculated under NatHERS for two different groups of houses in Adelaide. The sets of houses were built a decade apart and to significantly different energy performance standards. Mawson Lakes houses were built with household energy star ratings of approximately 4 stars (165MJ/m^2), whilst those in Lochiel Park that were built to approximately 7.5 stars (58MJ/m^2). This represents a thermal energy reduction of 65% in the latter group. An analysis of measured and reverse-engineered thermal energies, show that better insulated (higher star rated) houses do use less energy for heating and cooling, as previously discussed.

3.4.1 Housing Characteristics

The majority of general characteristics of houses within both the Lochiel Park and the Mawson Lakes developments are relatively typical mass housing market in South Australia, however with definable differences in floor area. Two of the Mawson Lakes houses were comparatively smaller homes of less than 120m^2 total floor area, whereas typically the Lochiel Park houses were at or slightly above the 204m^2 average for South Australian homes [108]. The Lochiel Park houses are all two storeys, typically detached, dwellings on small allotments. Basic and general specification details are listed below:

- External walls—Solid Brick 110 mm or Hebel Panel 75 mm. Stone veneers to front elevations or similar. Lightweight walls of Weathertex® weatherboard or Custom Orb Colorbond + 40 mm air gap.
- Windows and Doors– Aluminium windows – Double Glazed: 3 mm Clear/12 mm air gap/3 mm Clear U 3.51 SHGC 0.67, Weather seals to windows.

- Roof—Colorbond steel on timber frames with sarking (aluminium foils).
- Lower Floors—Concrete slab on ground. Hard surface to Family, meals, entry and wet areas. Carpet Living room.
- Upper Floors—Low emission 22 mm particle board. Hard surface to wet areas. Timber/Carpet to bedrooms, retreats and passages.
- Ceiling—Plasterboard on steel furring channels, 13 mm to both levels. Glasswool insulation R4.0 to under roof ceilings. Glasswool or Rockwool insulation R3.0 to under floor ceilings.
- Internal walls—Plasterboard 10 mm, Rockwool insulation R3.0 to external living areas
- External shading Metal louvre or mesh shade canopies to sliding doors and, generally up to a 600 mm wide main roof eave. Timber screens to upper level windows if required. Metal louvre or mesh shade canopies if required, or extended eave of roof.

Table 3-5 summarises the house characteristics from each housing development, along with the number of occupants and outdoor reverse-cycle air conditioning units. Table 3-6 summarises the air conditioner properties, including the electrical input and thermal output power ratings and conversion efficiencies, i.e. the COP's and EER's for heating and cooling modes. Note that the Mawson Lakes houses use greater capacity equipment with lower COP's and EER's as they were installed prior to the availability of now common variable-speed drives and inverter technology, as installed in the Lochiel Park houses.

Table 3-5: Housing and air conditioner characteristics of houses Mawson Lakes and Lochiel Park houses

	Number of occupants	Type of House	Number of stories	Conditioned Floor Area (m^2)	Star Rating	RCAC Type	Number of AC units
ML 1	3	Detached	1	84.7	4.1	Ducted	1
ML 4	3	Detached	1	153.2	4.7	Ducted	1
ML 5	3	Detached	1	104.8	4.2	Split	2
ML 6	5	Detached	2	180.2	3.4	Ducted	1
LP 1	3	Detached	2	183.3	7.5	Ducted	1
LP 2	1	Detached	2	159.0	7.5	Ducted	1
LP 3	2	Attached	2	142.9	7.5	Ducted	1
LP 5	2	Attached	2	150.3	7.5	Ducted	1
LP 6	2	Attached	2	127.8	7.7	Multi-head Split	1
LP 9	4	Detached	2	168.4	7.6	Multi-head Split	2
LP 11	4	Detached	2	162.6	7.5	Multi-head Split	2

The evaluation of the thermal building load is based on a fixed COP and EER value, applied to the total monitored electrical (minus standby) energy used by the air conditioner. The actual energy will be affected by the variation of the efficiency of air conditioners due to temperature and ducting losses. Furthermore, the actual thermal performance of the building envelope can vary depending on the quality of insulation installation [109], and building air tightness. These factors were not measured or inspected as part of this study, however, collectively these factors could cause variations of 50% as reported by Saman et al. [54].

Table 3-6: Air conditioner characteristics of houses Mawson Lakes and Lochiel Park houses. Note the number within square brackets, e.g. [3] represents the number of occupants in that house.

	Heating	Cooling	Average

	Outdoor units	Heating Capacity (kW)	Input Power (kW)	COP	Cooling Capacity (kW)	Input Power (kW)	EER	COP	EER
ML 1[3]	1	8.26	2.24	3.69	7.80	2.57	3.04	3.69	3.04
ML 4[3]	1	10.40	3.20	3.25	9.70	3.19	3.04	3.25	3.04
ML 5[3]	1	9.50	3.30	2.88	8.6	3.1	2.77	2.91	2.78
	2	2.80	0.95	2.95	2.65	0.95	2.79		
ML 6[5]	1	17.70	5.50	3.22	16.9	5.7	2.96	3.22	2.96
LP 1[3]	1	12.82	3.91	3.28	11.85	4.27	2.78	3.28	2.78
LP 2[1]	1	12.16	3.3	3.68	12.27	3.68	3.33	3.68	3.33
LP 3[2]	1	10.64	3.25	3.27	9.84	3.58	2.75	3.27	2.75
LP 5[2]	1	12.82	3.91	3.28	11.85	4.27	2.78	3.28	2.78
LP 6[2]	1	9.4	1.93	4.87	8.00	2.19	3.65	4.87	3.65
LP 9[4]	1	6.96	2.03	3.43	5.75	1.96	2.93	3.91	3.36
	2	9.6	2.19	4.38	8.00	2.11	3.79		
LP 11[4]	1	8.6	1.95	4.41	7.10	1.93	3.68	4.41	3.68
	2	8.6	1.95	4.41	7.10	1.93	3.68		

3.4.2 Monitoring Period and Weather Data

Four houses in Mawson Lakes were monitored from April 2002 – May 2004, which included separately metered (disaggregated) reverse-cycle air conditioner electrical energy usage. Lochiel Park for the period between 2011 – 2014 was analysed.

To fairly compare the space conditioning results, outdoor weather data was obtained from the BOM and this was compared over the monitoring years to show similarities amongst the conditions experienced by the respective houses. Both sets of houses fall within the Greater Adelaide metropolitan area and the locations are in low lying areas approximately 7 – 10 km from the coast. For NatHERS, the relevant climate zone for both developments is Adelaide (zone 16). The relevant weather data for the study period(s) is shown in Figure 3-57 and Figure 3-58 and Table 3-7 below, showing daily minima and maxima, for 2003-04 (years 1 – 2) and 2011-14 (years 3 – 6).

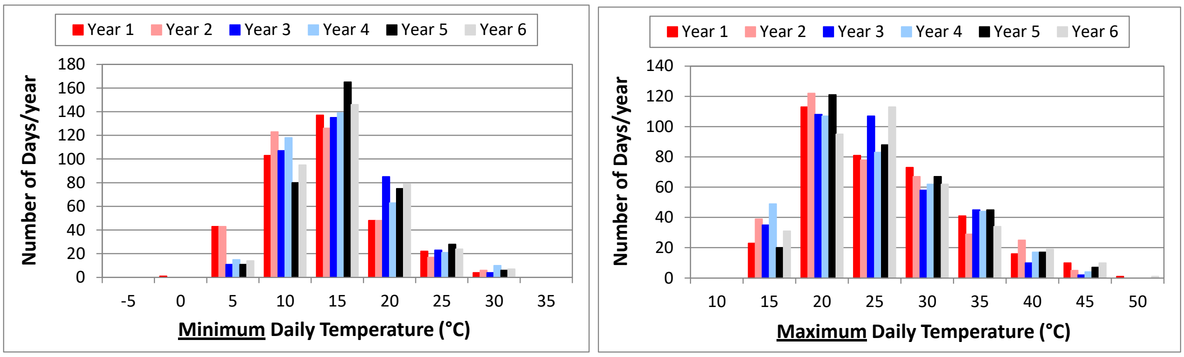


Figure 3-57: Temperature histograms for (a) minimum, and (b) maximum for each year of monitoring.

Figure 3-58 shows the number of days where the maximum temperature exceeds 32°C and similarly where the minimum falls below 18°C for each housing development. The variation across each year is small, and as such, the impact of weather variation over the years is likely to be limited.

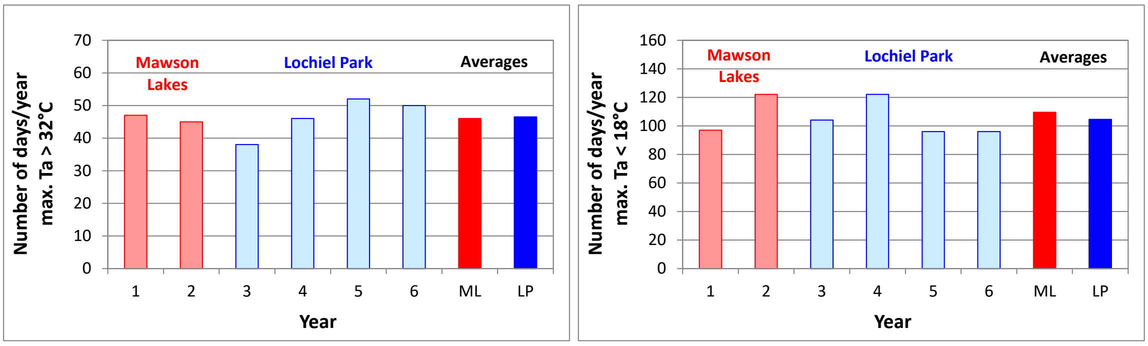


Figure 3-58: Combined days the maximum ambient air temperature was (left) < 18°C, and (right) > 32°C for each year of study for each housing development.

Table 3-7: Summary of the six-year monitoring period, showing dry bulb air temperature statistics. Years 1 and 2 correspond to the monitoring period of the Mawson Lakes houses, whilst 3-6 correspond to those for the Lochiel Park houses.

		Daily Minimum Temp. (°C)						Daily Maximum Temp. (°C)					
	Year	1	2	3	4	5	6	1	2	3	4	5	6
	Start	Apr-2002	Apr-2003	Jan-2011	Jan-2012	Jan-2013	Jan-2014	Apr-2002	Apr-2003	Jan-2011	Jan-2012	Jan-2013	Jan-2014
	End	Mar-2003	Mar-2004	Dec-2011	Dec-2012	Dec-2013	Dec-2014	Mar-2003	Mar-2004	Dec-2011	Dec-2012	Dec-2013	Dec-2014
	Min.	-0.8	0.4	1.3	2.2	3.6	0.9	12.4	10.2	11.4	10.8	11.9	10.9
	Avg.	11.3	11.1	12.8	12.3	13.1	12.8	23.7	22.8	22.7	22.8	23.5	23.5
	Max.	26.2	30.0	28.7	29.2	27.3	29.9	46.4	44.7	42.9	42.0	45.0	45.1
	Median	11.1	10.6	12.2	11.7	12.7	12.6	22.9	21.7	21.9	21.7	21.9	23.0
	Std. Dev.	5.4	5.3	4.8	5.1	4.7	4.9	7.2	7.1	6.3	7.0	6.9	7.1
Percentile	5%	2.3	3.7	5.9	5.4	6.2	5.7	14.9	14.1	14.4	14.0	15.0	14.0
	10%	4.1	4.7	7.1	6.6	7.8	6.4	15.7	15.0	15.1	14.7	15.7	15.4
	25%	7.8	7.6	9.5	8.5	10.1	9.5	17.5	16.7	17.4	16.9	17.7	17.9
	50%	11.0	10.6	12.2	11.7	12.7	12.6	22.8	21.7	21.9	21.7	21.9	22.9
	75%	14.3	14.3	16.1	15.1	15.6	15.9	28.5	27.3	27.1	28.0	28.1	27.9
	90%	18.4	18.1	19.2	19.3	20.0	19.5	33.4	33.6	32.1	33.1	33.8	33.1
	95%	21.1	21.4	21.5	22.4	23.0	21.6	38.2	36.4	34.5	35.7	36.7	36.7
	Location	ML		LP				ML		LP			

3.4.3 Results

The comparative measured results, for each house during each monitored year, are presented in the following sections. Firstly, the calculated thermal energy for heating and cooling modes is examined, followed by heating and cooling, individually. Finally, the measured electrical energy is compared, given that NatHERS aims to show improvements in energy consumption based on improved thermal comfort. Note that annual thermal loads (MJ/m^2) and the NatHERS calculated loads shown in Table 3-8, Table 3-9 and Table 3-10 are shown based on un-adjusted areas, i.e. they do not use an area-adjustment factor, which is used by the NatHERS scheme for rating purposes.

3.4.3.1 Thermal: Heating and Cooling

Table 3-8 and Figure 3-59 clearly demonstrates the higher energy demand of the lower rated (Mawson Lakes) houses in comparison to higher rated (Lochiel Park) houses. The data shows a substantial reduction of the energy requirements by improving the thermal characteristics of the building shell / envelope. However, it is worth reiterating that the interpretation of the results presented here has an overriding factor, i.e. occupancy - people use energy rather than buildings.

Table 3-8: NatHERS v monitored thermal heating and cooling load for each housing set (ML and LP) in MJ/m².

	ML		LP						
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6			
Start	Apr-2002	Apr-2003	Jan-2011	Jan-2012	Jan-2013	Jan-2014			
End	Mar-2003	Mar-2004	Dec-2011	Dec-2012	Dec-2013	Dec-2014	**AVG**	**Std dev**	**NatHERS**
ML 1	111.48	140.79	-	-	-	-	126.14	20.72	205.80
ML 4	177.15	190.60	-	-	-	-	183.88	9.51	144.40
ML 5	163.26	168.58	-	-	-	-	165.92	3.76	188.30
ML 6	248.34	223.68	-	-	-	-	236.01	17.44	205.10
LP 1	-	-	23.35	8.62	7.44	11.13	12.64	7.31	59.30
LP 2	-	-	-	-	-	40.82	40.82	n/a	61.10
LP 3	-	-	-	70.22	69.92	-	70.07	0.21	61.50
LP 5	-	-	-	63.90	61.87	67.84	64.54	3.04	63.70
LP 6	-	-	123.61	61.44	36.15	41.97	65.79	40.03	57.80
LP 9	-	-	83.94	-	-	-	83.94	n/a	58.80
LP 11	-	-	124.95	-	131.70	172.93	143.19	25.97	60.50

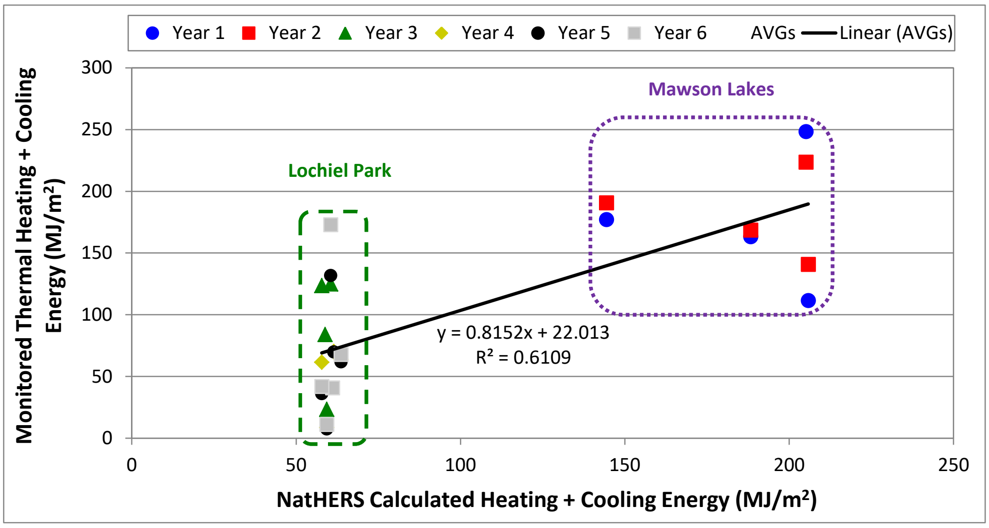


Figure 3-59: NatHERS v's Monitored thermal energy for each housing set (LP and ML) in MJ/m²

The results show a large variation in energy demand across the two sets of houses, most notably in the Lochiel Park (highly rated) houses, particularly:

- LP 1 average annual monitored consumption, measured over 4 years, is approximately 20% of NatHERS predicted load,
- LP 11 average annual monitored consumption, measured over 3 years, is about 2.5 times more than expected NatHERS predicted load.

Further investigations in separate studies [54, 110], which discussed behaviour, showed that house LP 11 is a high consumer of energy, being a house with 4 occupants and a studio occupied by a young adult. It is also a house with two outdoor RCAC units, where most have a single outdoor unit. In contrast, the occupants of house LP 1 could be accurately described as highly energy conservative.

To investigate the discrepancies further a separate analysis is provided for heating and cooling individually, as shown in the following subsections.

3.4.3.2 Thermal: Heating

Generally, Adelaide is a more heating dominant climate, where heating loads for individual houses in some cases are as much as 2 or 3 times the predicted cooling loads. The heating (Figure 3-60) shows less of a correlation than that for cooling (Figure 3-61 in Section 3.4.3.3), while the cooling load shows a strong relationship between the NatHERS predicted value and that determined from the monitored (electrical) energy data. Consider houses LP 6 and LP 11, which had the highest heating energies. The uncharacteristically high energy consumption for air-conditioning in these houses appears to relate to behaviour, i.e. relatively high and constant indoor air temperature (set points). It must be noted that detailed data analysis revealed that these residents were not absent during these periods. Since the air conditioner applies convection heating, the occupant is susceptible to feel the effects of drafts, which can result in more energy being used, depending on building layout. Finally, the two-storey houses in LP, and some in ML, may promote thermal stratification which may result in additional heating (or over-heating) of downstairs spaces. Downstairs heating will occur depending on how the building is occupied, and this is expected to vary between houses. Although the heating season is generally longer than the cooling season, it is less intense, and as such, considerable household heating variations were expected.

Table 3-9: NatHERS Heating calculated load v monitored heating thermal energy (LP and ML).

	ML		LP						
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6			
Start	Apr-2002	Apr-2003	Jan-2011	Jan-2012	Jan-2013	Jan-2014			
End	Mar-2003	Mar-2004	Dec-2011	Dec-2012	Dec-2013	Dec-2014	**AVG**	**Std dev**	**NatHERS**
ML 1	51.34	102.22	-	-	-	-	76.78	35.98	161.73
ML 4	56.57	107.95	-	-	-	-	82.26	36.33	88.98
ML 5	82.16	97.30	-	-	-	-	89.73	10.71	147.47
ML 6	128.79	137.62	-	-	-	-	133.21	6.24	112.86
LP 1	-	-	13.09	0.34	0.10	3.96	4.37	6.07	33.00
LP 2	-	-	-	-	32.96	21.35	27.15	8.21	36.40
LP 3	-	-	-	21.34	17.73	-	19.54	2.56	28.10
LP 5	-	-	14.02	14.02	9.61	8.98	11.66	2.74	32.30
LP 6	-	-	119.39	57.49	34.37	34.17	61.35	40.21	17.30
LP 9	-	-	40.99	-	43.35	-	42.17	1.67	26.90
LP 11	-	-	96.38	130.82	84.75	127.92	109.97	22.93	28.50

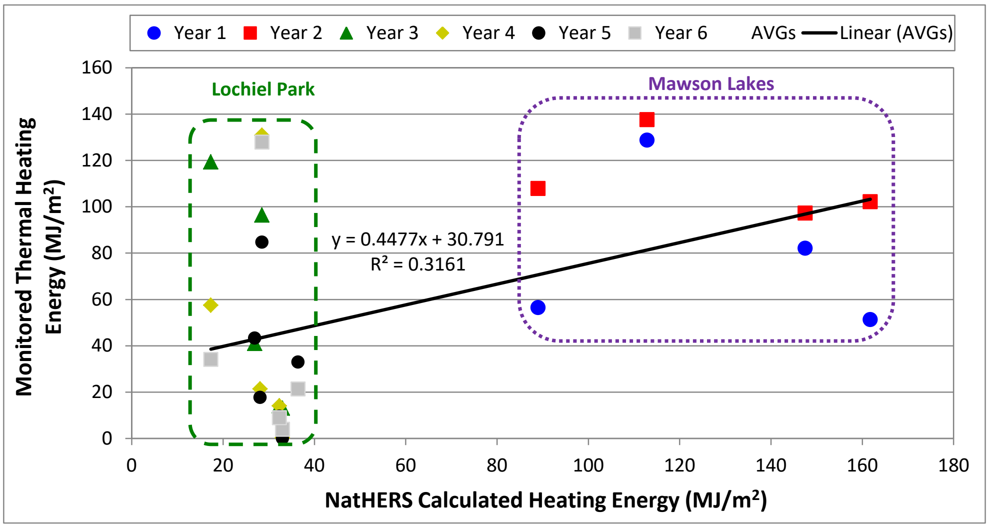


Figure 3-60: NatHERS Heating load v monitored heating thermal energy (LP and ML)

3.4.3.3 Thermal: Cooling

Table 3-10 and Figure 3-61 show similar thermal energy, however for cooling performance. Consider LP 1 and 6, which have the lowest cooling energy over the monitoring periods. The uncharacteristically low energy consumption for air-conditioning in these houses appears to relate to behaviour, i.e. a tolerance towards higher temperatures, as shown in previous studies [111]. The R^2 value for cooling is 0.546 and a gradient of 1.288 demonstrating a strong casual effect. This result is consistent with the Adelaide climate. Cooling demand generally only occurs on hot days and on these days, differences in behaviour across households is less apparent, as people are more likely to use air conditioning.

Table 3-10: NatHERS Cooling calculated load v monitored cooling thermal for each housing set (LP and ML).

	ML		LP						
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6			
Start	Apr-2002	Apr-2003	Jan-2011	Jan-2012	Jan-2013	Jan-2014			
End	Mar-2003	Mar-2004	Dec-2011	Dec-2012	Dec-2013	Dec-2014	**AVG**	**Std dev**	**NatHERS**
ML 1	60.14	38.56	-	-	-	-	49.35	15.26	40.33
ML 4	120.58	82.66	-	-	-	-	101.62	26.82	55.48
ML 5	81.10	71.28	-	-	-	-	76.19	6.95	40.85
ML 6	119.55	86.06	-	-	-	-	102.80	23.68	92.19
LP 1	-	-	10.26	8.28	7.35	7.16	8.26	1.42	26.40
LP 2	-	-	-	-	-	19.47	19.47	n/a	24.60
LP 3	-	-	45.33	48.88	52.19	-	48.80	3.43	33.40
LP 5	-	-	-	51.08	52.26	58.86	54.07	4.19	31.40
LP 6	-	-	4.23	3.95	1.78	7.80	4.44	2.49	40.50
LP 9	-	-	42.94	49.61	-	-	46.28	4.71	31.90
LP 11	-	-	28.56	-	46.95	45.01	40.18	10.10	32.00

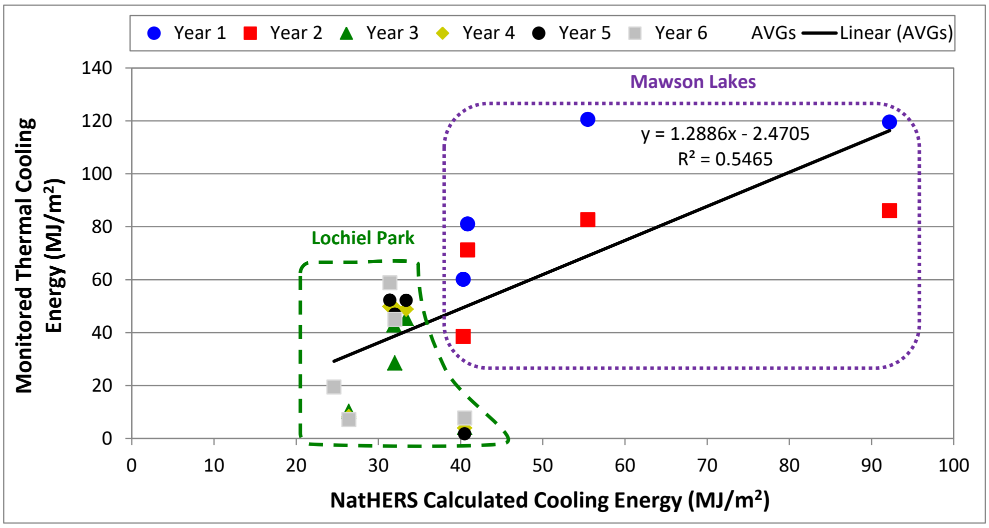


Figure 3-61: NatHERS Cooling calculated load v monitored cooling thermal for each housing set (LP and ML)

Considering the data for total thermal heating and cooling for each house and across housing sets the average derived from the absolute values presented in Table 3-8, for annual energy for a Mawson Lakes house is 178 MJ/m^2 floor area whereas, for Lochiel Park the average is 71.45 MJ/m^2. This is a factor reduction of 60% or stated in other terms the ML houses use approximately 2.5 times the thermal energy of a LP house. NatHERS calculates an average (area un-adjusted) value for annual thermal loads of 185.9 MJ for Mawson Lakes and only 60.4 MJ for Lochiel Park houses. In this study then, NatHERS evaluated thermal loads based on the many considerations that go to make a star rating do closely correlate with the monitored energy figures across several years of data. This significant energy demand reduction of as much as 60% less energy when a building is improved from 4 stars to 7.5 stars is anticipated in NatHERS ratings values.

Figure 3-59 showed a reasonable correlation of the measured heating and cooling energy use and those predicted by NatHERS, with an R^2 value of 0.611 and a gradient of 0.815, demonstrating a strong causal effect. This result presents a significantly greater effect of star rating than that presented for Adelaide in the CSIRO report, which had a larger set of Adelaide homes but across a much narrower star band range [50]. It is recognised that the 4 houses in Mawson Lakes (used in this study) are a relatively small sample, and the question remains whether these homes do represent the wider development. In contrast, the Lochiel Park homes used in this study have previously been shown (in another study) to be representative of all homes in Lochiel Park [111].

3.4.3.4 Electrical: Heating and Cooling (including Standby)

The purposes of the NatHERS scheme is more than the environmental benefits of reductions in GHG emissions through minimum performance settings and is also to achieve lower running costs for heating and cooling for households through the process of improving the energy efficiency of the building envelope, with all other factors affecting the impact. Figure 3-62 correlates the actual measured electrical energy used by the heating and cooling equipment (kWh/m^2), with the NatHERS predicted value (MJ/m^2). Although the correlation isn't as strong as other results above, the data does show that this objective has been achieved, when all factors are included.

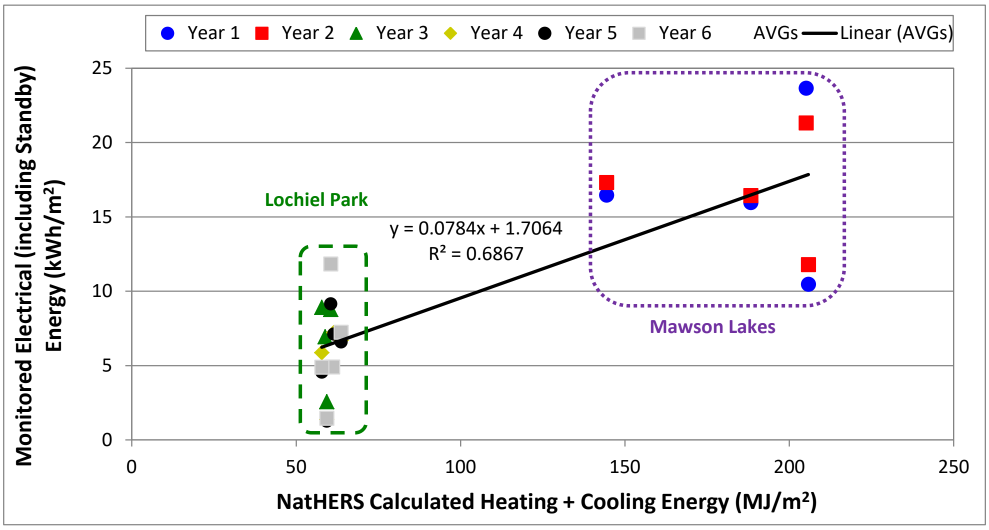


Figure 3-62: NatHERS calculated thermal loads (MJ/m2) versus monitored electrical loads (kWh/m2) for both Lochiel Park and Mawson Lakes studied houses.

3.4.4 Conclusions

By comparing the estimated thermal load, from monitored electrical data, from two housing sets with a wide range of star bands, the principle behind NatHERS is shown to be accurate. More specifically, in addition to the purpose of the NatHERS scheme, which is to facilitate the achievement of minimum regulatory targets for energy demand from housing, the results here confirm that on average, one can achieve lower running costs for heating and cooling by improving the energy efficiency of the building envelope. The data presented here correlates the actual energy used by the heating and cooling equipment with the NatHERS predicted value.

Overall, the higher star rated houses of this study do use less energy for heating and cooling than the lower star rated houses. On average the 7.5 star rated Lochiel Park houses used 60% less heating and cooling energy, compared with those in Mawson Lakes, which were built about one decade earlier.

Although, this study is based on a statistically small sample size (highlighting the need for ongoing, extensive national energy consumption data collection and associated research), it does contribute to the validation of concepts used in NatHERS, i.e. household energy consumption can be significantly reduced by designing and building houses to achieve higher star ratings.

3.5 Household Occupancy

This section examines household occupancy characteristics of monitored houses within the Lochiel Park housing development (SA) and those from CSIRO's RBEES data set (SA, VIC and QLD).

3.5.1 Methodology

To determine the household user occupancy, the household's electrical power profile was examined for both data sets. Data exists for a different number of houses over the various years that were monitored. Table 3-11 summarises the number of houses that were averaged and hence used for each monitored year, by each data set. Note that although both data sets had significantly more monitored data than used here, only houses with complete data sets, for each respective monitoring period, were used in this analysis. For confidence and to be consistent with other analyses, UniSA limited their analysis of CSIRO's RBEES data to 42 of the houses, as previously discussed.

Table 3-11: Summary of number of houses used for each monitoring period of each data set.

Monitoring Period	Data Set	
	Lochiel Park	**RBEES**
2011*	19	-
2012	38	-
2013	53	-
2014	53	-
2015	49	-
mid 2012 - mid 2013*	-	42
mid 2013 - mid 2014	-	42

* corresponds to the first monitored year from each data set.

Household power data from each data set was organised into its respective summary table, which was then averaged. Note that to achieve the analyses presented below, the data was expanded to include Boolean (True / False) flags for days to indicate whether days fell during the week or on weekends, as well as their season.

Note that the power profiles for the RBEES data set appear to be smoother than those for the Lochiel Park houses, as data is collected every 30 minutes for the RBEES data set, whilst that for Lochiel Park is collected every minute.

3.5.2 Preliminary Analyses of Household Power Profiles

Preliminary analyses were conducted separately for each housing set, for the first monitored year; refer to Table 3-11. These are presented here and grouped by housing estate / data set. Household power profiles were determined for the following factors:

- Type of day: weekday vs. weekend,
- Season of year + type of day,
- Month of year + type of day.

3.5.2.1 Lochiel Park houses, 2011 (19 houses)

Figure 3-63 shows the average daily household power profile for 19 houses that were monitored in 2011. The figure shows two clear differences between weekend and weekday power profiles, i.e.:

- The morning peak is about one hour later during weekends, likely as people sleep in on the weekends, and
- A higher power usage throughout the day on weekends between 08:00 and 17:00, likely as people are home for more time during the day, where they consume energy.

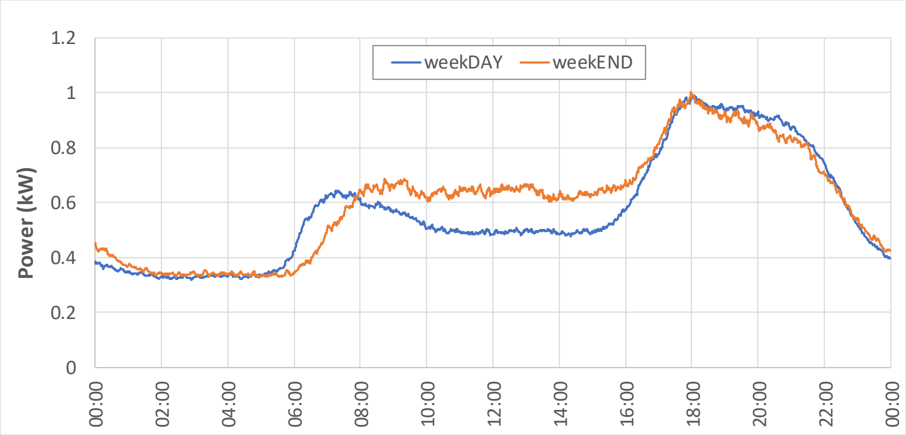


Figure 3-63: Average daily power profile for 19 Lochiel Park houses, monitored in 2011, by type of day.

Figure 3-64 examines the average daily power profile for the 19 Lochiel Park houses for each season. The figure clearly shows that average daily power profiles vary with the seasons. The daily profiles are consistent for spring and autumn as these Lochiel Park (7.5 NatHERS star rated) houses do not ordinarily require heating or cooling during these months. The profile during summer is slightly higher in summer due to the need for cooling, however the increases is only small, likely due to the higher star rating of the houses. In contrast, the profile during winter is much higher than the other seasons, likely due to the need for heating, which explains the increased power usage during the higher morning and afternoon peaks.

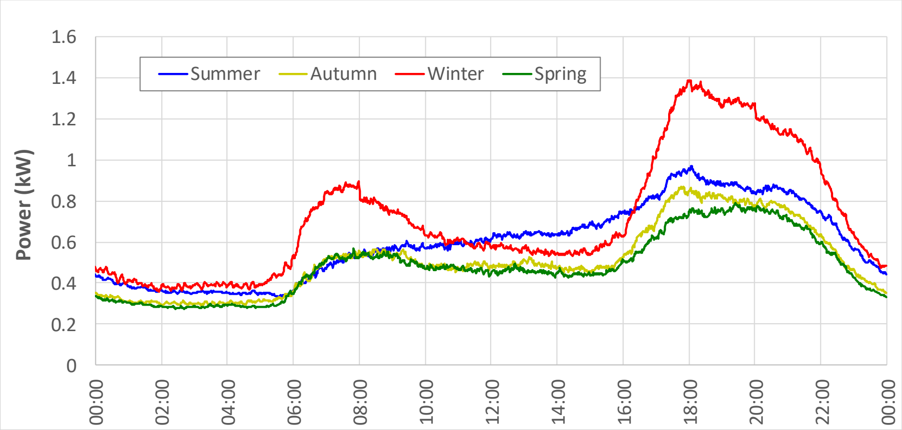


Figure 3-64: Average daily power profile for 19 Lochiel Park houses, monitored in 2011, by season.

It was shown in Figure 3-63 that the type of day (weekend vs. weekday) is an important factor, as is the season. As such, Figure 3-65 further examines this by building upon Figure 3-64, i.e. the seasons are now split by day types. The following information is deduced from Figure 3-65:

- People appear to sleep in on the weekends (consistent with Figure 3-63) for each season, except for summer.
- Power profiles are generally identical between 18:00 and 05:00 for each respective season.

- More power is drawn during the weekends for each month, indicating that people occupy their houses during the day.

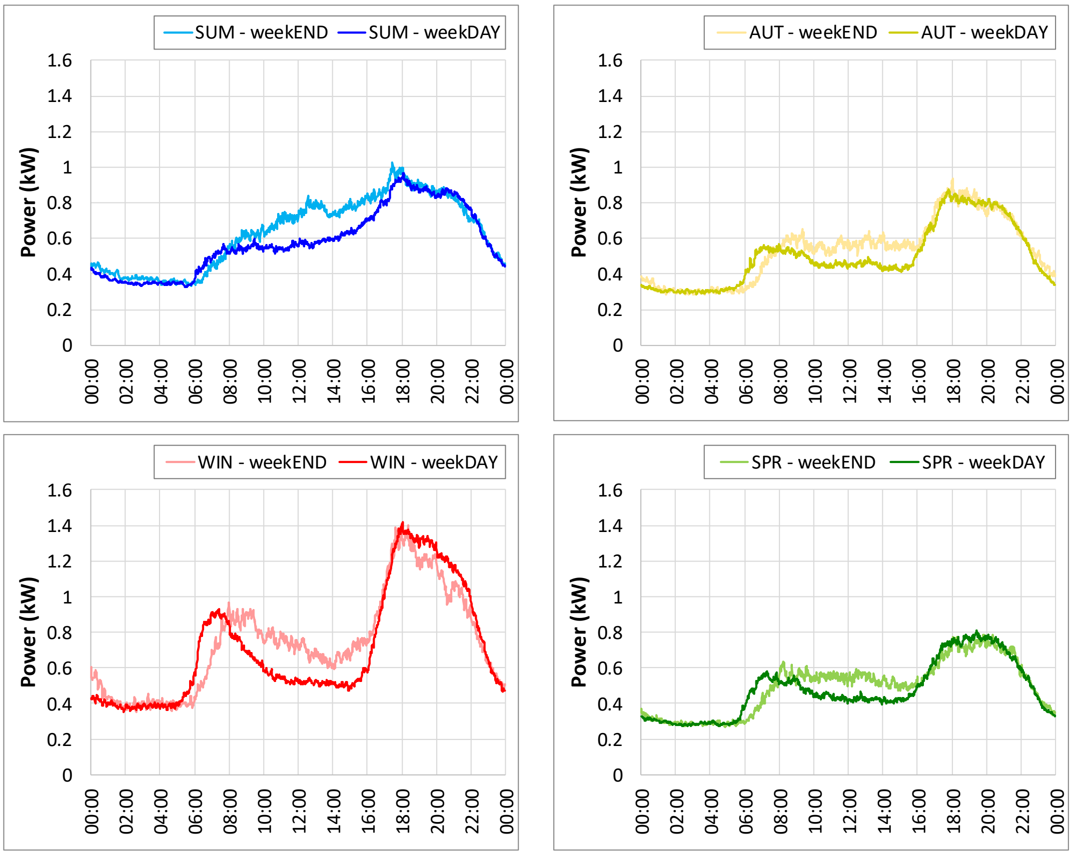


Figure 3-65: Average daily power profile for 19 Lochiel Park houses, monitored in 2011, by season and type of day.

The variation of power profile varying by season and day type is further examined below, where Figure 3-66 shows how the average daily power profile varies by month. This figure again shows the months with highest morning and afternoon peaks correspond to winter months (June, July, and August). The months with the next highest morning and afternoon peaks are January and February (two summer months).

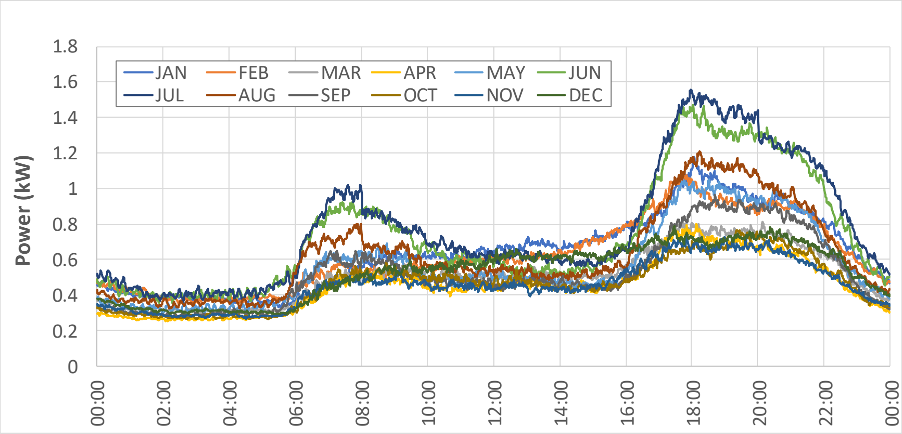


Figure 3-66: Average daily power profile for 19 Lochiel Park houses, monitored in 2011, by month.

The variation of power profile by month is further expanded in Figure 3-67, where each month shows the average weekday and weekend day types. The average daily power profiles for each month again shows that people generally sleep in for all months, other than January and December where they appear to use power at the same time of morning. This explains why a time shift of about one hour was seen in Figure 3-65, for summer.

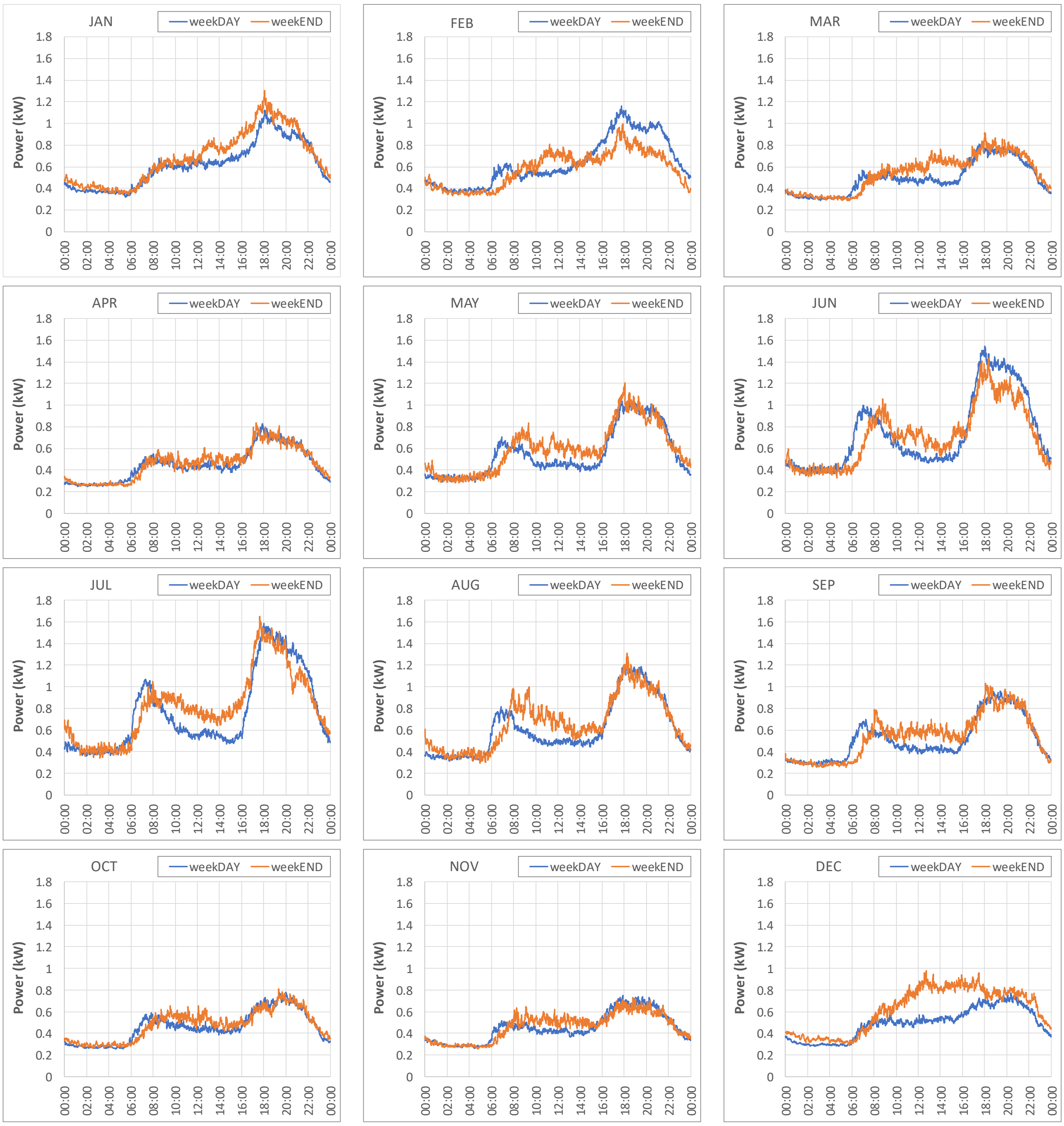


Figure 3-67: Average daily power profile for 19 Lochiel Park houses, monitored in 2011, by month and type of day.

3.5.2.2 RBEES Data Set, mid 2012 – mid 2013 (42 houses)

This section repeats the analysis presented in Figure 3-63 – Figure 3-67, however, this focusses on the RBEES data set, which contains data for 44 houses that is collected every 30-minutes. As such the average power profiles for the RBEES data set appears to be much smoother than those for the Lochiel Park houses.

In the same manner with the Lochiel Park houses, Figure 3-68 shows the difference between weekend and weekdays for the houses within the RBEES data set, i.e. people tend to draw power about one hour later on weekends than they do on weekdays.

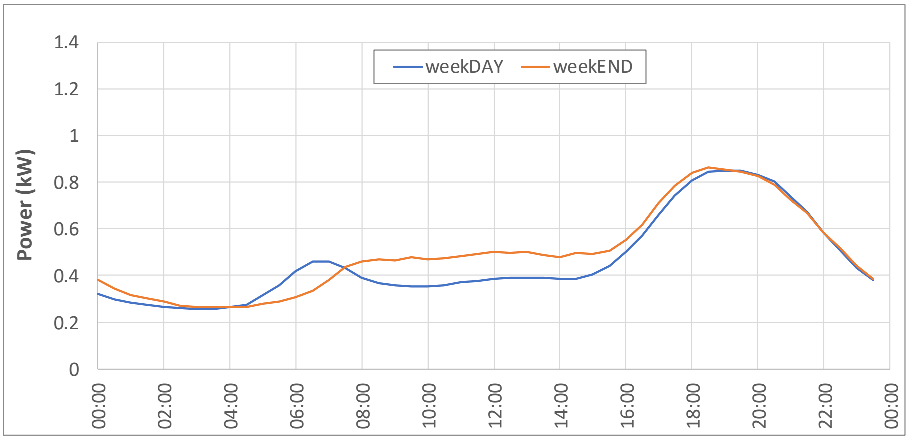


Figure 3-68: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2013, by <u>type of day</u>.

Figure 3-69 examines the variation of power usage for seasons for the RBEES data set. This figure shows similar properties of that for the Lochiel Park houses, i.e.:

- Similar patterns of usage for spring and autumn.
- Higher morning and afternoon peaks in winter.
- Slowly ramp-up throughout the day in summer after the morning peak.

In contrast however, the RBEES houses appear to have smaller morning and afternoon peaks in summer than those in spring and autumn. This cannot be easily explained without knowing more information about the individual houses, however it is possible that:

- These houses are more resilient to heat than those (two-storey) in Lochiel Park.
- These houses may require less cooling than heating, given the NatHERS star ratings take the sum of the total cooling and heating thermal loads.

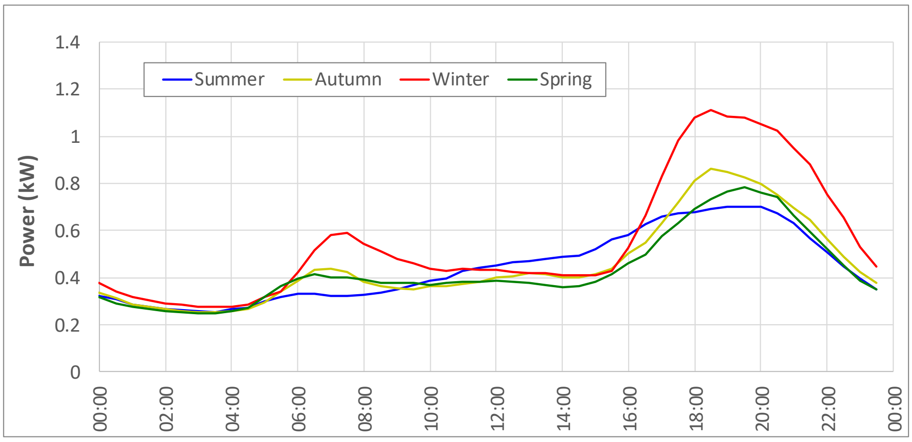


Figure 3-69: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2013, by <u>season</u>.

Figure 3-70 examines the difference in day type (weekend vs. weekday) for each month, which appear to show the same trends seen for the Lochiel Park houses, i.e. people appear to:

- Sleep in on weekends, see by a time shift of about one hour between 05:00 and 06:00 when people start drawing power.
- Be home for longer periods on weekends than week days, as they their houses consume more energy / draw higher average power between the morning and afternoon peaks.

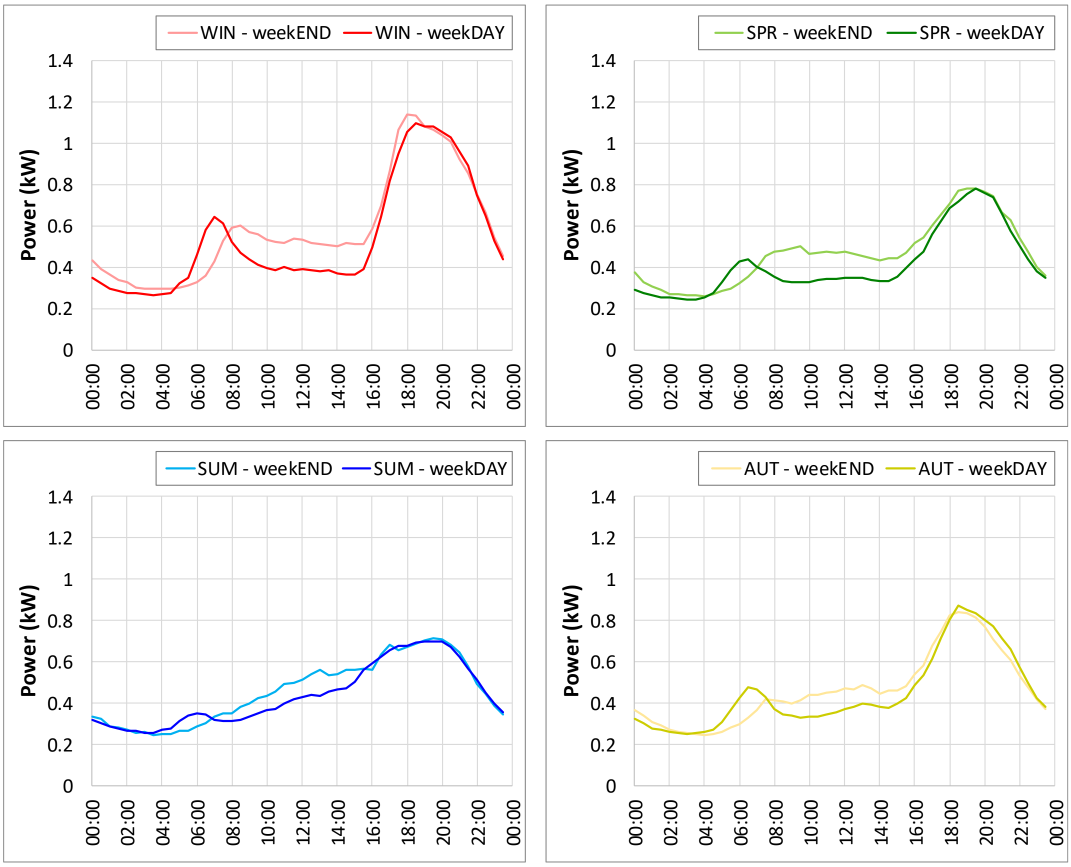


Figure 3-70: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2013, by season and type of day.

The daily average power profile for each month is shown in Figure 3-71, which also shows that the months yielding the highest morning and afternoon peaks are the winter months (June, July and August). Similar to the Lochiel Park houses, two of the next three months that draw the (next) highest morning and afternoon peaks, are January and February.

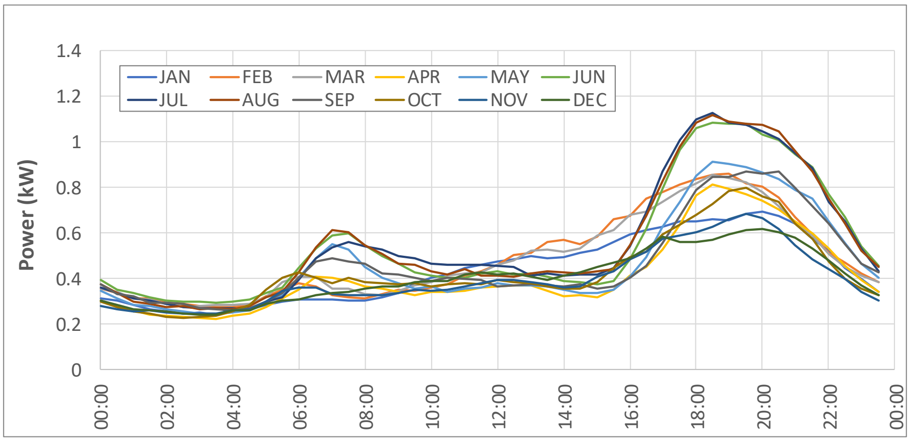


Figure 3-71: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2013, by month.

The impact of type of day, on month, is examined in Figure 3-72 for the houses within the RBEES data set. This figure shows similar trends those for Lochiel Park, however it should be noted that the figure starts with July given this first year of monitoring spanned July 2012 – June 2013. The main difference is that the one-hour time shift between weekdays and weekends is seen here for the summer months, unlike the Lochiel Park houses.

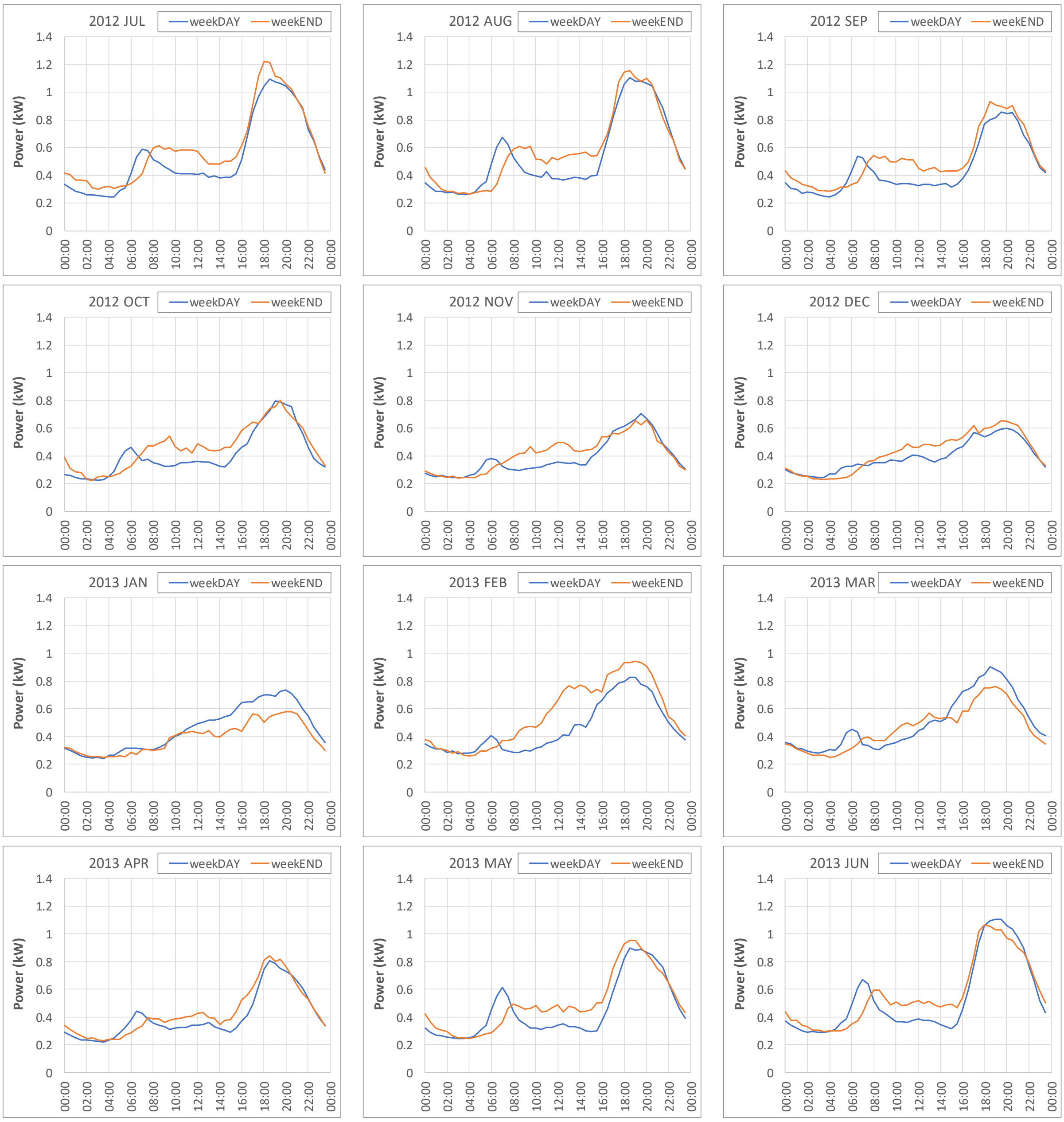


Figure 3-72: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2013, by month and type of day.

3.5.2.3 Concluding Remarks

Although the results presented here show that there is significant difference between household power usage corresponding to respective data sets, based on the type of day, season, and month, it should be noted that these are shown only for one monitoring period. As such, the following section examines similar analyses for each data set, over multiple years of monitoring, to determine if power profile usage patterns exist, or if these vary from year to year.

3.5.3 Combined Analyses of Household Power Profiles over Entire Monitoring Periods

This section presents similar analyses to that in Section 3.5.2 however now over multiple years, to determine if household power profile patterns vary year to year or if they remain consistent. Although Figure 3-63 - Figure 3-72 showed that significant differences between power household power usage existed based on the type of day, season, and month, the analysis presented here focusses only on the type of day, shown in Figure 3-73, and the season, shown in Figure 3-74, for numerous Lochiel Park houses. Refer to Table 3-11 to see the number of houses used to calculate the average power profile, per year.

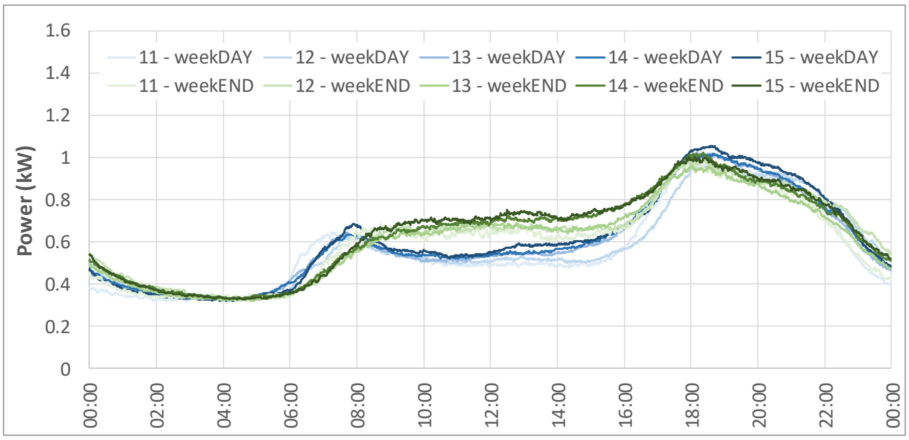


Figure 3-73: Average daily power profile for Lochiel Park houses, 2011 - 2015, by type of day. Note that 11, 12, 13, 14, 15 represent 2011, 2012, 2013, 2014, and 2015, respectively.

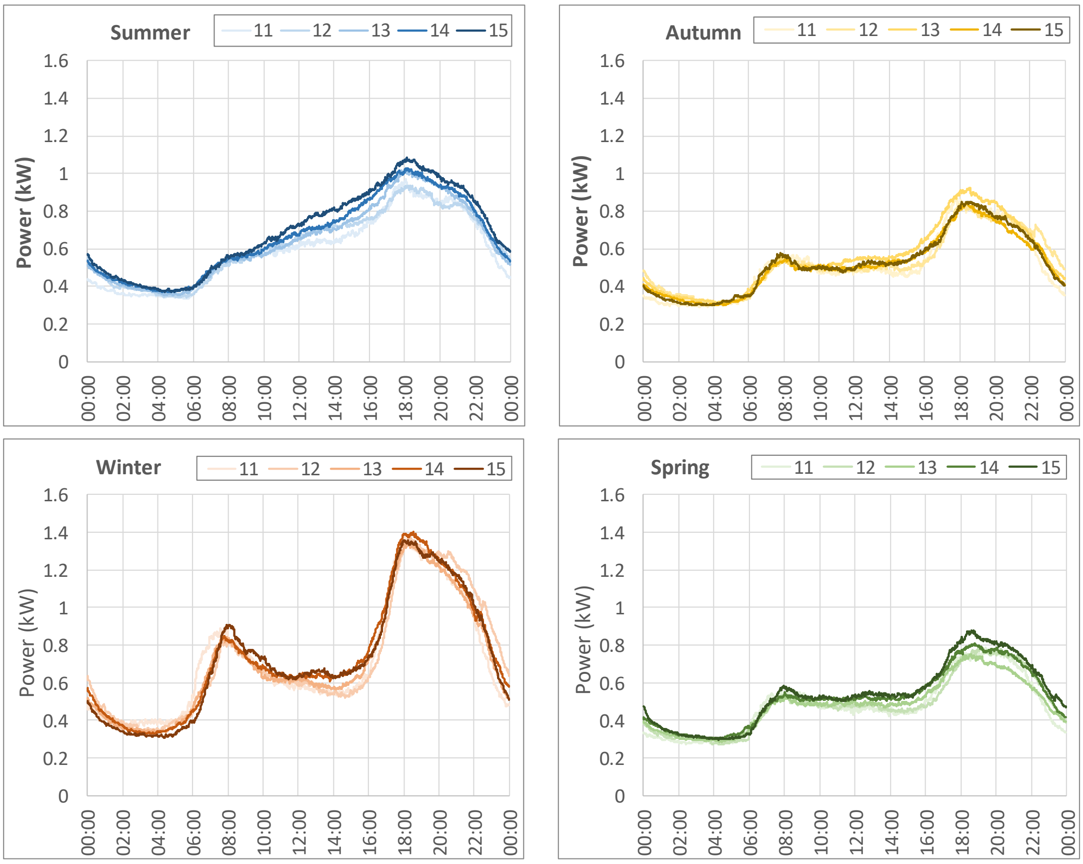


Figure 3-74: Average daily power profile for Lochiel Park houses, 2011 - 2015, by season. Note that 11, 12, 13, 14, 15 represent 2011, 2012, 2013, 2014, and 2015, respectively.

Figure 3-73 again shows that the type of day (weekend vs. weekday) has an impact on the time of day that electricity is used in the Lochiel Park houses, however, only small differences are observed year to year. Similarly, Figure 3-74 shows that power usage profiles change season by season, but not year by year for any season.

Figure 3-75 shows that the type of day has an impact on the time of day that electricity is used in the RBEES houses, and that a noticeable difference is observed year to year. This difference between the two years of monitoring is also shown for each season, except summer, in Figure 3-76. This difference is only in magnitude of power and not by time of use of electricity, and appears to occur during the typical time of day that most people are assumed to be awake, i.e. 07:00 – 22:00.

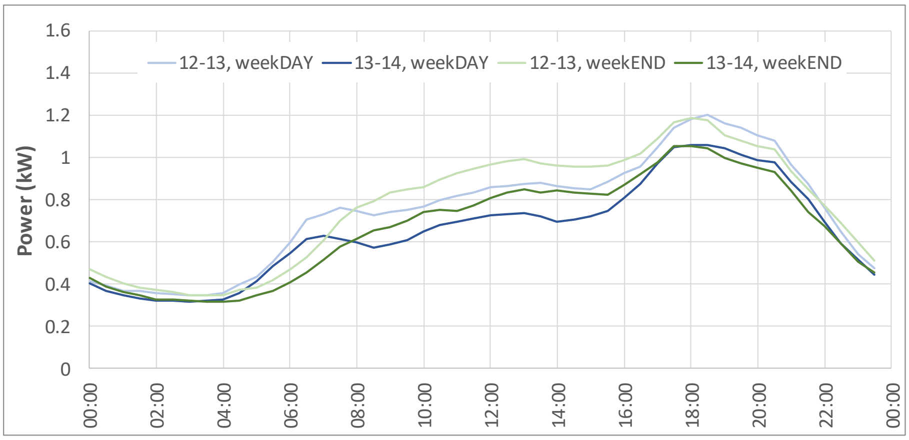


Figure 3-75: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2014, by type of day. Note that 12-13 represents mid 2012 – mid 2013.

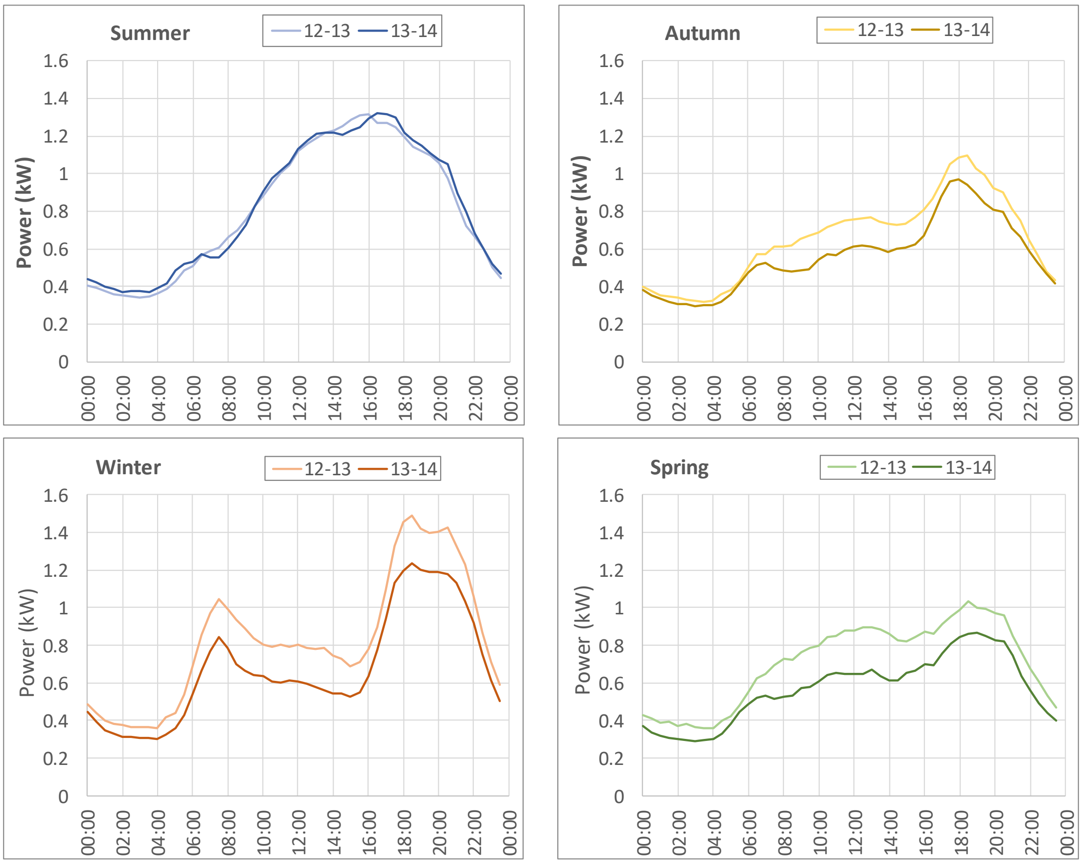


Figure 3-76: Average daily power profile for 42 RBEES Data houses, monitored mid 2012 - mid 2014, by season. Note that 13-14 represents mid 2013 – mid 2014.

3.5.4 Summary and Recommendations for Future Generations of Rating Tools

The results presented here show there is significant difference between the average power usage profile, and hence occupancy, based on the type of day (weekend vs. weekday), the season, and the month. This was seen for two distinct monitored housing developments, i.e. Lochiel Park and those in QLD and VIC (in the RBEES data set), over different years of monitoring, which showed similar usage patterns regarding:

- morning and afternoon peaks highest in winter months,
- morning and afternoon peaks next highest in January and February,
- power being drawn approximately one hour later (time-shift) between weekdays and weekends seen for most months, except for January and December for the Lochiel Park houses.

As such it is highly recommended that the next version of NatHERS investigates and varies the occupancy patterns assumed by the current (2nd generation of NatHERS). It is also recommended to monitor the occupancy of people in certain zones, to reflect the different way in which people occupy rooms at various times of days. For example:

- People use bedrooms as studies, which may contain small office / home office equipment and as such require heating or cooling during hours outside of standard bedroom occupation.
- Shift-workers occupy bedrooms during the middle of the day.

Please note that this occupancy analysis commenced before the release of the 2019 version of the updated NCC (currently under the review phase), which does indicate that the occupancy profiles are to be adjusted / updated.

4 New Assumptions and Settings

The purpose of this chapter is to describe modified and additional assumptions, which are recommended to be incorporated into AccuRate Sustainability and associated modules, based on the analysis of measured household data and the review of existing assumptions in earlier sections. This chapter will also present the results of investigations into the impact of changing certain existing assumptions, along with recommendations associated with these impacts. Furthermore, new assumptions associated with the development of a new module for evaluating PV systems and associated battery storage, to be described in a later section, will also be discussed.

4.1 The impact of acceptability limit on cooling energy requirement

As previously mentioned, the thermostat in the existing cooling model in AccuRate is set equal to the neutral temperature, T_n, defined in Equation 1 for the corresponding climate zone, up to a limit of 28.5°C. The upper limit of the comfort zone at 50% relative humidity is taken to be $T_n + 2.5°C$, which corresponds to the 90% acceptability limit of thermal comfort in ASHRAE 55-2013 [35]. For common naturally ventilated building designs, the ASHRAE standard specifies that the allowable indoor operative temperature shall be determined using the 80% acceptability limits which is $T_n + 3.5°C$. Using a slightly different four category system, EN 15251-2007 [101] specifies $T_n + 4.0°C$ for 70% acceptability limit. It is noted that there has been little analysis on the impact of different acceptability limits on housing heating and cooling energy requirements. In order to fill this knowledge gap, Ren and Chen [112] carried out a study for understanding the impact of potentially relaxing the thermal comfort acceptability limits currently used in AccuRate.

In Ren and Chen [112], three house designs with different thermal performance and constructions are evaluated in the representative cities of seven Australian NCC climate zones (except NCC Climate zone 8 the Alpine region, considering that there are few residential buildings in this region). The seven representative cities are Darwin, Brisbane, Alice Springs, Mildura, Sydney, Melbourne and Hobart respectively as listed in Table 4-1. Figure 4-1, Figure 4-2 and Figure 4-3 show the plans of the three houses investigated. House 1 (the medium construction) is a single-storey house with Colorbond external wall (steel cladding on 90 mm stud) with slab-on-ground concrete floor. House 2 (the heavyweight construction) is a two-storey house with double brick cavity external wall with slab-on-ground concrete floor. House 3 (the lightweight construction) is a high set (2.32m fully raised off the ground) single-storey house with weatherboard external wall and timber floor, which is a typical passive house designed for tropical and sub-tropical regions.

Figure 4-4 shows the heating and cooling energy requirements at different thermal acceptability limits for House 1 with 3 stars and House 2 with 6 stars (when rated with the current 90% acceptability limit) in the seven cities: Darwin, Brisbane, Alice Springs, Mildura, Sydney, Melbourne and Hobart (from top to bottom). The results show that for both houses there are no energy requirements for space cooling in Hobart and space heating in Darwin. For House 2, the heavyweight construction, the decrease from 90% to 70% in the acceptability limits has no impact on the cooling loads in Brisbane and Hobart, and reduces 3.1% of the cooling load in Darwin (increasing its rating by 0.2 stars, from 6.1 to 6.3 stars). For House 1 there is a minor impact on the space cooling loads in Brisbane and Hobart with the decrease in the acceptability limits from 90% to 70%. However, in Darwin it reduces 13.7% of the cooling load and increases the energy rating by 1 star (from 3.1 to 4.1 stars). For both houses in Darwin, the decrease from 90% to 80% in the acceptability limits has greater impact on the cooling load than that from 80% to 70%. Specifically, for House 1, the reduction from 90% to 80% increases the energy rating by 0.7 star (i.e. from 3.1 to 3.8 stars) and the reduction from 80% to 70% increases the energy rating by only 0.3 star (i.e. from 3.8 to 4.1 stars).

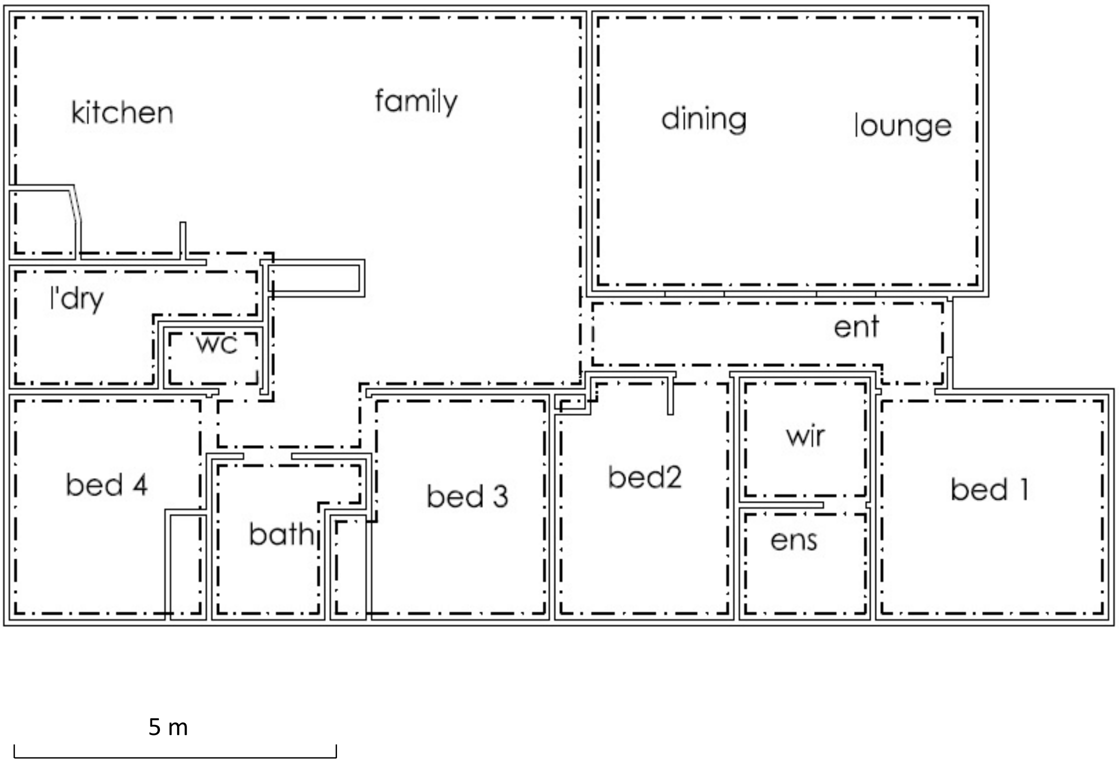
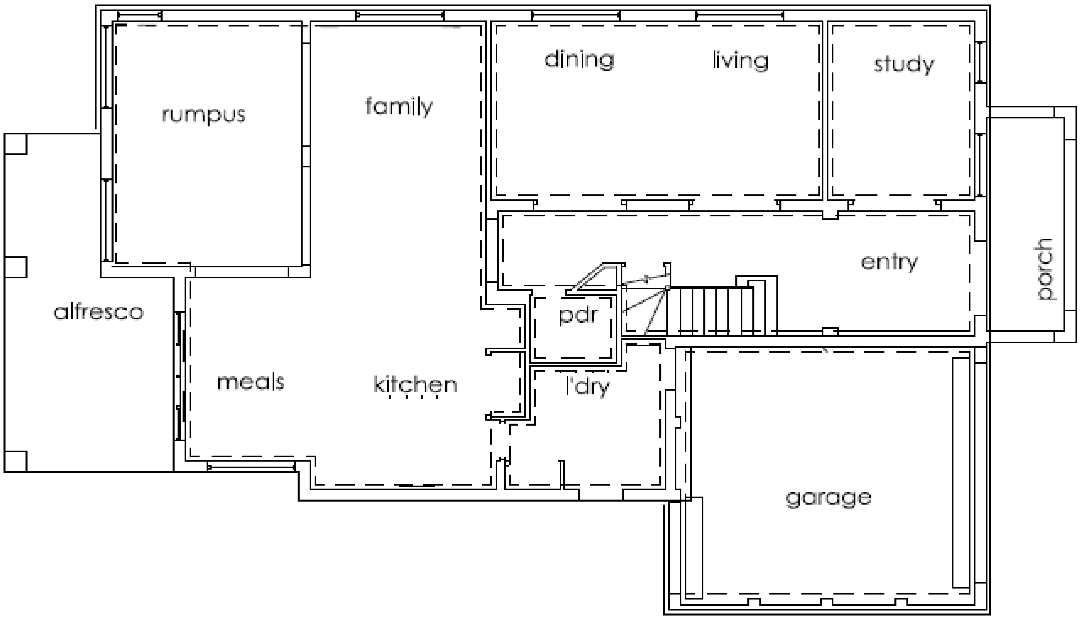
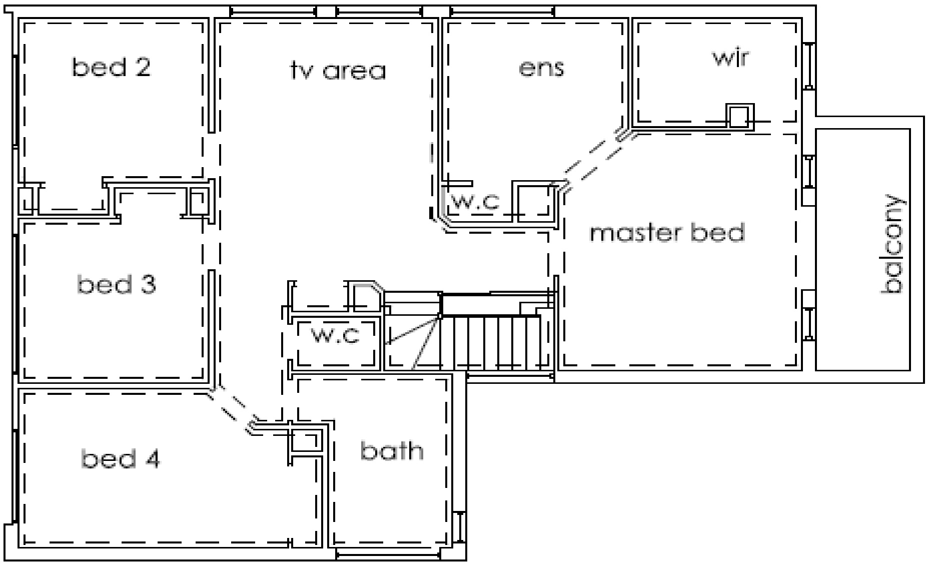


Figure 4-1: Floor plans of House 1



Ground floor



First floor

Figure 4-2: Floor plans of House 2

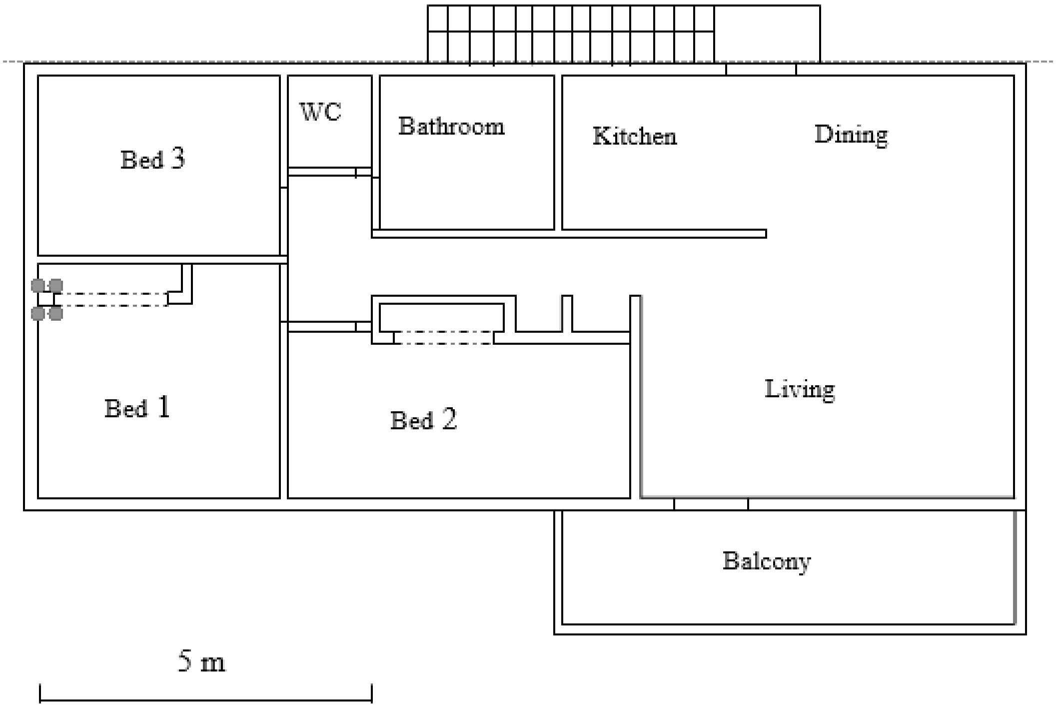


Figure 4-3: Floor plans of House 3

Table 4-1: Cooling thermostat settings for the representative cities

NCC climate zone	Representative city	Climate sub-zones defined in NatHERS	Thermostat setting temperature (°C)
Zone 1	Darwin	1	26.5
Zone 2	Brisbane	10	25.5
Zone 3	Alice Springs	6	26.5
Zone 4	Mildura	27	25.0
Zone 5	Sydney	17	25.5
Zone 6	Melbourne	21	24.0
Zone 7	Hobart	26	23.0

The results also showed that the energy requirement for space heating in Alice Springs (hot dry summer with warm winter) is less than in Mildura (hot dry summer with cool winter). Consequently, the impact of the acceptability limits on the space cooling load in Alice Springs is relatively greater than that in Mildura. The cooling loads for Houses 1 and 2 are reduced by 48.4% and 41.9% respectively due to the decrease in the acceptability limits in Alice Springs. The reductions are 45.8% and 35.0% for Houses 1 and 2 in Mildura respectively. For House 1 it increases 0.6 star (from 3 to 3.6 stars) in Alice Springs and 0.1 star (from 2.9 to 3 stars) in Mildura due to the decrease from 90% to 70 % in the acceptability limits. For House 2 the increase is 0.4 star (from 5.9 to 6.3 stars) in Alice Springs and 0.2 star (from 5.9 to 6.1 stars) in Mildura. Again, it was found that for both houses in the two cities the decrease from 90% to 80% in the acceptability limits has a greater impact on the cooling loads than that from 80% to 70%.

The impact of the acceptability limits on space cooling loads is limited in both Sydney and Melbourne. In terms of house energy star rating, their impact can be ignored due to the fact that cooling loads are significantly small in comparison with heating loads.

In warm tropical climates, lightweight buildings may achieve better thermal comfort after sunset by removing unwanted heat quickly. In tropical and sub-tropical regions in Australia, there are high-set lightweight houses, which are raised off the ground to facilitate cross ventilation to cool down the buildings quickly at night. House 3 is a lightweight house with timber/uPVC frame single glazed clear glass windows and medium size gaps of the windows and doors. Its floor is raised 2.32m off the ground with under floor space totally open to the surroundings. The impact of relaxing the thermal comfort criteria on its energy performance under current climate in the four regions with hot to very hot summer (Darwin- tropical, Brisbane -subtropical, Alice Springs and Mildura both having hot dry summer) is shown in Figure 4-5. Except in Darwin, the energy performance is poor (below 1 star even with 70% of the acceptability limits) and significant energy is required for space heating in the other three cities. With the decrease from 90% to 70% in the acceptability limits, the space cooling loads are reduced by 45.5% in Darwin, 53.7% in Brisbane, 25.7% in Alice Springs and 24.7% in Mildura. With the decrease in the acceptability limits, the energy rating is increased by 3.6 stars (from 3.4 stars to 7 stars) in Darwin, 0.2 star in Brisbane, 0.3 star in Alice Springs and 0.5 star (from 0 to 0.5 star) in Mildura. Again, the decrease from 90% to 80% in the acceptability limits has greater impact than that from 80% to 70%.

In summary, the Ren and Chen [112] study shows that for cooling energy requirements, the thermal comfort acceptability limits have the largest impact on the energy star rating for lightweight high-set houses in tropical climates. The least impact of acceptability limits on cooling energy requirements and star rating is found for the heavy weight double brick houses in relatively mild and cold climates such as Melbourne and Hobart. The impact on the cooling energy requirements for all the three constructions can also be large in hot summer climates such as Alice Spring and Mildura. However, due to the substantial heating energy requirements in these climates, its impact on energy star rating is subdued, in comparison with tropical regions. For cooling energy requirements and energy star rating, the decrease from 90% to 80% in the acceptability limits has greater impact than that from 80% to 70%.

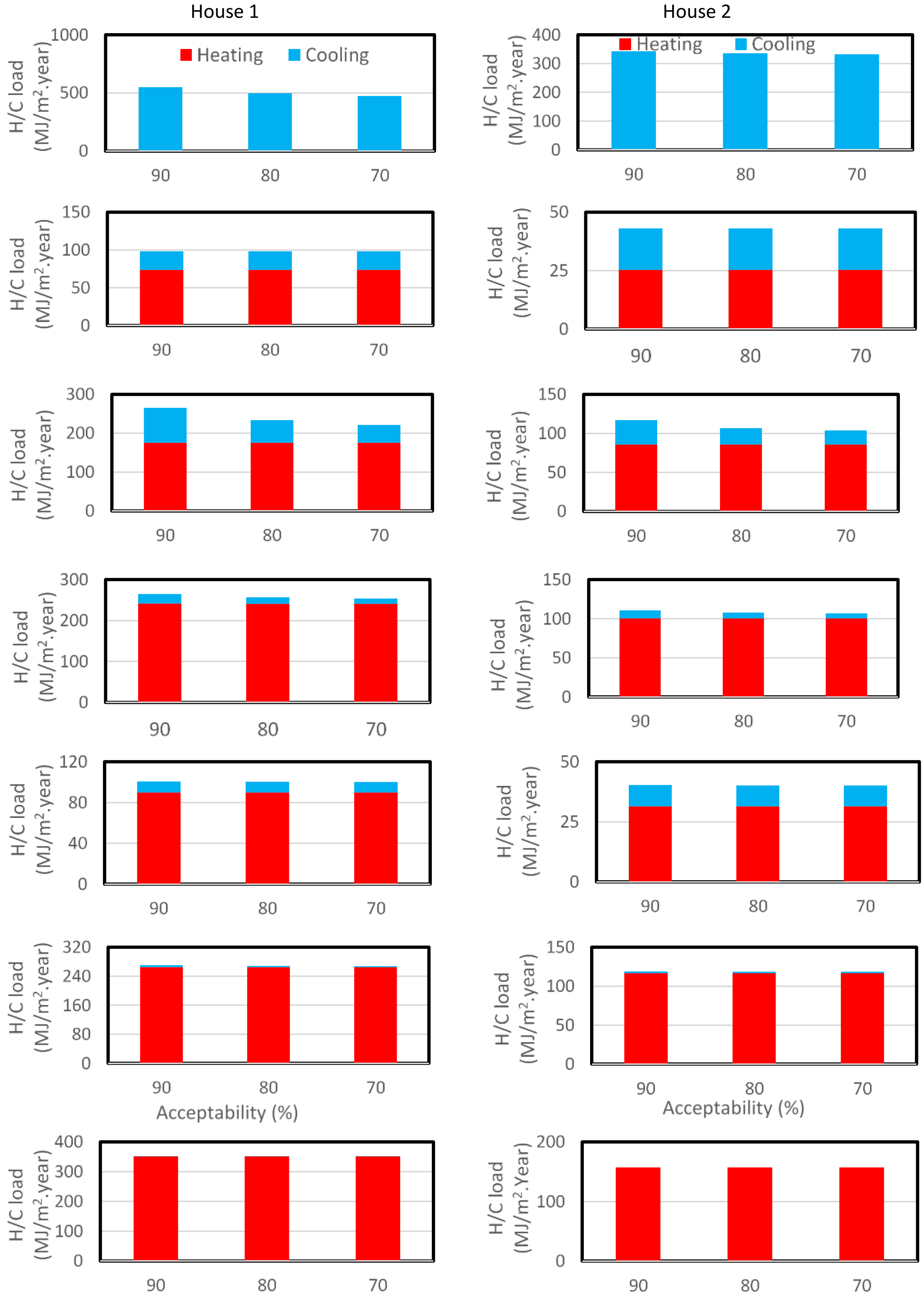


Figure 4-4: Heating/Cooling energy requirements at different thermal acceptability limits for House 1 with 3 stars and House 2 with 6 stars in seven cities: Darwin, Brisbane, Alice Springs, Mildura, Sydney, Melbourne and Hobart (from top to bottom).

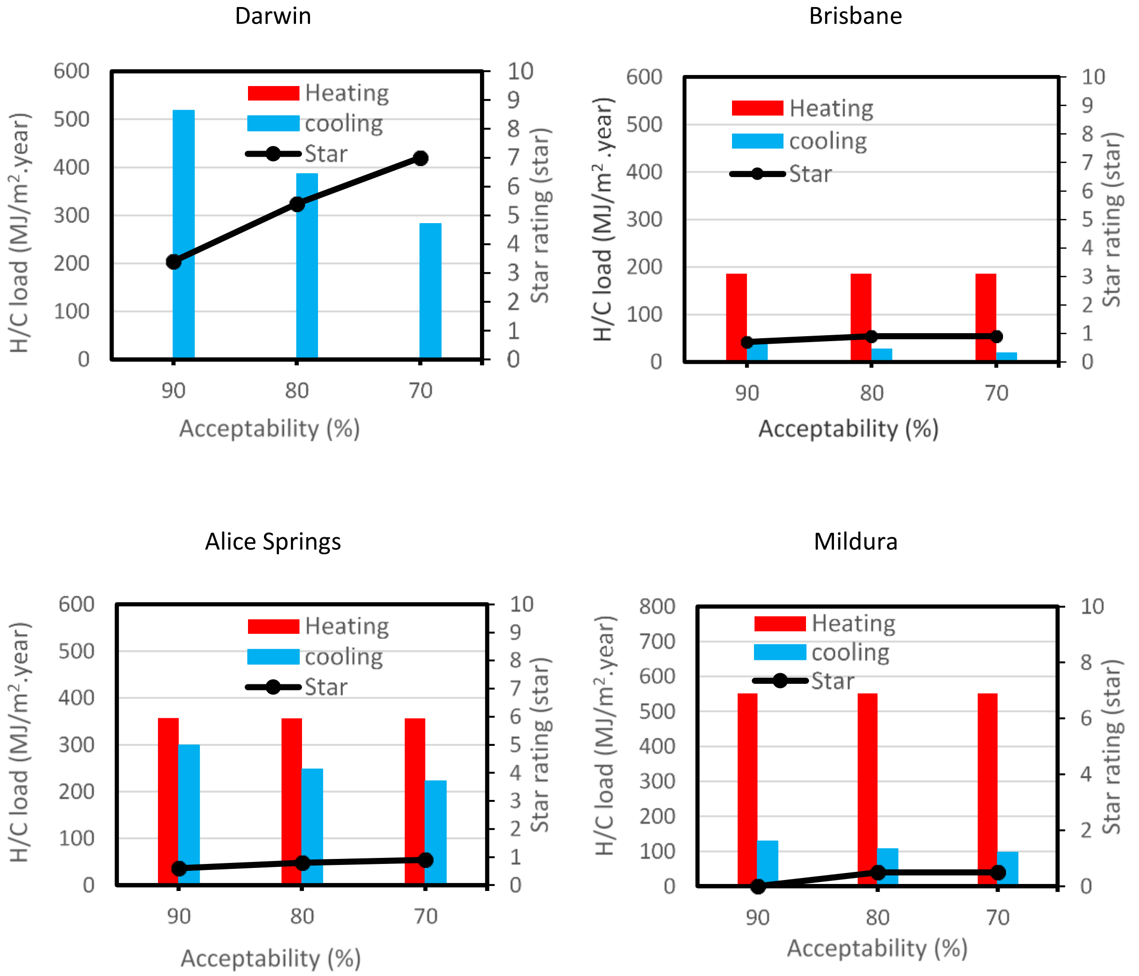


Figure 4-5: Heating/Cooling energy requirements and star rating to indoor thermal acceptability limits under current climate for House 3 in the four regions with hot to very hot summers

4.2 Machine Learning

Machine Learning takes output (target) data and uses various input parameters to predict the output. MATLAB has been used to perform the following analysis that uses Neural Networks to predict outputs (from monitoring systems used in Lochiel Park, SA) based on user inputs. User inputs include information obtained from:

- house plans, e.g. habitable and conditioned floor areas,
- user selection process, e.g. the number of ovens to be used, and the number and type of fixed lighting devices,
- the number of occupants

Given the whole of house concept of Accurate Sustainability, the next generation NatHERS rating tool, this section aims to determine whether Machine Learning can be used to predict the electrical energy consumption of whole house, or certain appliances; examples of the latter are listed below:

- Refrigeration (i.e. Fridge-Freezers),
- Lighting,
- Air conditioning,
- Oven,
- Dishwasher,

4.2.1 Output Data (targets)

The monitoring systems used in Lochiel Park collect data every minute. This data has been converted to daily, weekly and monthly totals, however due to the nature of machine learning that requires lots of data for training purposes, a time suitable frame needs to be determined.

Initial analyses were performed using household monthly totals, which yielded a good match with monitored refrigeration data and respective household inputs, however the models created performed poorly when extrapolated or applied to other houses. As such, it was decided to perform machine learning on daily totals, which produced far more data for training purposes which resulted in a better model and smaller errors between monitored data and predicted targets. Minute and hourly data was deemed too fine and therefore daily energy consumption of appliances and the whole house are investigated here.

4.2.2 Input Data

The matrix in Table 4-2 below shows which user inputs were used by the machine learning algorithms for individual target training validation and modelling. The cells highlighted yellow are common to each machine learning model

Not all user inputs were required for each model, and that after some initial trial and error for each appliance, in some instances certain inputs were removed as these did not improve the machine learning model accuracy. An example of this is the daily standby energy consumed by the RCAC, which improved the RCAC energy model accuracy when included as an input parameter. This shows that the total RCAC energy must be disaggregated into standby and operational (actual heating and cooling).

Table 4-2: Machine learning input data matrix

Output Inputs	Refrigeration	RCAC	Lighting	Dishwasher	Oven	Total ELEC
Month	Y	Y	Y	Y	Y	Y
Day of Month	Y	Y	Y	Y	Y	Y
Season	Y	Y	Y	Y	Y	Y
Day of Year	Y	Y	Y	Y	Y	Y
Day of week	Y	Y	Y	Y	Y	Y
Weekend?	Y	Y	Y	Y	Y	Y
Public Holiday?	Y	Y	Y	Y	Y	Y
T_a max (°C)	Y	Y	Y	Y	Y	Y
T_a min (°C)	Y	Y	Y	Y	Y	Y
Occupants	Y	Y	Y	Y	Y	Y
Number of fridge / freezers	Y					Y
Total volume of fridge / freezers	Y					Y
Habitable floor area			Y	Y	Y	Y
Conditioned floor area		Y				Y
Type of RCAC (ducted / split)		Y	Y			Y
Number of RCAC outdoor units		Y				Y
RCAC daily standby energy		Y				Y
Type of Lighting (CFL, LED)			Y			Y
Number of INDOOR lights			Y			Y
Installed capacity of INDOOR lights			Y			Y
Number of OUTDOOR lights			Y			Y
Installed capacity of OUTDOOR lights			Y			Y
Number of ovens					Y	Y

Note that:

- The output data uses cleaned daily total energy collected between 2011 and 2018, where applicable, for up to 11 detailed monitored houses.
- The occupancy changed for two of these houses throughout the monitoring period and the input data has been adjusted to include this.
- Data issues were experienced between June – October 2016 and are basically excluded from the data used for training, validation and testing.
- A small number of lighting energy data outliers were excluded from the model, i.e. where the daily total lighting energy consumption was > 5kWh/day.
- This represents 10 of 22,920 samples.

4.2.3 Machine Learning Algorithms

MATLAB was used to create the machine learning models and offers three main training algorithms when using the Neural Net Clustering application. These are:

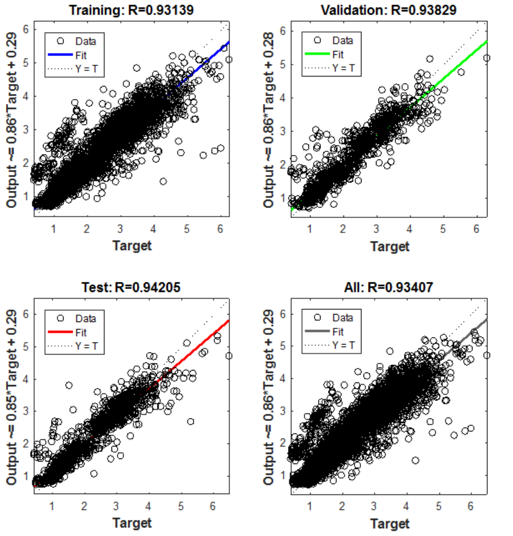
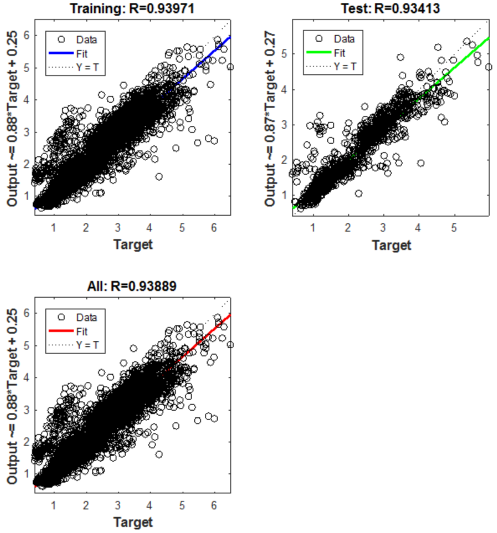
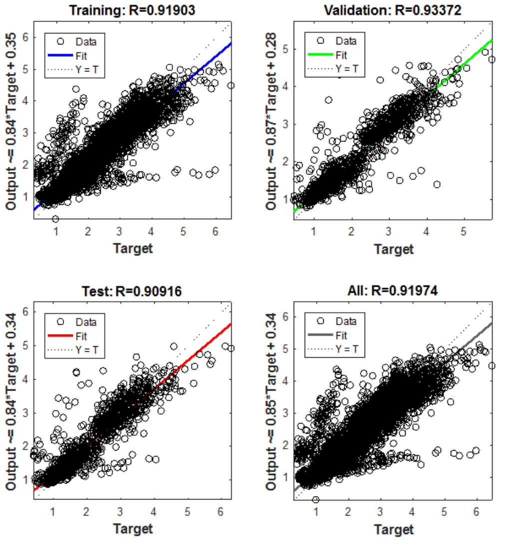
- Levenberg-Marquardt (LM),
- Bayesian Regularization (BR),
- Scaled Conjugate Gradient (SCG).

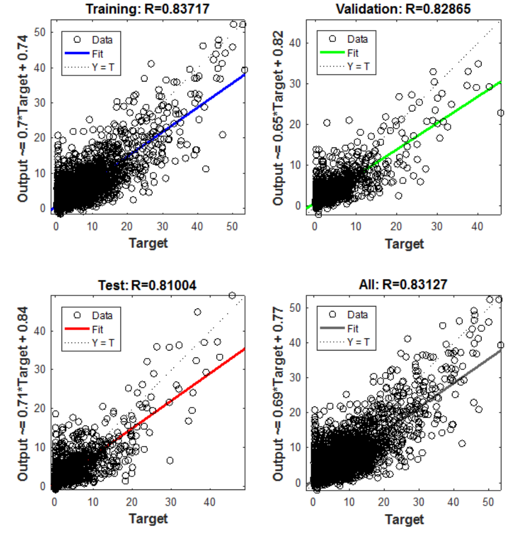
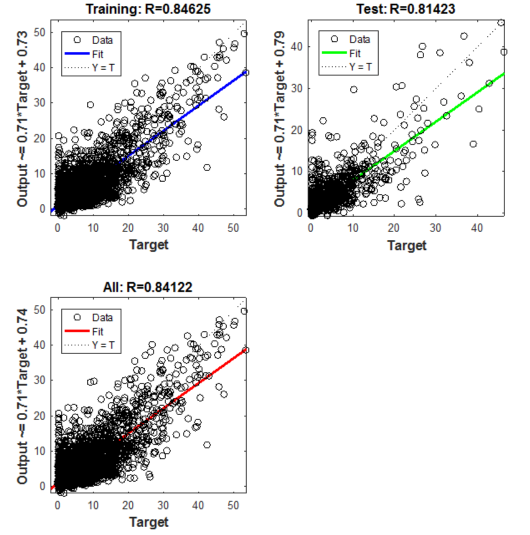
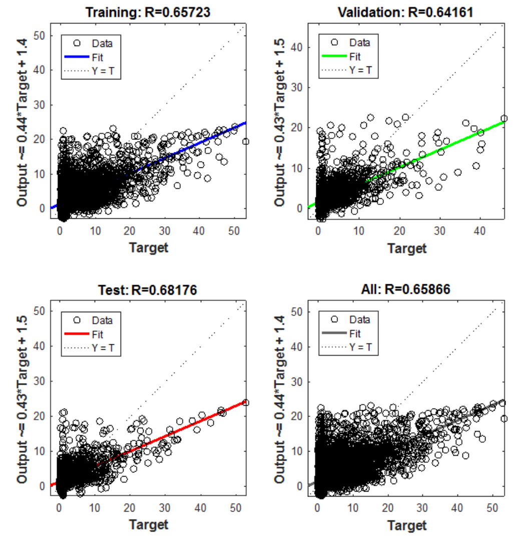
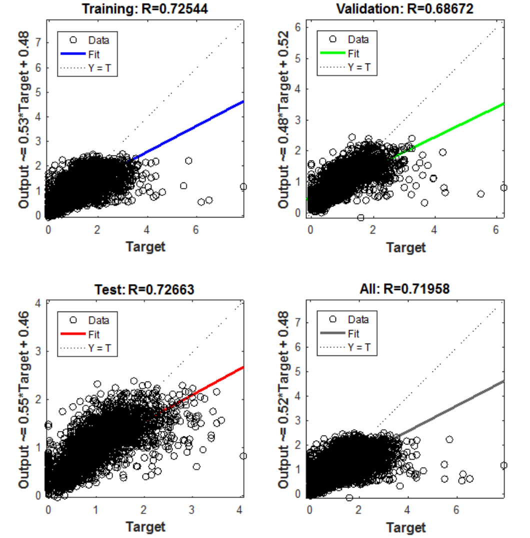
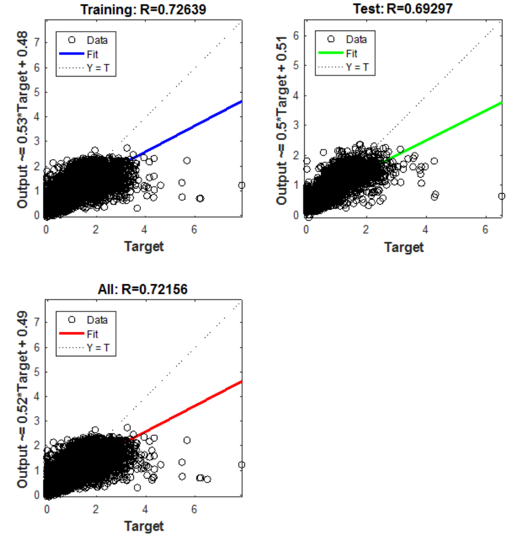
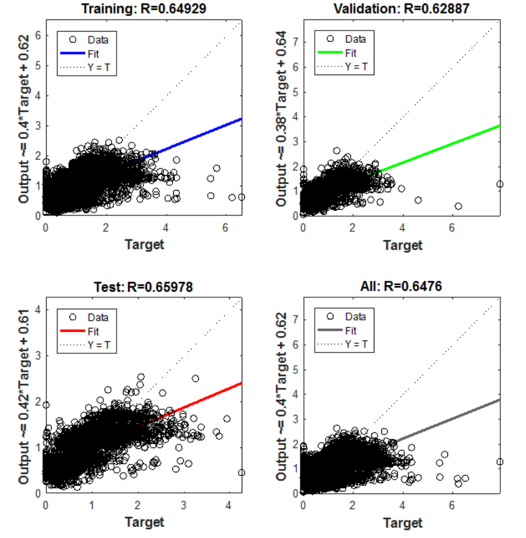
Each algorithm offers slightly different methods and results. As such, each appliance is predicted using all three algorithms to determine which offers the best accuracy.

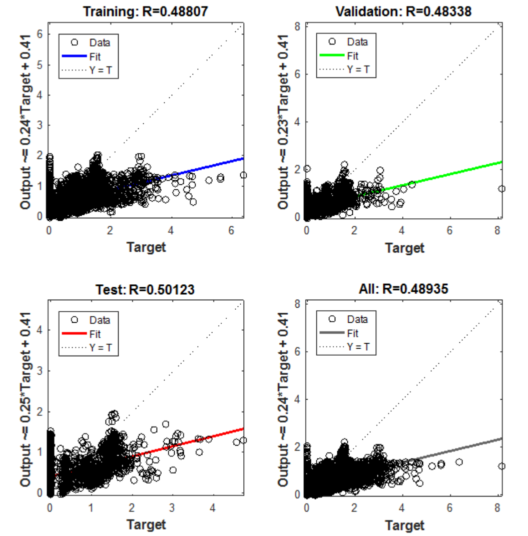
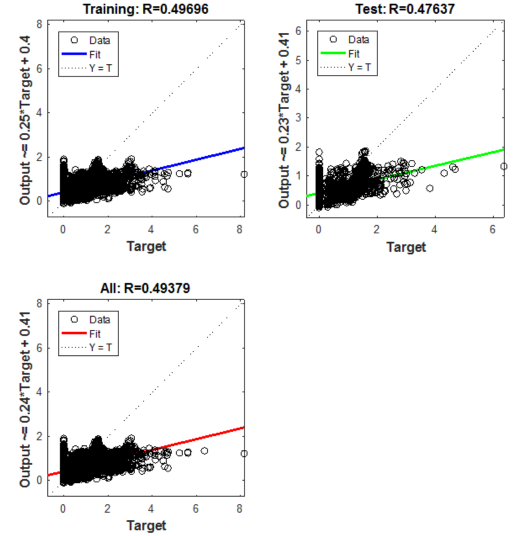
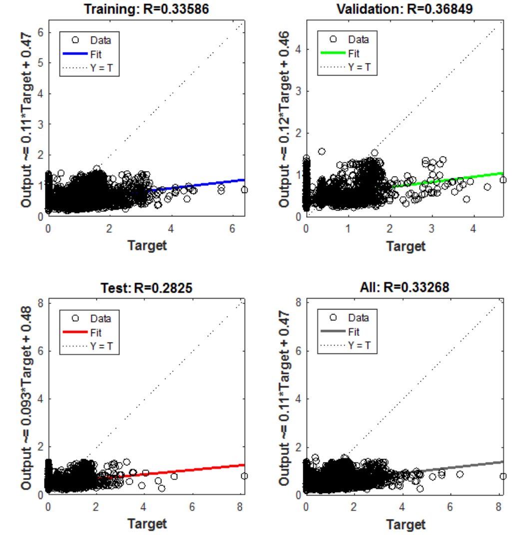
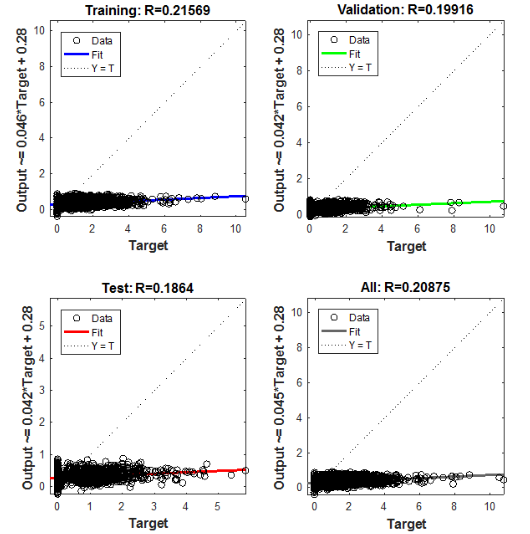
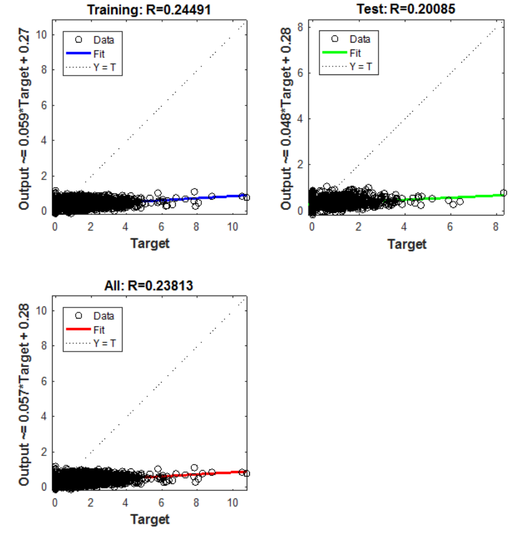
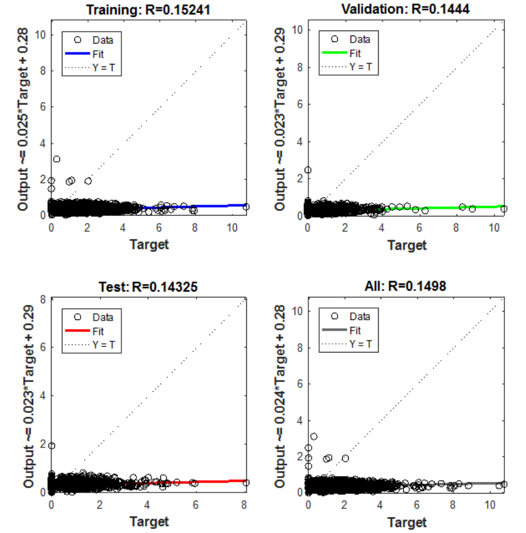
4.2.4 Results

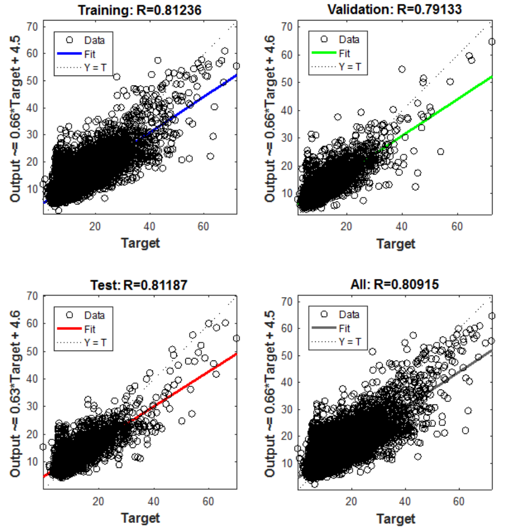
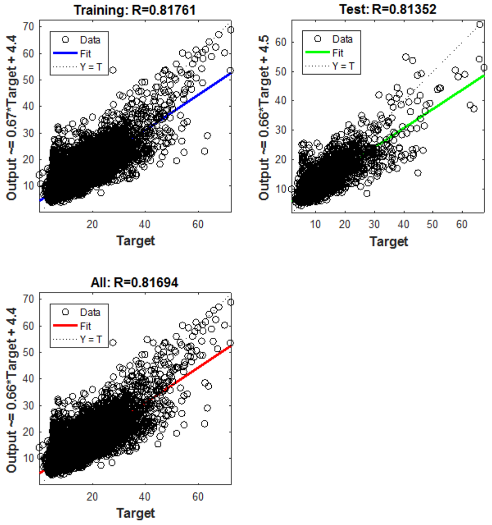
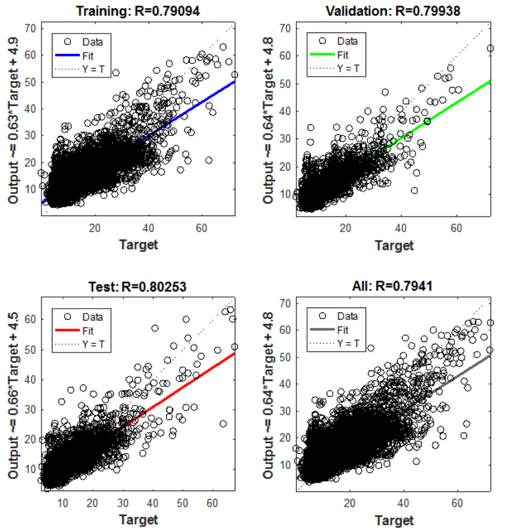
The results of the three training algorithms are shown in the Table 4-3 below, for each of the five appliances and the total electrical consumption of the house.

Table 4-3: Machine learning output data for LM, BR and SCG methodologies, relating to: Fridge-Freezers; Reverse Cycle Air Conditioners; Lighting Systems, Dishwashers; Ovens; and Total Household Electricity Consumption

<table>
<tr><th>Training Algorithm
Appliance</th><th>Levenberg-Marquardt (LM),</th><th>Bayesian Regularization (BR),</th><th>Scaled Conjugate Gradient (SCG).</th></tr>
<tr><td>Refrigeration</td><td>
</td><td>
</td><td>
</td></tr>
</table>

RC Air Conditioning	 Training: R=0.83717 Validation: R=0.82865 Test: R=0.81004 All: R=0.83127 	 Training: R=0.84625 Test: R=0.81423 All: R=0.84122 	 Training: R=0.65723 Validation: R=0.64161 Test: R=0.68176 All: R=0.65866
Lighting	 Training: R=0.72544 Validation: R=0.68672 Test: R=0.72663 All: R=0.71958 	 Training: R=0.72639 Test: R=0.69297 All: R=0.72156 	 Training: R=0.64929 Validation: R=0.62887 Test: R=0.65978 All: R=0.6476

Dishwasher			
Oven			

Total Electrical			

The results displayed in the various figures contained in Table 4-3 above, are concisely summarised in Table 4-4 below, which shows the R value for each training algorithm and appliance. The R value shown in bold represents the highest R value achieved for that particular electrical end-use, based on the training algorithm used. The Bayesian Regularization (BR) training algorithm yielded the highest R value for all cases, except for refrigeration, where the Levenberg-Marquardt (LM) training algorithm obtained the highest R value. Note that R value in this context differs from that for insulation.

Table 4-4: Summary of machine learning results (R value)

Appliance	Training Algorithm	Training	Validation	Test	All
Refrigeration	**LM**	0.93139	0.93829	0.94205	**0.93407**
	BR	0.93971		0.93413	0.93889
	SCG	0.91903	0.93372	0.90916	0.91974
RCAC	LM	0.83717	0.82866	0.81004	0.83127
	BR	0.84626		0.81423	**0.84122**
	SCG	0.65723	0.64161	0.68176	0.65866
Lighting	LM	0.72544	0.68672	0.72663	0.71958
	BR	0.72639		0.69297	**0.72156**
	SCG	0.64929	0.62887	0.65978	0.64760
Dishwasher	LM	0.48807	0.48338	0.50123	0.48936
	BR	0.49696		0.47637	**0.49379**
	SCG	0.33586	0.36849	0.28250	0.33268
Oven	LM	0.21569	0.19916	0.18640	0.20875
	BR	0.24491		0.20085	**0.23813**
	SCG	0.15241	0.14440	0.14325	0.14980
Total ELEC	LM	0.81236	0.79133	0.81187	0.80915
	BR	0.81761		0.81352	**0.81694**
	SCG	0.79094	0.79938	0.80253	0.79410

4.2.5 Conclusion

Machine Learning has been shown to predict the daily energy consumption of the whole house, as well as certain appliances such as refrigeration and RC air conditioning, with a high level of accuracy (R value > 0.8). It predicted the lighting energy consumption with a degree of confidence (R value > 0.7), however it does not seem suitable for predicting the daily energy consumed by dishwashers and ovens (R value < 0.5).

The lowest R values are most heavily impacted by intermittent use between days, given that dishwashers and ovens are not necessarily used every single day, and therefore a significant number of the data targets (outputs) are equal to zero. This highlights that the use of daily totals for machine learning is inappropriate, in relation to these types of intermittent end-uses. This is unlike lighting, RCAC, refrigeration and whole of house electrical energy consumption, where for most data points, electrical energy input data points exceed 0kWh/day.

If required for rating tool purposes, the whole of house energy consumption can be predicted using inputs available from:

- RMY data, such as daily minimum and maximum ambient air temperatures,
- Floor plans, such as conditioned and habitable floor areas,
- Selection processes, such as number of ovens, dishwashers and lighting fixtures,
- Other means, such as number of occupants, number and volume of refrigeration / freezers.

4.3 Thermal Bridging

Thermal bridging is the process where heat is able to flow through construction layers that have been insulated, but where there are materials which bridge the full depth of the insulation. In Australian house construction, this often occurs through the timber or steel ‘stud frames’ in the walls and ceilings. The impact of this classic two-dimensional thermal bridging is currently not considered in the regulation of house star rating. Thermal bridging has been well accounted-for in many jurisdictions throughout the world, for a couple of decades, and in a number of applications is banned [109]. The impact of thermal bridging in Australian houses and relevant recommendations has been well outlined some time ago [54].

In the context of increasing house star rating, addressing this issue will become a significant factor for future regulation of house energy efficiency. AccuRate sustainability has built in thermal bridging considerations which considers the classical two-dimensional thermal bridging. This calculation was applied to a modified version of the demonstration house, which is provided in the AccuRate software package. This demonstration house is a wooden-framed, brick-veneer, four bedroom, single-storey, Class 1a dwelling with a concrete tiled roof and the bulk of living spaces facing Northwest. The dwelling has a total floor area of 210m^2, consisting of approximately 163m^2 of conditioned spaces with the balance of unconditioned spaces including a 34m^2 Garage zone.

The demonstration house model was then used as a template to produce similar models achieving star ratings of approximately six and seven for Adelaide, Amberley and Moorabbin climate zones. This was achieved by applying high performance windows or increasing the bulk insulation levels in external and internal walls, and the ceiling, to the demonstration model, as required, whilst making no other changes to these 6- and 7-star models, for each climate zone.

Table 4-5 provides the equivalent impact of thermal bridging of a timber frame on this star rating. Overall, the impact is significant reducing the star rating by an average of 12.8% and 13.6% for 6- and 7-star designs, respectively.

Table 4-5: Change in AccuRate star rating, and associated unadjusted heating and cooling load, associated with the addition of thermal bridging

Climate Zone (AccuRate)	Without Thermal Bridging		With Thermal Bridging		
	Star Rating	Unadj. Total H & C Load (MJ/m^2)	Star Rating	Unadj. Total H & C Load (MJ/m^2)	% Difference (Unadj. H & C Load)
Adelaide 6*	6.0	100.6	5.6	112.3	11.6%
Adelaide 7*	6.9	75.5	6.6	85.3	13.0%
Amberley 6*	5.9	71.4	5.2	85.3	19.5%
Amberley 7*	6.8	56.1	6.1	67.9	21.0%
Moorabbin 6*	5.8	139.6	5.5	153.9	10.2%
Moorabbin 7*	6.8	103.4	6.5	113.8	10.1%

Of particular significance is the increase in impact with higher star rating, consistent with building physics, in Adelaide and Amberley. As levels of insulation and energy efficiency of the building fabric increases, so does the impact of thermal bridges that allow leakage of heat. This impact can essentially negate energy efficiency improvements at very high star rated buildings.

The impact of thermal bridging is well understood and catered for in other jurisdictions, as presented in ASHRAE Standard 90.1-2007 [113], ISO 10211:2007 [114], EN ISO 6946:1996 [115], and in Passivhaus [116, 117], a world leading energy efficient building system developed in Germany. Table

4-5 presents the impact of classical thermal bridging. The cumulative impact of factors including poor installation and poorly designed or manufactured insulation systems is also significant. Research has shown that the measured R-value of insulation systems can be half the value that is specified in building plans and subsequently used in AccuRate modelling [118]. The Oak Ridge National Laboratory in the USA has conducted decades of research to develop reliable wall and roofing insulation systems through whole of wall and roof testing and modelling [119]. It has been found that, especially for steel framed structures, measured R-values of installed systems can be up to 60% lower than the rated R-value of the insulation. Without an appreciation for the installed performance of insulation within house energy rating, there is only limited confidence in the actual improvement in energy efficiency that these insulation systems are delivering in newly constructed housing.

Further areas of concern relate to three-dimensional thermal bridging which exists at edges, corners, balconies, outdoor living spaces and all connections between the conditioned indoor space and the external envelope of a building. The impact of such construction parameters are regulated in regions such as the UK [120], defined by correction factors which reduce the effective R-value of the insulation system. Nominally, this impact is a 10% reduction in R-value, however given that this detail has not been investigated for Australian building systems, the actual impact, is likely to be higher, particularly for high star rated homes.

Recommendations to improve the building energy efficiency through the building fabric, on a cost effectiveness basis, were made in a study conducted by ASBEC. This study did consider the impact of thermal bridging, however it did not demonstrate the associated significance, especially in relation to the potential impact at higher star ratings.

It is recommended that issues relating to thermal bridging are addressed within AccuRate, either in rating on non-rating mode. This approach will require that insulation be defined not only by R-value, but as an integrated system defined by both the insulation and the frame in which it is installed. Relevant correction factors for three dimensional details should also be developed and included. These parameters could be developed through appropriate experiments or accredited numerical modelling techniques.

The value of this approach will provide a market opportunity for those insulation systems which can offer a validated improvement to building thermal performance. The research team is aware of a local manufacturer, which demonstrated through experiments conducted in US labs that the wall system they developed achieved twice the R-value of traditional systems. Under current regulations, despite this improvement, the manufacturer was unable to present these results to customers.

4.4 Heatwave Assessment

To adequately assess the heatwave performance of a building design, it is important to apply the correct weather, address the building physics assumptions within AccuRate and the methodology. With climate change, heatwaves are expected to increase in number and intensity [54]. It is therefore recommended that an appropriate heatwave weather file be developed, notionally comprising a one-week weather data set. RMY files represent average periods, and by definition tend to subdue these heatwave periods. These heatwave weather files can incorporate the impact of climate change.

The impact of thermal bridging (Section 4.3) and the derating of insulation becomes more critical during these periods. Table 4-6 presents the impact on the daily cooling energy required considering these impacts on the current hottest days presented in the RMY files for each location, and Table 4-8 shows this same situation for a 'future' RMY, incorporating climate-change and heatwaves. Overall it shows how the impact of these assumptions increase the difference between currently rated cooling energy and more likely cooling energy. These impacts are compounded by increased inefficiency of the air conditioner and ducting as operational temperatures approach maxima.

4.4.1 Impact of Thermal Bridging, R-Value Degradation

The thermal resistance, or R-value, of insulation is critical to reliably achieving an energy efficient house. Insulation R-values are currently rated at a fixed temperature, which relates to measurement of the R-value at 23°C (AS/NZS 4859.1:2002) [121]. However, no consideration has been allowed in NatHERS for the degradation of the R-value, due to temperature-based effects, especially during the most extreme weather. As stated in AS/NZS 4859.1:2002, the R-value can degrade by 0.49%/°C above 23°C. This value is consistent with recent experimental work for fibreglass, whereas rockwool experiences a slightly lower degradation rate [122]. Based on this value, during peak summer days, a significant reduction in R-value of more than 10% can occur.

Overall, this impact is likely to be small, particularly considering that the R-value is likely to be higher in colder periods. However, this effect highlights that cooling loads are underestimated relative to heating loads. This impact has significance during heatwave periods where the degradation in R-value is least desirable.

The impact on the peak daily cooling load in a variety of locations was examined using the demonstration house model. For the purpose of analysis, the demonstration house was used with concrete slab insulation (waffle pod) removed, all air-gaps between internal and external walls changed to unreflective and left unventilated. The dwelling model was first run using the Standard RMY weather data for Adelaide, SA, Amberley, QLD and Moorabbin, VIC and the load ('Standard Only') over the hottest day was recorded for each climate zone (see Table 4-6). Hourly loads for Adelaide are also recorded in this table, for comparative purposes.

The dwelling model was then run again in the same manner as previously described for the three climate zones, except with thermal bridging applied across the insulation of all external walls and ceilings, comprising 90mm x 45mm softwood. The load ('Bridged Only') over the hottest day was recorded in Table 4-6, for each climate zone, with hourly loads for Adelaide also recorded.

The dwelling model was then run again in the same manner as initially described, except with simulated temperature based degradation of R-Value across both the external wall and ceiling insulation. R-Value degradation was applied at a rate of 0.49%/°C above 25 °C. For ceiling insulation degradation, the temperature used was the difference between the weighted average roofspace temperature on the hottest day, weighted by hourly cooling load ('Standard Only') for the same day, and 25°C. For external wall insulation degradation, the temperature used was the difference between the weighted average outdoor temperature on the hottest day, weighted by hourly cooling load ('Standard Only') for the same day, and 25°C. The load ('R-Val. Deg'n Only') over the hottest day for each climate zone is shown in Table 4-6, including hourly loads for Adelaide.

The reduction in R-Value that was modelled for ceiling insulation ranged from 10.6% in Moorabbin to 14.2% in Adelaide and for wall insulation ranged from 3.2% in Amberley to 7% in Adelaide. This was achieved by selecting the original type of insulation for the insulation layer by conductance and reducing the original thickness by the percentage calculated as previously described.

The dwelling model was then run again, with the application of combined thermal bridging and R-Value degradation characteristics previously described. The load ('Bridged + R-Val. Deg'n') over the hottest day was also recorded for each climate zone (see Table 4-6), including hourly loads for Adelaide.

Table 4-6: Hourly and Total Daily Cooling Load on the hottest day for different building model scenarios

ADELAIDE	***Cooling Load (MJ): Standard RMY, Hottest Day (Tmax = 41°C)***			
Hour	**Standard Only**	**Bridged Only**	**R-Val. Deg'n Only**	**Bridged + R-Val. Deg'n**
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	3.29	11.76	3.40	12.09
13	11.34	11.19	11.86	11.53
14	12.25	16.10	15.37	16.52
15	15.31	13.77	12.99	16.89
16	3.74	18.95	15.07	16.51
17	16.93	13.57	4.23	13.90
18	28.28	36.81	36.38	40.00
19	18.11	16.63	16.27	16.88
20	11.19	14.05	11.11	14.22
21	2.80	0	2.86	0
22	0	2.44	0	2.48
23	0	0	0	0
24	0	0	0	0
Total	123.24	155.27	129.54	161.02
% Increase	N/A	26.0%	5.1%	30.7%
AMBERLEY	***Cooling Load (MJ): Standard RMY, Hottest Day (Tmax = 37.1°C)***			
	Standard Only	**Bridged Only**	**R-Val. Deg'n Only**	**Bridged + R-Val. Deg'n**
Total	167.70	195.31	172.66	198.23
% Increase	N/A	16.5%	3.0%	18.2%
MOORABBIN	***Cooling Load (MJ): Standard RMY, Hottest Day (Tmax = 39.3°C)***			
	Standard Only	**Bridged Only**	**R-Val. Deg'n Only**	**Bridged + R-Val. Deg'n**
Total	159.99	182.67	166.32	182.49
% Increase	N/A	14.2%	4.0%	14.1%

It can be seen from Table 4-6 that the application of both thermal bridging and R-Value degradation has a significant impact, except in Moorabbin, where thermal bridging is most significant and the cumulative impact of R-Value degradation is insignificant on the hottest day.

4.4.2 Impact of Thermal Bridging, R-Value Degradation and Climate-Change/Heatwave Weather Data

In addition to thermal bridging and R-value degradation, the effects of climate changed weather are examined for the Adelaide climate zone (*i.e.* climate zone 16), as this is expected to impact on the thermal energy load of a building. This section briefly describes the methodology used to create a weather data file in the RMY format, designed to incorporate the impact of climate change and associated heatwaves, by adjusting both the ambient air (dry bulb) temperature and solar irradiation. This weather data file will be referred to as the Climate-Change/Heatwave RMY. Further details, relating to the Climate-Change/Heatwave RMY weather data file, can be found in the corresponding journal publication resulting from this work [123].

4.4.2.1 Dry Bulb Temperature

Common 'morphing methods', used in literature, to adjust weather data have limitations as they cannot adjust minimum and maximum temperatures independently, nor can they integrate extreme weather features such as extreme temperatures and heatwaves. This work resolves these limitations by presenting a method based on time series analysis to integrate three climate change features of dry bulb temperature (DBT) that cannot be integrated by the morphing method, i.e.:

- Feature One = Increase of average maximum and minimum DBT by different amounts,
- Feature Two = Feature One + Adjustment of the number of extreme days,
- Feature Three = Feature Two + Integration of heatwave characteristics.

The methodology used here separates the DBT into three components: a Fourier Series (FS), an autoregressive–moving average model, and residuals. The Fourier Series model of the DBT is extracted from the original (RMY) data, and the residuals of the Fourier Series are separated into an autoregressive–moving average model and further residuals. The climate changed weather data are developed by adding the three components, after applying necessary modifications to the FS model and randomly sampling the residuals. This methodology is comprehensively explained in [123], along with various autoregressive model parameters and FS daily cycle coefficients.

Despite the meaningful work and results of Features One, and One and Two, in their own right, see [A] for details, this work focusses only on the impact of Climate-Change/Heatwave RMY file that satisfies Feature One, Two and Three. As such, the new climate changed DBT data that includes the impact of: varying degree of increased average maximum and minimum, higher number of extreme days and heatwaves. Figure 4-6 shows a scatter plot of the climate changed hourly DBT as a function of the original RMY file. Figure 4-7 shows the new daily maximum DBT over the year, if it exceeds 35°C.

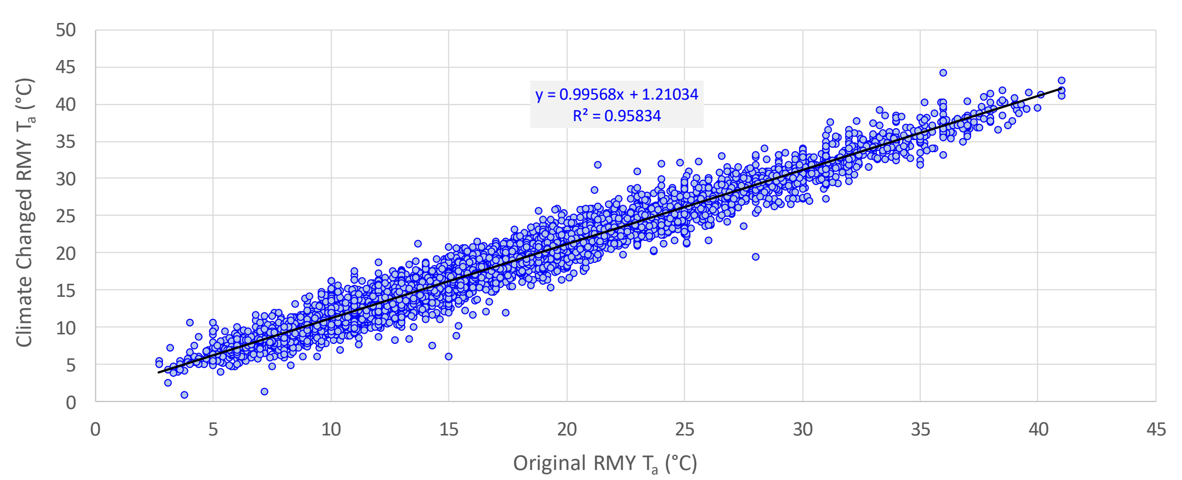


Figure 4-6: Scatter plot of hourly dry bulb temperatures throughout the year (using Features One, Two and Three).

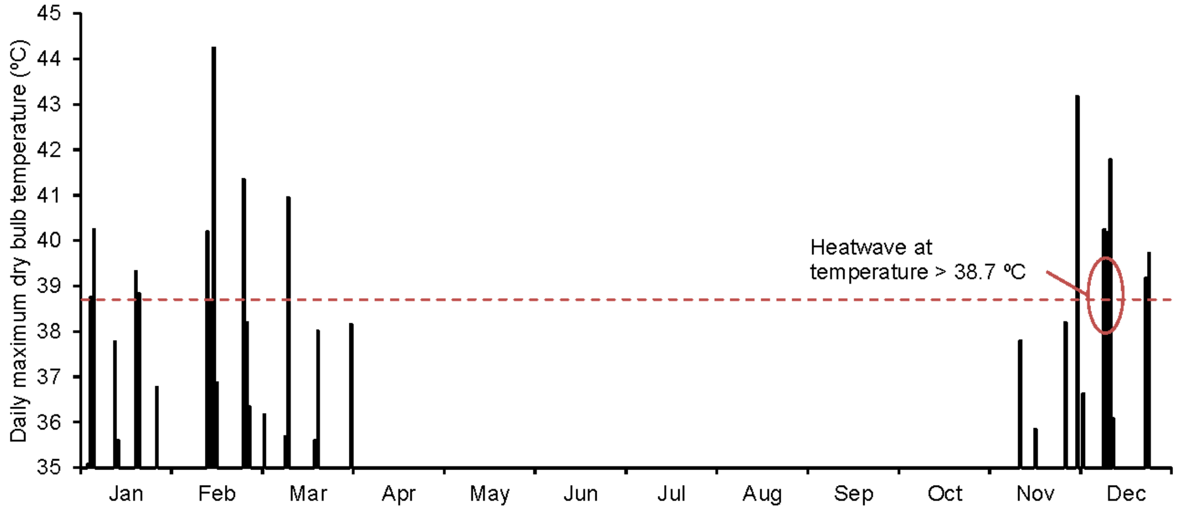


Figure 4-7: Daily maximum temperature (> 35°C) distribution throughout the year (using Features One, Two and Three).

4.4.2.2 Solar Irradiation

Unlike the changes to DBT, the change of solar irradiation, due to climate change, is expressed as percentages of the monthly means of total solar irradiation, as shown in Table 4-7 [124]. The changes are minimal during the summer months, whilst they are more significant during the winter months.

Table 4-7: Predicted change of total solar irradiation. Source: [124].

Month	**Change percentage Δ_k (%)**
January	0.0
February	0.2
March	-0.1
April	0.4
May	1.1
June	2.5
July	2.4
August	2.3
September	1.7
October	1.5
November	0.7
December	0.4

Although the total hourly solar irradiation for the entire year can be calculated using the percentage changes in Table 4-7, NatHERS and other building energy simulators require the diffuse irradiation on a horizontal surface, and direct normal irradiation. As such these are modified as briefly described below, see [123] for more information:

- Horizontal diffuse radiation: scaled based on modified monthly mean (Table 4-7).
- Direct normal irradiation: difference of scaled irradiation (Table 4-7) and horizontal diffuse, divided by the sine of the solar altitude.

Note that the sine of the solar altitude can be approximated at sunrise and sunset, as these values are close to zero and give unrealistic values of direct normal irradiance. Figure 4-8 and Figure 4-9 show scatter plots for the climate changed direct normal and diffuse radiations, as a function of their respective original RMY values. More information regarding the dry bulb temperature and the solar irradiation methodologies are summarised in a recent journal paper [123].

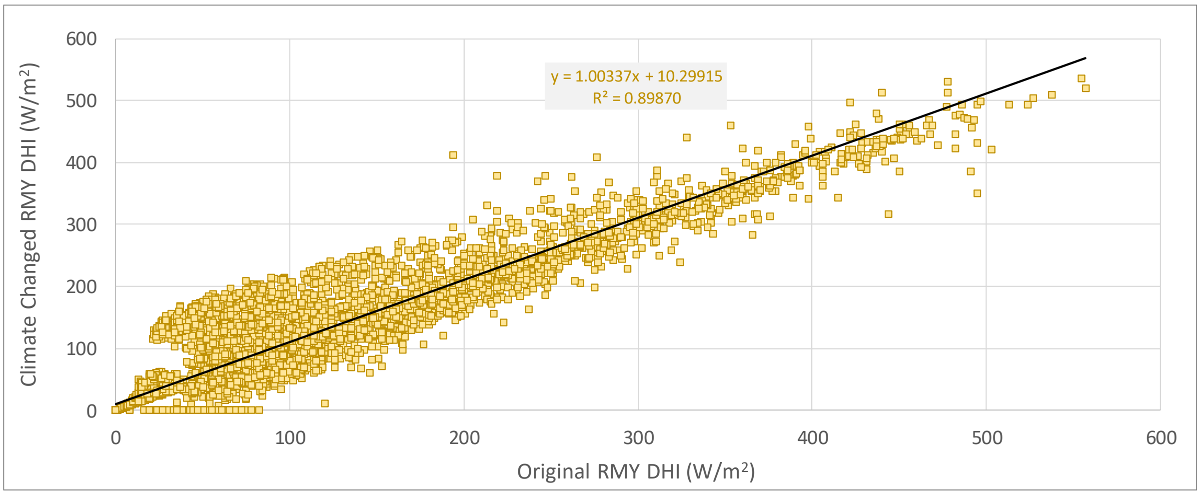


Figure 4-8: Hourly climate changed horizontal diffuse irradiation (DHI) vs original TMY DHI.

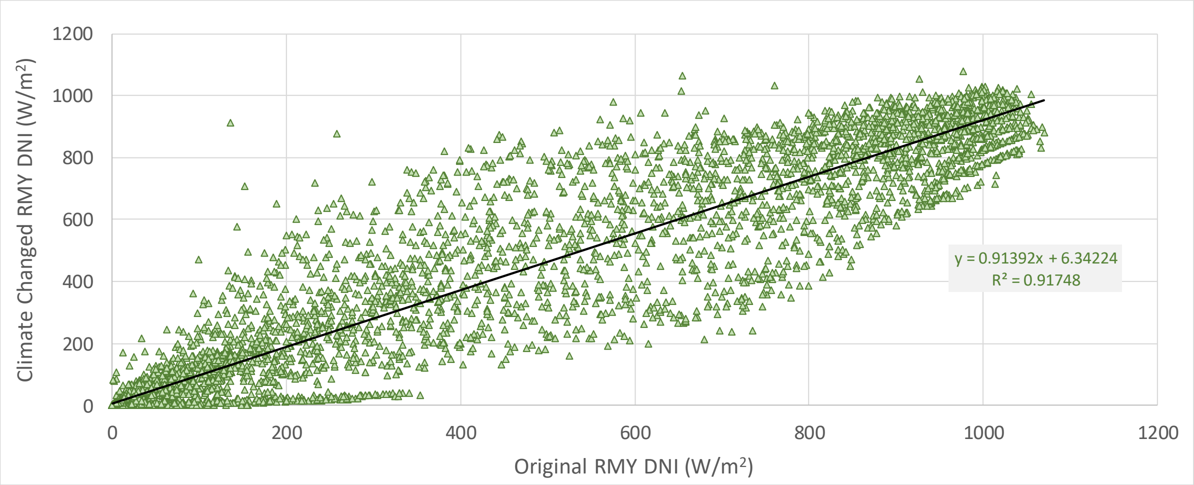


Figure 4-9: hourly climate changed direct normal irradiation (DNI) vs original TMY DNI.

4.4.2.3 Preliminary Heating and Cooling Energy Performance – TRNSYS

An assessment of the comparative impact of the Climate-Change/Heatwave RMY weather data file, which was conducted using TRNSYS software, is presented in the following section. Figure 4-10, Figure 4-11 and Figure 4-12 show the impact of the climate changed (input) weather data on the heating and cooling thermal energy, daily maximum thermal energy, and maximum thermal power, respectively. Each figure compares the impact of Features One, Two and Three, with that which was obtained using the standard RMY weather data file. Results relating to standard RMY weather data files are distinguished by grey shading in each of the three figures.

As the input weather data has changed to reflect increases in DBT, one might expect that the amount of energy required to keep a house cool in hotter, summer conditions would increase, whilst the thermal energy required to maintain comfort during the colder, winter conditions would decrease. This is shown in Figure 4-10, where the cooling energy has increased by 29-31%, whilst the heating energy has decreased by 21-22%. When the heating and cooling energies are combined, as is the case under NatHERS, the overall heating and cooling energy has decreased by 4-5%. This is because originally the heating energy makes up a significantly larger proportion of the total load.

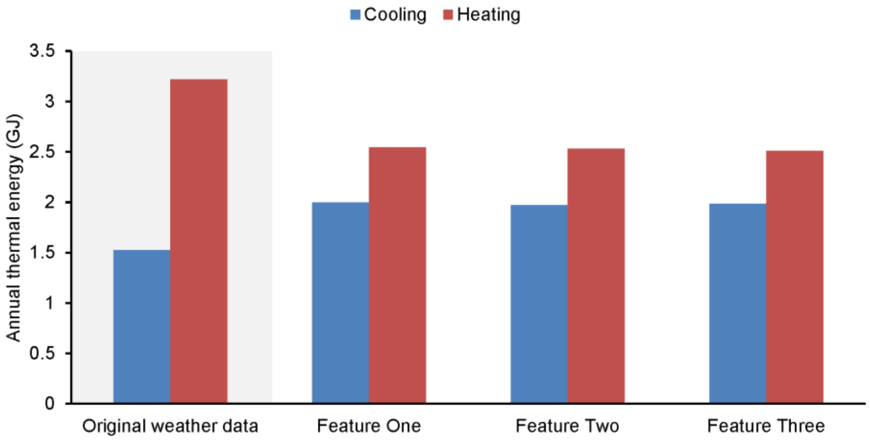


Figure 4-10: Comparison of heating and cooling annual thermal energy.

Now that the impact has been shown on the annual heating and cooling energy, we examine the impact on the daily maximum energy, as shown in Figure 4-11. It is observed that Features One, Two and Three slightly increase the maximum daily cooling energy by 3-5%, yet they decrease the maximum daily heating load by 11-15%. Subsequently, the maximum daily cooling load has increased from 63% larger than the maximum daily heating load, to 93-99% larger than the maximum daily heating load.

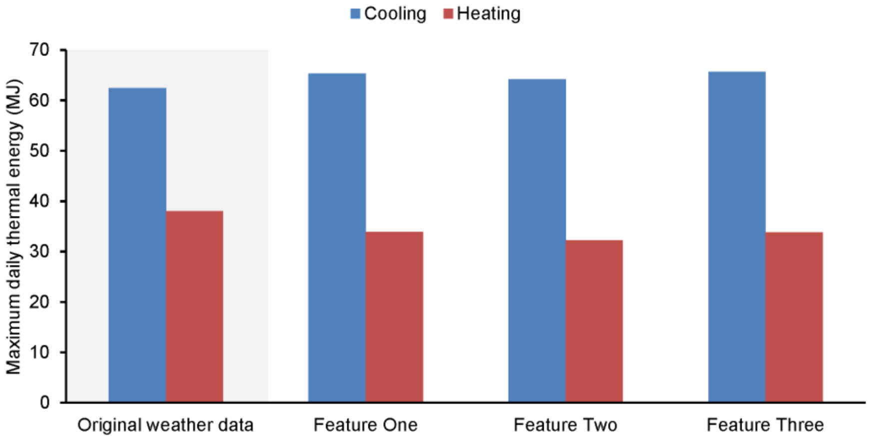


Figure 4-11: Comparison of maximum daily heating and cooling thermal energy.

Figure 4-12 shows the maximum hourly heating and cooling powers experienced through the year, as a result of the climate changed (input) weather data file. The figure shows that the maximum cooling power has increased by 6-8%, whilst the corresponding maximum hourly heating powers have decreased by 5-6%. As such, the maximum hourly cooling power is now 217-223% of the maximum hourly heating power, which was previously 196%.

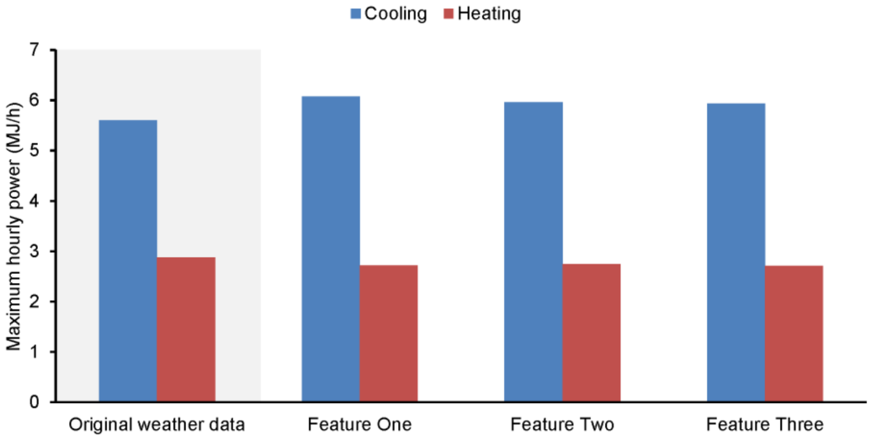


Figure 4-12: Comparison of heating and cooling of hourly maximum thermal power.

Although the results shown in this subsection were modelled using a building simulator, other than those accredited under NatHERS, it clearly shows the impact of climate changed input weather data, on a house's:

- heating and cooling thermal energy,
- its maximum (hourly) thermal power,
- daily maximum thermal energy.

For this reason, it is necessary to investigate the impact of this new climate changed weather data using NatHERS accredited software, together with the impact of thermal bridging and R-value degradation. This is shown in the following section, which clearly warrants the need to address each of these three impacts in future versions of NatHERS software.

4.4.2.4 Heating and Cooling Energy Load – NatHERS using AccuRate Sustainability

The demonstration house model was then run for Adelaide, SA, with the standard RMY weather data file substituted with the modified RMY weather data file, described earlier in this section, containing data aimed to represent a future climate change scenario, with heatwaves (i.e. 'Climate-Change/Heatwave RMY'). The hourly total cooling load over the hottest day ('Clim. Change Only') was then recorded in Table 4-8. Table 4-8 lists the percentage increase in cooling load relative to that for the 'Standard Only' model, which is the uppermost green highlighted value in the second column of Table 4-6.

The demonstration house model was then run again for Adelaide, SA, using the Climate-Change/Heatwave RMY weather data file, in addition to the application of combined thermal bridging and R-Value degradation characteristics, described in Section 4.4.1. The hourly cooling load over the hottest day ('Clim. Change + Bridged + R-Val. Deg'n') was then recorded (see Table 4-8).

Table 4-8: Hourly and Total Daily Cooling Load on the hottest day for different building model scenarios, using Climate-Change/Heatwave RMY

ADELAIDE	***Cooling Load (MJ): Climate-Change/Heatwave RMY, Hottest Day (Tmax= 44.2°C)***	
Hour	**Clim. Change Only**	**Clim. Change + Bridged + R-Val. Deg'n**
1	4.73	2.06
2	1.84	3.11
3	2.1	3.51
4	1.1	1.68
5	0	1.09
6	1.64	0
7	0	0
8	6.64	5.63
9	9.9	11.09
10	6.77	12.46
11	10.49	11.13
12	2.67	14.91
13	17.43	12.19
14	12.49	18.77
15	19.89	21.6
16	16.01	20.27
17	15.79	19.35
18	34.68	39.61
19	15.84	20.95
20	22.21	20.41
21	7.26	16.54
22	4.67	0
23	10.49	12.26
24	1.73	1.37
Total	226.37	269.99
% Increase	83.7%	119.1%

Table 4-8 shows a dramatic increase in hourly cooling load for the demonstration house in Adelaide using the Climate-Change/Heatwave RMY, with an increase of 119%, in comparison to the daily cooling load for 'Standard Only', shown in Table 4-6. In comparison to 'Clim. Change Only', this also shows that a 35.4% increase in cooling load results from the combined impact of thermal bridging and R-Value degradation, when using the Climate-Change/Heatwave RMY, in comparison to an increase of only 30.7%, when simply using the standard RMY.

Overall, the impact of thermal bridging and R-Value degradation is highly significant in the context of assessing the energy efficiency of a building, especially during heatwave periods. It is recommended that, particularly for insulation materials, R-values should be adjusted, as necessary, dependant on the average temperature of adjoining regions, including roofspace zones and outdoor spaces.

Overall it is clear that the times of extreme weather are where the assumptions compound and this impact needs to be recognised and further demonstrates the need to continuously improve the building physics within AccuRate, over time.

Heat resilience relates to the how well a building design maintains thermal comfort during a heatwave. Defining heat resilience is a challenge. The recent report [125], showed a strong correlation with the Excess Heat Factor and heatwave related deaths. This factor is a measure of the long-term average of the daily maximum temperature, and is effective for emergency health authorities. What is particularly noteworthy is that most heat-related deaths occur just after the heatwave. In addition, the heatwave is defined by the combination of the duration and the temperature.

Thermal comfort and heat stress are physiologically two very different phenomena. In relation to thermal comfort, cooling degree hours is often used as a metric in which 1 hour at 35 deg. C equates to 3 hours at 28 deg. C, with 25 deg. C as the comfort temperature. Heat stress cannot be reflected by this approach, and identifying a suitable measurement is beyond current knowledge. Attempts have been made [125] to use the Excess Heat Factor with adaptive comfort models in an attempt to quantify heat stress discomfort, without success highlighting the need for further research.

Within AccuRate the potential metrics that can be used to measure heatwave resilience are cooling degree hours, defined by the free running mode, or energy required to maintain thermal comfort, as currently conducted. Neither of these terms satisfactorily determine heat stress. Therefore, in the absence of such a metric, a more meaningful approach is to determine the peak cooling demand, based on a running average consistent with air conditioning capacity sizing. In South Australia, air-conditioners are currently sized based on a peak cooling load of approximately 120W/m^2, though some also use a value as high as 250 W/m^2 (Saman et al. 2013). In the Lochiel Park development, the sizing of air-conditioners in all houses, having a star rating of around 7.5, was based on a relatively low peak load of 90W/m^2 [54].

The hourly cooling load (W/m^2) on the hottest day, in relation to the weather data file used, was simulated with AccuRate Sustainability using the demonstration house model in the Adelaide climate zone. Three different scenarios were modelled in total, two of which utilised the standard RMY weather data with the house, the first with the house in unmodified configuration and the second with thermal bridging across external wall and ceiling insulation and simulated R-Value degradation. The third scenario utilised weather data comprising simulated climate-change with heatwaves, for the modified model used in the second scenario. The results for this simulation are shown below in Table 4-9, for the hours from 7:00am through to 12:00am, for the three aforementioned scenarios. Data for the hours prior to 7:00am were omitted, based on the fact that cooling loads were relatively small and therefore lack relevance regarding this section.

Table 4-9 also shows the three hourly running average of these values for each scenario, given that this has been identified as a highly significant metric regarding heatwaves, in previous work (Saman et al. 2013). It can be seen that all peak values (highlighted in orange for Table 4-9) for this hottest day are well above the value of 120W/m^2. More importantly, Table 4-9 shows in red text that for the models using standard RMY weather data, the 3-hour running average values were found to be above 120W/m^2 for only 5 hours using the unmodified model and 7 hours using the same model with bridged insulation and simulated R-Value degradation. In significant contrast, whilst utilising simulated Climate-Change/Heatwave RMY weather data in the model having bridged insulation and simulated R-Value degradation, Table 4-9 shows in red text the 3-hour running average values were found to be consecutively above 120W/m^2 for a majority of 14 hours throughout the course of the hottest day.

Table 4-9: Air-conditioning load on hottest day for different building model scenarios and using Climate-Change/Heatwave RMY

ADELAIDE	***Cooling Load (W/m²): Standard RMY, Hottest Day (Tmax = 41°C)***				***Cooling Load (W/m²): Clim.-Ch./Heatwave RMY, Hottest Day (Tmax= 44.2°)***	
	Standard Only		**Bridged + R-Val. Deg'n**		**Clim. Change + Bridged + R-Val. Deg'n**	
Hour	Hourly	Running Avg. (3hr)	Hourly	Running Avg. (3hr)	Hourly	Running Avg. (3hr)
7	0	0	0	0	0	24.9
8	0	0	0	0	130.9	43.6
9	0	0	0	0	143.2	91.4
10	0	0	0	0	333.3	202.5
11	0	0	0	0	85.9	187.5
12	51.9	17.3	101.9	34.0	180.8	200.0
13	90.3	47.4	95.3	65.8	100.5	122.4
14	99.7	80.6	192.7	130.0	232.2	171.2
15	179.8	123.2	166.7	151.6	298.8	210.5
16	59.0	112.8	192.5	184.0	235.9	255.6
17	191.6	143.5	120.5	159.9	227.8	254.2
18	437.7	229.4	916.5	409.8	963.2	475.6
19	237.1	288.8	183.0	406.7	317.6	502.9
20	57.3	244.0	103.5	401.0	221.1	500.6
21	44.2	112.9	0	95.5	312.7	283.8
22	0	33.8	39.1	47.5	0	177.9
23	0	14.7	0	13.0	115.7	142.8
24	0	0	0	13.0	94.0	69.9
Daily Total	1449	N/A	2112	N/A	4345	N/A
% Increase	N/A	N/A	45.8%	N/A	200%	N/A

This analysis highlights how the unmodified design already experiences cooling loads that significantly exceed the 120W/m^2 design load for five hours. The use of an adaptive comfort model within AccuRate Sustainability, during the hottest day, could mitigate the impact of peak cooling loads, however not when considering the additional impact of factors such as thermal bridging, insulation performance degradation and climate change. It is unlikely that an air-conditioner could meet cooling loads that exceeds design conditions for seven hours, as seen for the model incorporating the impact of both thermal bridging and R-Value degradation. It is therefore highly unlikely that an air-conditioner could meet cooling loads that exceeds design conditions for 14 consecutive hours, as seen when the additional impact of simulated climate change and associated heatwaves is considered.

It is reasonable to assume that a house will have an air conditioner operational during a heatwave, and therefore if the peak building cooling load can meet nominated design loads for each region, then it can be assumed that adequate comfort can be sustained. This approach will eliminate those designs which unintentionally result in dramatically high load denying the householder from achieving thermal comfort. Suitable design loads can be readily determined using AccuRate, as presented in a recent report [54].

It is important to stress that energy efficiency should not be sacrificed for the sake of a buildings heat resilience, given that designs which achieve both goals are readily achievable at negligible additional cost.

4.5 Summary of Research Outputs, New Assumptions and Recommendations

Various recommendations have been made for new assumptions, in relation to AccuRate Sustainability and additional modules, which should be incorporated into AccuRate Sustainability, throughout various sections of this report. These recommendations will be presented in this section of the final report.

Air conditioner on and off set points were correlated against running average outdoor temperatures across a number of climates. It was identified that in some locations, a non-linear relationship is needed. Updating correlations were developed.

In relation to AccuRate Sustainability set temperatures, the constant heating thermostat setting of 20°C in the living room appears reasonable for most locations, especially Adelaide, even though it was observed to be about 0.7°C higher for Melbourne and 0.9°C lower for Brisbane. However, the heating switch on temperatures in Adelaide and in Melbourne in the existing AccuRate Sustainability software for living room is too high and a switch on indoor temperature of around 17.0°C may be more adequate. For cooling, the average median cooling switch on temperatures are around 0.5°C lower than the currently assumed values for the three cities. However, the median indoor temperatures when A/C is running, which may be considered as the real thermostat set point, are about 1.5°C above the currently assumed values for the three cities.

In summer months, some houses in all cities were recorded to experience living room temperatures in excess of 35°C, with several temperatures in excess of 40°C recorded in Melbourne houses, although no indication of occupancy was provided. On average, houses had average maximum living room temperatures in summer of over 30°C, which is well outside accepted comfort ranges. In winter some houses in Adelaide and Melbourne recorded living room temperatures below 8°C, while most winter recordings in Brisbane remained above 10°C. On average most houses experienced winter minimums of around 12°C in Living Rooms, though again, the occupancy and time are not indicated. All of these results do however suggest a tendency of occupants to tolerate a much wider range of indoor temperatures.

In terms of monitored indoor temperatures, it was found that the range of space heating is wider than that of space cooling. With 80% acceptability, it was found that the ranges of space heating are 1.7K, 0.7K and 0.8K wider than those listed in ASHRAE 55-2013 [35] in Melbourne, Brisbane and Adelaide respectively, and for space cooling the ranges are 2.2K, 1.3K and 1.8K narrower than those listed. This suggests that when the houses are occupied, and mechanical air conditioning is operated for space cooling, the indoor environment is decoupled from the outdoor environment and the adaptive range is significantly smaller than when the house is free-running/naturally-ventilated as shown in Standards [35]. It was also found that, with different acceptability limits, the air conditioning turning off temperatures are different. This observation is different from those defined in Standards [35], which define the operative temperature with identical air conditioning turning off temperature (neutral temperature) with different comfort zone widths for different acceptability limits. For Chenath engine building thermal performance simulation, separate calculations are required for the operations of free-running/natural ventilation and mechanical ventilation.

Most research associated with temperature has indicated that incorporating a wider band of acceptable winter temperatures into AccuRate Sustainability is likely to be appropriate in a number of climate zones, however further research is needed. It was concluded that although the use of a heating thermostat setting of 20°C is supported, the triggering temperature should be 2 to 3°C lower. The existing constant cooling thermostat settings for climate zones studied are supported and even though the median indoor temperatures when air-conditioning is running, which may be considered as the real thermostat set point, are about 1.5°C above the currently assumed values.

Analysing the existing heating and cooling thermostat settings, assumptions and models used in NatHERS software, it was shown that aspects requiring further upgrades and improvements include: heating and cooling thermostat temperatures; triggering temperatures for heating and cooling; the cooling effect of air movement; and occupant window operation rules.

It was observed that, on average, heating in Melbourne and Adelaide households was switched off at approximately 10pm, rather than 12am, as assumed by AccuRate Sustainability. This indicates the need to adjust assumed living area zone-based occupancy patterns. Actual observed occupancy patterns were also seen to differ, based on the type of day, season and month. Highest peaks in occupancy were seen in winter months, with next highest peaks in Summer months. A one-hour shift was also seen when comparing weekdays and weekends.

With regard to adaptive thermal comfort models, observed cooling in bedroom zones during Summer demonstrated consistency with the adaptive comfort model. These results also showed that the impact of whether the air-conditioner was on or off was negligible. These results suggest that the adaptive thermal comfort model is acceptable for use in relation to cooling. Winter bedroom heating results were however, found to be inconsistent with the adaptive comfort model. This inconsistency was maintained regardless of the impact of whether the air-conditioner was on or off.

Close agreement was observed between AccuRate Sustainability modelled and measured, aggregated monthly heating and cooling data, for higher star rated Adelaide buildings, with less agreement being observed in relation to lower star rated buildings in Adelaide, Melbourne and Brisbane. Monthly measured heating data aggregated over a five-year period, best correlated with AccuRate Sustainability modelled data utilising actual BOM weather data with windows simulated as closed. When the same data were aggregated annually, measured data best correlated to AccuRate Sustainability modelled data utilising actual BOM weather data. Aggregated measured cooling data best correlated with AccuRate Sustainability modelled data utilising Standard RMY, based on both monthly and annual values.

A trend was observed towards increasing accuracy of modelled monthly heating and cooling data, in higher star rated Adelaide houses, with increasing outdoor temperature. As such, AccuRate Sustainability is likely to more accurately predict building performance during heatwaves, expected as a result of climate change in warm temperate climate zones, however the impact in relation to other climate zones is unclear.

The impact of thermal bridging and insulation R-Value degradation on cooling load, is compounded at increased temperature, especially during heatwaves, which are expected to result from climate change. Assessment of such impacts, especially during heatwaves, should form part of NatHERS outputs in rating mode.

Research into the impact of changing the thermal comfort acceptability limits showed that the largest impact on the energy star rating would be experienced by lightweight, high-set houses in tropical climates. The least significant impact of acceptability limits on cooling energy requirements and star rating is found for the heavy weight double brick houses in relatively mild and cold climates such as Melbourne and Hobart. The impact on the cooling energy requirements for all construction types considered can also be large in hot summer climates such as Alice Spring and Mildura. However, due to the substantial heating energy requirements in these climates, its impact on energy star rating is subdued in comparison with tropical regions. For cooling energy requirements and energy star rating, the decrease from 90% to 80% in the acceptability limits has greater impact than that from 80% to 70%.

Machine Learning has been shown to predict the daily energy consumption of the whole house, as well as certain appliances such as refrigeration and RC air conditioning, with a high level of accuracy. The ability to predict total electricity consumption with machine learning informs the recommendation for this to be used in the star rating of PV and associated energy storage systems.

5 Whole of House Energy Assessment

Since 2003, a minimum energy performance is required for all new homes in Australia. However, the requirement is only for the building fabric. To reduce GHG emission effectively from residential buildings, other major household appliances must be included in the assessment. Also, with increasing building fabric efficiency, energy consumption impact of other appliances becomes more significant. These arguments led to formulate one of the objectives of this project, which was to include other household appliances in the house energy performance assessment process. This approach would enable householders and industry greater flexibility to cost effectively achieve increased energy efficiency.

Accurate Sustainability, in the non-rating mode (as presented in Chapter 2), can estimate the annual energy consumption of heating and cooling equipment, hot water systems and lighting. However, the estimations are done in separate modules, not interlinked and therefore, total whole of house energy efficiency is not evaluated. In addition, it does not estimate the consumption of other major household appliances nor does it provide any assessment or rating of the whole house, incorporating both building fabric efficiency and key appliances. There is, however, an enhanced version of Accurate Sustainability available named AusZEH Design developed by CSIRO, which includes the energy consumption of all household energy end-use. AusZEH Design, however, is not available for general use and was intended mainly for research purposes focusing on assessing greenhouse gas (GHG) emissions of Australian Households [126]. In this chapter, an assessment methodology for whole-of-house energy performance for Australian houses has been presented. The objectives were:

- to explore how whole-of-house energy assessment can be done in the Australian context,
- to explore how the assessment outcomes can be communicated to the relevant parties,
- to explore the impact of other appliances on the total household energy efficiency performance,
- explore a star rating approach to consider the use of distributed renewable energy resources, such as on-site solar PV and battery systems.

A review was conducted regarding house energy rating schemes and assessment methods in general and in other comparable countries around the world. The aim was to develop a methodology based on the knowledge, experience and practices applied in other countries which have whole-of-house assessment processes.

It is important to note that the methodology presented in this chapter does not intend to predict actual energy consumption of a house, instead, it attempts to propose an integrated assessment, which assesses the house considering both building fabric and major household appliance efficiency.

5.1 Energy Rating Schemes and Assessment in Other Countries

From the literature, it is clear that the main motivation behind most of the rating systems was to enable consumers to make informed choices from the evaluated energy efficiency of homes regarding building, renting or purchasing a house [127-130].

There are two established ways to assess building energy performance, either by asset assessment or operational assessment. Asset ratings focus on the theoretical energy use of a building following a set of defined, standardized conditions and apply modelled or calculated methods. Operational ratings focus on the actual energy use based on energy bills and consumption. The latter approach is applied to existing buildings, particularly the large and complex ones where asset rating is not economically viable [127]. Furthermore, these approaches, as analysed by O'Leary et al [5A] can be problematic particularly in the Australian context where behavior and occupancy can dramatically vary actual energy consumption. Asset ratings are generally the preferred option and can provide standardized comparison of whole-of-house building energy performance. To rate building energy performance, three methods are followed, prescriptive, calculation-based and performance based.

Prescriptive schemes commonly known as deemed to satisfy (DTS) methods provide minimum standards for different components of a building while calculation-based ratings employ computer-based models to evaluate the energy performance of a building relative to a notional baseline performance [127]. Performance-based ratings apply actual building energy consumption data to validate building energy efficiency. These later rating techniques require substantial time and are generally not applied to residential buildings, leaving the two former methods being the dominant approaches [127, 130, 131].

Rating schemes are generally associated with either certification or labelling. The former refers to the evaluation of building performance at the design stage, while labelling assesses the as-built performance of the building when it is compared with other similar buildings. All assessments are evaluated against a reference building. The benchmark energy usage is derived either through statistical data analysis or from a hypothetical building through simulations [128, 132]. Reference buildings ideally share the same basic characteristics as the building being evaluated including climate zone and building type [133, 134].

Various metrics are used to communicate building energy performance, however most of these rating schemes use a grading scale to score buildings (Figure 5-1). One hundred- point scales and star rating systems are most common, while some use either a pass/fail system, or simply classify by terms such as bronze, silver, or gold. Scales can be either continuous or discreet. With a continuous scale, values can fall anywhere on a number line. On the other hand, with a discrete scale, values are grouped in a limited number of categories, such as from A to G. It is generally agreed that continuous scales allow better differentiation between best and worst energy performers since building scores are not lumped together [127, 128, 132, 135]; however, it requires more effort to illustrate comparative performance in a continuous scale. Discrete scales often are more challenging since if the performance lies near the border between categories, slight changes have a significant impact [127, 136].

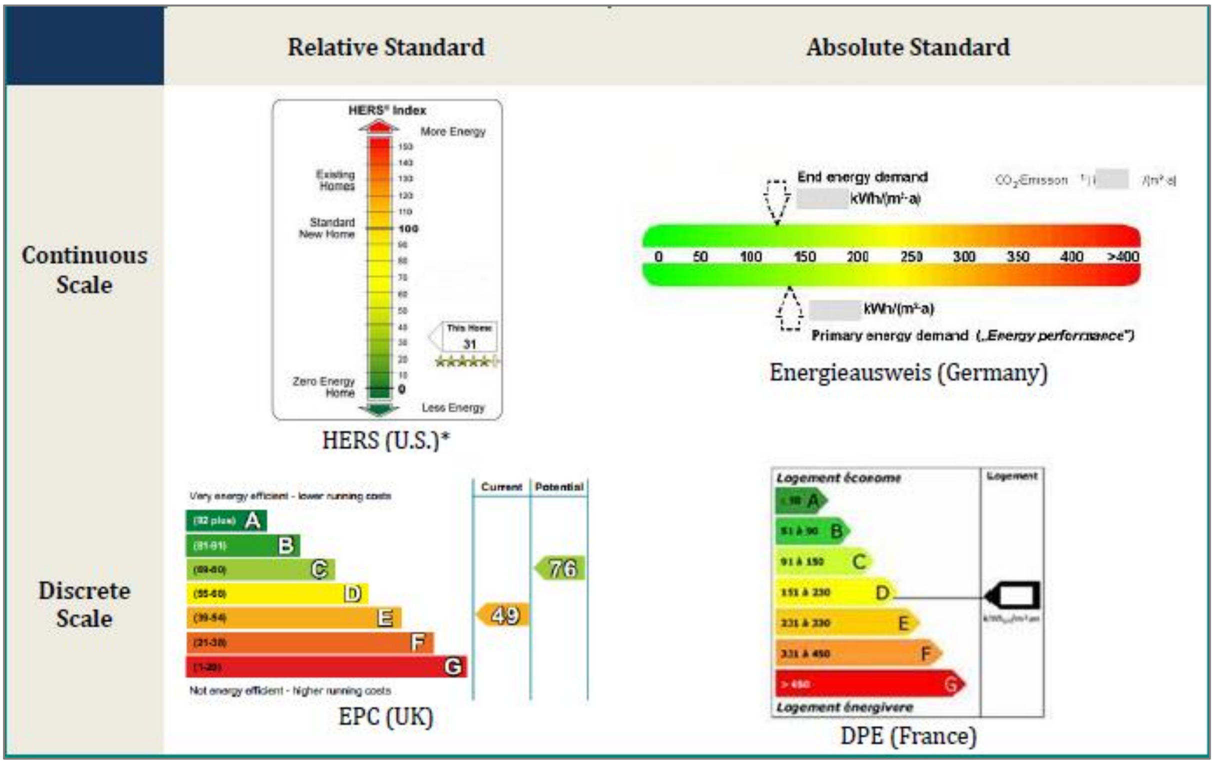


Figure 5-1: Different types of metrics; Source: CA-EBPD Country Reports 2010

Energy performance assessment systems do not always evaluate all energy end-uses [128]. The major building end use types evaluated are heating and cooling, hot water, lighting, mechanical ventilation, and significant plug and process loads. Calculated ratings commonly exclude uses like plug loads and lighting which are considered largely occupant-dependent. Calculated ratings almost always include regulated end uses such as heating, cooling, mechanical ventilation, and hot water [136].

The following analysis discusses the energy rating schemes and assessments in the USA, Canada, UK & Wales, and Germany in further detail, followed up by a comparison to the Australian NatHERS scheme.

5.1.1 USA

In the USA, the main objectives of the energy rating schemes are to supply higher quality and more comfortable homes requiring lower operational costs along with reduced environmental impact [137, 138]. Energy rating is voluntary and can be done for both existing and new homes. All new homes, however, must meet minimum energy performance, which is regulated by IECC standards [139]. The energy rating certificates and labels can be used to qualify for a more favourable mortgage loan to upgrade an existing home to a better efficiency or to buy a higher-efficient home [139]. In addition to qualifying for a favourable loan, another aim of the certificates and labels are to assist home-buyers and renters to make a more informed decisions towards their housing choice. For example, in California, the following statement is commonly advertised to encourage people to go for higher-efficient houses [140]:

> *"You wouldn't buy a new car without knowing its "miles per gallon" rating. So why buy a home without a "home energy rating?"*

Energy performance of a house is commonly expressed through the Home Energy Rating System (HERS) index score (Figure 5-2). HERS Index score was developed by the Residential Energy Services

Network (RESNET) and was introduced in 2006. The index score (0-100) is given by comparing the rated home to a HERS Reference Home (a new home that meets 2006 IECC Standards). HERS Reference Home is considered to have a score of 100 (least energy efficient), while a net-zero energy (no energy use) home has a score of 0. Each one-point score reduction is equal to a one percent reduction in energy consumption compared to the reference home. For example, if a home receives a HERS score of 61, that means it is 39% more energy efficient than the HERS Reference Home.

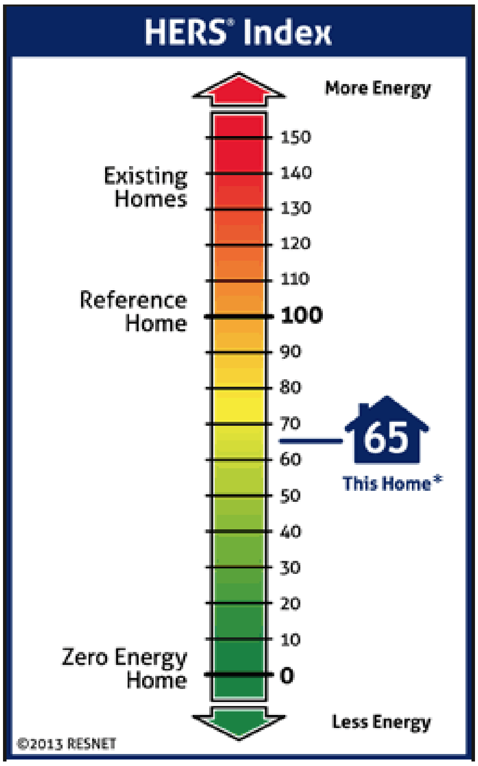


Figure 5-2: HERS Index Score

The HERS index score is calculated using Equation 7 and Equation 8, below:

HERS Index:

Equation 7

$$\frac{PE_{frac} \times 100 \times (E_{heating} + E_{cooling} + E_{wh} + E_{la})_{rated\ home}}{(E_{heating} + E_{cooling} + E_{wh} + E_{la})_{reference\ home}}$$

Equation 8

$$PE_{frac} > \frac{(E_{used} - E_{produced})}{E_{used}}$$

Where, **E**=energy consumption**, wh**=water heating**, la**=lights and some appliances, **PE**=purchased energy (fraction).

The energy use of the rated home is compared to the energy use of the reference home. If both use the same amount of energy, then the fraction part of the equation (PE_{frac}) equals 1, corresponding to a HERS Index Score of 100. Conversely, if the rated home's energy use is half that of the reference home, its HERS Index Score would be 50. However, if the rated home uses twice as much energy as the reference home, then its HERS Index Score would be 200.

The Purchased Energy or PE_{frac} is a multiplier that can reduce the HERS Index Score for the homes that produce some or all of the energy they use over the period of one year. For example, if a home produces no power ($E_{produced} = 0$), it has a PE_{frac} of 1 and doesn't affect the HERS Index Score. A home producing an amount of energy equal to half of what it uses ($E_{produced} = 0.5 \times E_{used}$) will have a $PE_{frac} = 0.5$, which will cut the HERS Index by half. Similarly, a home producing the same amount of energy as it produces ($E_{produced} = E_{used}$) will have a PE_{frac} of 0, producing a HERS Index Score of 0, which is a net-zero energy home.

The HERS scheme assesses the following elements within the home; heating equipment, cooling equipment, domestic hot water, control systems (thermostat type), light fixtures, refrigeration, dishwashing, ceiling fans, mechanical ventilation systems and on-site power generation [134].

The energy rating certificate includes the HERS Index score (on a 0 to 250-point scale) as well as the home's major energy-efficiency features, the estimated annual energy use and operating cost of the home, greenhouse gas emissions, and the annual amount of solar or other onsite renewable energy generation.

The USA HERS rating process is rigorous, which requires third-party on-site verification as well as applying a strict calculation method. However, the scheme has been criticised due to its dependency on efficient appliances. Hence, caution is needed to require a sufficiently high minimum building fabric efficiency to avoid trading this off against higher rated appliances [134].

It is evident that the home energy rating scheme in the USA is more market driven, which aims at changing the market demand for higher-efficient homes through incentives such as favourable mortgage loan.

5.1.2 Canada

In Canada, home energy rating systems began in 1997 and was initiated by the Office of Energy Efficiency (OEE) of Natural Resources Canada (NRCan). Canada has separate energy rating programs for existing and new houses where Ener-Guide House (EGH) is for existing houses and Ener-Guide New House (EGNH) is for new houses [137].

The objectives of the schemes were to [138, 141]:

- raise consumer awareness of energy-cost savings, improved thermal comfort and indoor air quality, and increase building lifespan and resale value of new and existing homes;
- identify and prioritize energy efficiency upgrades, giving homeowners the facts needed to make informed decisions;
- serve as a marketing tool for promoting energy efficiency upgrades, and enhance the credibility and professionalism of the renovation industry;
- stimulate continued growth in the home renovation industry and increase demand for services and new energy-efficient products which in turn will result in job creation;
- provide financial institutions with a recognized and objective rating of the annual energy consumption of the home; and
- quantify and verify actual home energy improvements, for statistical and program design and evaluation purposes.

Since Canada is going through a transition of rating schemes currently, there are two rating systems. The former version is based on 0-100 scale consistent with the scheme used in the USA. The upgraded (newer) version is based on the actual annual energy consumption expressed in GJ/year.

The former version (0-100 scale) is based on the home's annual energy consumption and rated against a reference building. A zero (0) on the scale represents an uncomfortable house that has major air leakage, no insulation and extremely high-energy consumption. The lower limit is set at zero. At the other end of the scale, a 100 represents a house that is very well insulated, airtight and requires no purchased energy (such as a solar powered home). Houses with moderate air leakage and insulation in all exterior wall cavities will typically have a rating of over 50. The energy ratings do roughly correspond to electric or natural gas bills per square foot of a house.

There are two standard or reference buildings for evaluation. The R-2000 standard is applied to new homes and requires a rating of 80-85 while the Model National Energy Code for Buildings (MNECB) of Canada, is applied to existing houses requiring a 70-75 rating to comply with the Model National Energy Code for Houses (MNECH). The rating system only deals with energy consumption for space heating as residential cooling loads are only between 2% and 5% of annual energy use. The rating system assumes pre-defined base loads for appliances and domestic hot water.

The score is calculated by applying Equation 9:

Equation 9

$$Energy\ Efficiency\ Rating = 100 - \left(20\left(\frac{Equivalent\ Total\ Energy\ Consumption}{Reference\ Energy\ Consumption}\right)\right)$$

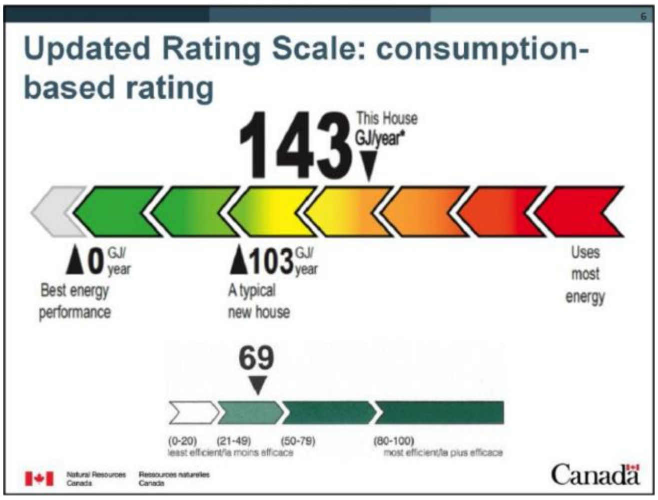
Where:

Equation 10

$$\begin{aligned} &Equivalent\ Total\ Energy\ Consumption \\ &\qquad = Equivalent\ Space\ Heating\ Consumption \\ &\qquad + \ Equivalent\ Occupancy\ Consumption \end{aligned}$$

In the newer version (EnerGuide Gigajoules Rating System), actual consumption in GJ/year is shown, which is estimated using computer simulation tool HOT2000. Input data for the simulation is collected through on-site visits, blower-door testing, photography and documentation of building construction, major equipment and appliance [142]. Lower value means lower energy consumption. If a house's total annual energy consumption is estimated as 102 GJ/year and it produces 28 GJ/year through on-site renewable sources, then the final rating of the house will be 74 GJ/year.

Included in the calculation are: space heating, space cooling, ventilation, hot water, lights (default) and appliances.



Updated Rating Scale: consumption-based rating

Figure 5-3: Rating Scale, Canada

In addition to the rating scale, the certificate also includes suggestions about improvements, which can enhance the energy-efficiency of the rated house.

5.1.3 UK and Wales

The Energy Performance Certificate (EPC) was introduced in England and Wales in late 2007 as part of the EPBD in EU and is applicable for both new and existing houses [132, 143]. For any property to be sold and rented in UK and Wales, an EPC is needed. For rental properties, certificates are valid for 10 years, required on a new tenancy commencing on or after 1 October 2008.

There are two house energy-rating schemes:

- the SAP (Standard Assessment Procedure), for new buildings, and RdSAP (Reduced Data version of SAP), for existing buildings), and
- the NHER (National Home Energy Rating Scale, for all types).

The SAP and RdSAP are the preferred assessment method and are accepted by the Government for mandatory rating, whilst NHER is a voluntary scheme [143, 144]. The main objective of the SAP schemes is to decrease energy consumption and GHG emissions.

SAP (& RdSAP), shows the current and potential energy rating of a property, known as a 'SAP rating'.

The SAP follows discrete scale and is divided into 7 bands ranging from A-G. Each range has a set amount of 'SAP' points. Each chart has a current and a potential energy rating out of a maximum of 100 points, representing maximum efficiency or zero energy cost. Dwellings with a rating in excess of 100 are net exporters of energy. The average property in the UK is in the band D or E. The energy rating is based on the sum of the energy cost for space heating, water heating and lighting per square meter of floor area, assuming average occupancy patterns. However, it does not consider domestic appliances and ignores the location of the building. The omissions have been criticized as it would appear to have a significant effect on the accuracy of the rating system, and discriminate against the value of a building design, which might be more suitable for a particular location and climate. The SAP calculation for the annual energy cost is based on following:

- The elements of building fabric
- The heating and hot water system

- The internal lighting
- The renewable technologies used in the home.

The SAP calculations allow comparison to be made of the energy running costs of dwellings anywhere in the UK. This is achieved because the calculations are predominantly location independent and are based upon a notional standard occupancy that overcomes variations associated with physical location and the differing ways in which people utilize their homes.

The energy certificate includes suggestions for the rated house to improve energy efficiency further. Also, possible cost savings after the improvement.

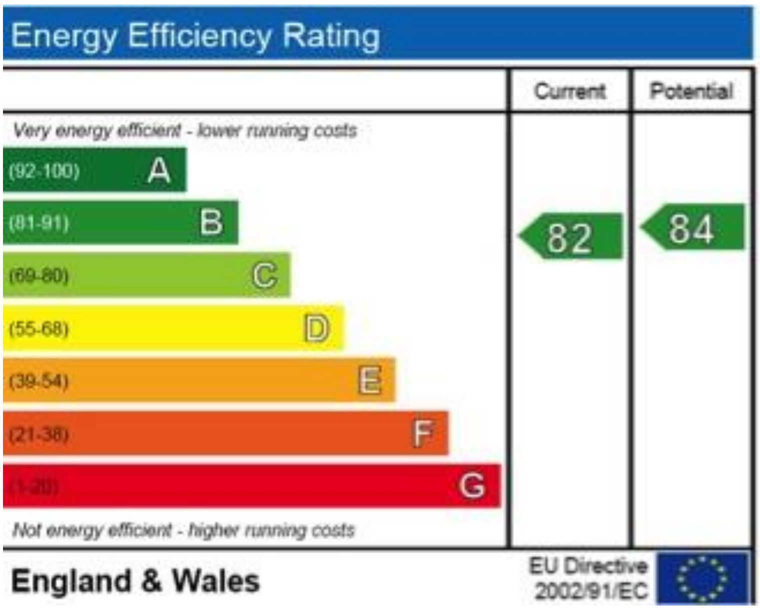


Figure 5-4: Rating Scale, England & Wales

5.1.4 Germany (Energieausweis)

In Germany, the Energy Saving Ordinance (EnEV) determines the minimum energy performance standards for all new and significantly refurbished buildings. The Energy Certificate (Energieausweis) is needed whenever a house is sold or leased; this has been in force since January 2009 [145, 146].

Two types of Energy Certificates are generated, a Demand Certificate (Bedarfsausweis) and a Usage Certificate (Verbrauchsausweis), for the case of existing buildings.

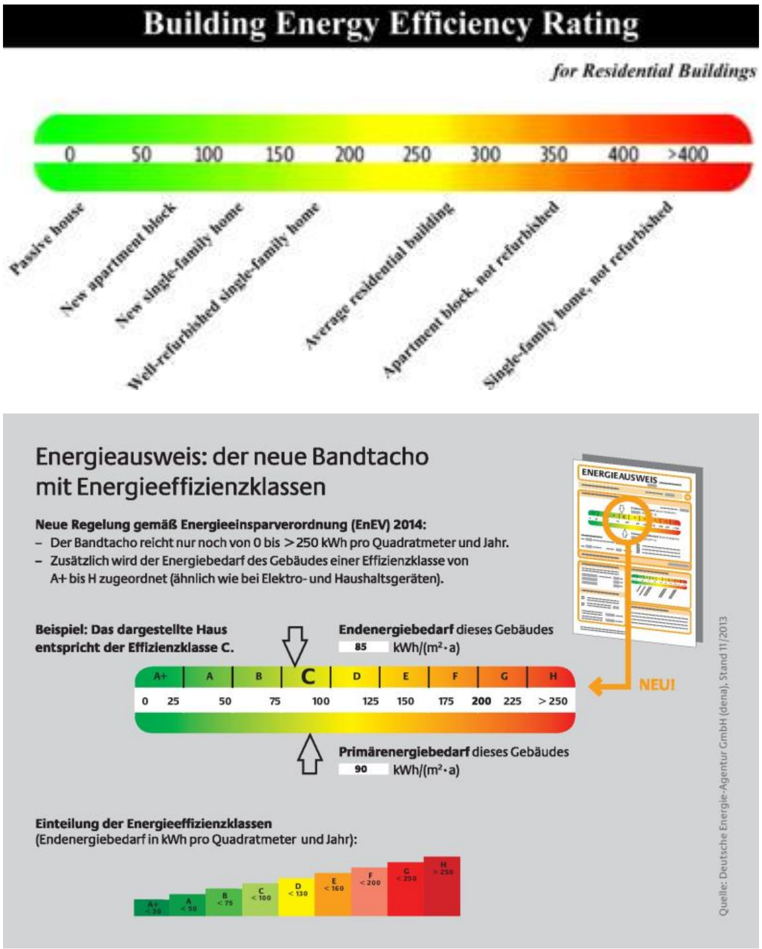
A Demand Certificate is an asset rating, issued based on on-site inspection of energy efficiency of the walls, roof, windows and furnace. The Usage Certificate is based on the actual energy use of the property over the past three years. While the demand certificate is issued for new buildings, the usage certificate is issued for existing buildings.

The primary objectives of the German schemes are to [147, 148]

- comply with the EU Energy Performance of Buildings Directive,
- provide all market participants with reliable information on energy efficiency requirements,
- to improve energy efficiency quality of a building.

The building is measured against a reference building and captures the heating equipment, ventilation and hot water appliance efficiencies.

The Rating is provided in a continuous scale expressed in primary energy in kWh/m^2/year.



Energieausweis: der neue Bandtacho mit Energieeffizienzklassen

Neue Regelung gemäß Energieeinsparverordnung (EnEV) 2014:

- Der Bandtacho reicht nur noch von 0 bis > 250 kWh pro Quadratmeter und Jahr.
- Zusätzlich wird der Energiebedarf des Gebäudes einer Effizienzklasse von A+ bis H zugeordnet (ähnlich wie bei Elektro- und Haushaltsgeräten).

Beispiel: Das dargestellte Haus entspricht der Effizienzklasse C.

Endenergiebedarf dieses Gebäudes 85 kWh/(m²·a)

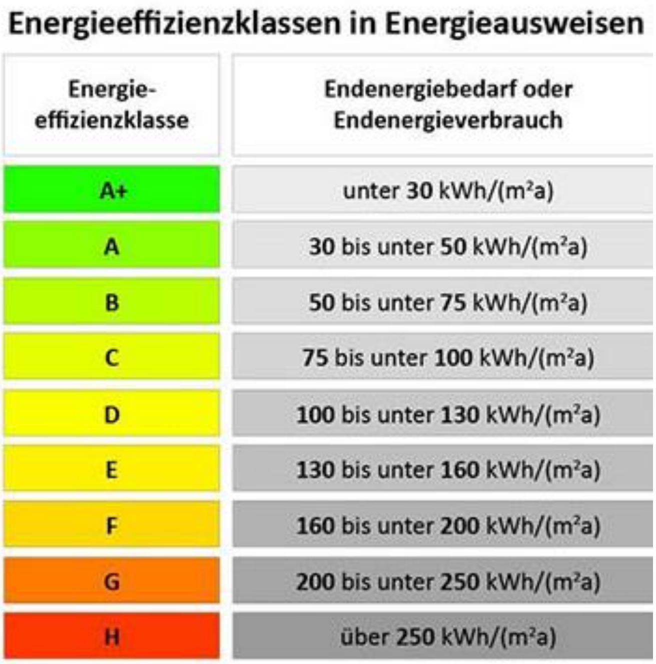
Primärenergiebedarf dieses Gebäudes 90 kWh/(m²·a)

Einteilung der Energieeffizienzklassen
(Endenergiebedarf in kWh pro Quadratmeter und Jahr):

Figure 5-5: Rating Scale, Germany

In addition to meeting minimum energy requirements or EnEV standards, the scheme is designed to encourage the industry to pursue higher efficient buildings. To support this objective the government provides incentives through the state-owned bank KfW Bankengruppe [149, 150]. In case of exceeded EnEV requirements, Low-interest loans and subsidies are available.

Houses that are eligible for KfW loans are commonly termed as KfW Efficiency House or Energy Efficiency House. A KfW Efficiency House distinguishes between different categories such as KfW 100, KfW 85, KfW 70 and so on. The value attached to the KfW refers to the percentage of primary energy demand compared to the EnEV reference building. This means a KfW 100 house consumes as much energy as a new EnEV building; whereas, a KfW 85 house will consume 85% of the primary energy requirement of the reference building. The most efficient KfW building in the market at present is KfW40, which consumes 40% of the primary energy of a reference building. KfW buildings are expressed in a discreet rating scale as shown in Figure 5-6 [150].



Energieeffizienzklassen in Energieausweisen

Energie-effizienzklasse	Endenergiebedarf oder Endenergieverbrauch
A+	unter 30 kWh/(m^2a)
A	30 bis unter 50 kWh/(m^2a)
B	50 bis unter 75 kWh/(m^2a)
C	75 bis unter 100 kWh/(m^2a)
D	100 bis unter 130 kWh/(m^2a)
E	130 bis unter 160 kWh/(m^2a)
F	160 bis unter 200 kWh/(m^2a)
G	200 bis unter 250 kWh/(m^2a)
H	über 250 kWh/(m^2a)

Figure 5-6: Discreet Rating Scale for KfW efficiency Houses

5.1.5 Comparative Analysis

This review has shown that there is a fundamental difference between the Australian house energy rating scheme and those systems applied in comparable jurisdictions around the world, as summarised in Table 5-1. Australia's house energy rating scheme is a policy instrument focused on compliance to meet a minimum standard. Whereas in the UK, US, Germany and Canada schemes go beyond compliance and act to encourage an energy efficient housing market. Furthermore, the scope of these schemes is beyond just the thermal efficiency of the building fabric but encompass a range of appliances. Finally, all schemes cover both new and existing homes, while Australia generally only regulates new homes or major renovations. Overall, in principle all schemes are based on the framework of comparison against some reference building.

In the US, Canada and in Germany, substantial focus is on consumer awareness through providing energy efficiency information enabling informed decision making while purchasing or renting a home. With that approach in mind, these schemes provide performance certificates or reports which include additional information regarding further improvement opportunities and probable energy cost savings. The energy rating certificate and labels in North America (USA and Canada) are voluntary, however, are in demand as it adds economic value to the property. Energy rating scores are provided in both continuous and discrete scales each with their own advantages and disadvantages.

In Australia and UK, energy rating is conducted based only on architectural plans, and energy assessors do not visit the site or verify the building after construction. In all other jurisdictions third-party verification based on on-site data collection is required. Furthermore, unlike in Australia, performance assessments have a limited life.

Overall, the US has the most comprehensive scheme regarding whole-of-house energy assessments while Australia has the least comprehensive. Among the countries studied, Australia only assesses heating and cooling load associated with the building fabric while, all other countries assess at least the energy consumption of heating and cooling equipment and hot water systems.

Table 5-1: Residential Energy Rating Schemes in different Countries- a Comparative Chart

Scheme Parameter	**USA**	**Canada**	**UK & Wales**	**Germany**	**Australia**
Name	HERS	EnerGuide	SAP	Energieausweis	NatHERS
Authority	Residential Energy Services Network (RESNET)	Office of Energy Efficiency (OEE) of Natural Resources Canada (NRCan)	Building Research Establishment (BRE), Department of Environment	German Energy Agency	NatHERS Administrator, Department of Environment & Energy
Year introduced	2006	1997	2007	2009	2003
Property covers	Both new and existing houses	Both new and existing houses	Both new and existing houses	Both new and existing houses	New houses & major renovations
Validity	1 year	10 years	10 years	10 years	n/a
Objectives	i) Higher quality and more comfortable home for less money ii) qualifying for a more favourable mortgage loan and iii) environmental protection.	i) Raise consumer awareness ii) Identify and prioritize energy efficiency upgrades, iii) Serve as a marketing tool iv) Stimulate continued growth v) Quantify and verify actual home energy improvements	To decrease energy consumption and GHG emissions	To provide all market participants with reliable information on the energy requirements and energy quality of a building.	A policy instrument used for NCC compliance to reduce GHG emission
Procedure	Measured against a reference building; Based on on-site inspection and measurement by an energy consultant	Measured against a reference building; Based on on-site inspection and measurement by an energy consultant	Based on Architectural Plan	Measured against a reference building; Based on on-site inspection and measurement by an energy consultant	Based on Architectural Plan
Energy rating scale/score	i) Continuous, relative scale ii) 100-point scale of efficiency	Both, continuous 0-100 relative scale and continuous absolute scale	Discrete; A-G (where A is most efficient)	Continuous 0-100 relative scale and continuous absolute scale	Star-band ranging from one star to ten (one star is the least efficient)
Energy score quantifies	Total annual Energy consumption	Total annual Energy consumption	Energy use/unit area	Energy use/unit area	Energy use/unit area
Integration of RE production	Included	Included	Included	Included	Not included
What's included (for Energy Assessment)	Heating, cooling, hot water, lighting and other appliances	The 0-100 scale (old) version: i) heating, predefined DHW, lighting and appliances load. The GJ (new) version: heating, cooling, DHW, pre-defined DWH, lighting, ventilation & other appliances	i) Space Heating; ii) Hot Water iii) Lighting & iv) Ventilation	Heating; cooling; Hot water; Ventilation	Building Fabric

5.2 Whole-of-House Energy Assessment Methodology

This section proposes a whole-of-house energy assessment methodology for Australian houses. The assessment, in addition to the building fabric, incorporates other major household equipment and fixed appliances.

The methodology has utilised knowledge drawn from practices in other countries as presented in the previous section. In Australia, while NatHERS regulates the minimum energy efficiency of the building fabric, Minimum Energy Performance Standards (MEPS) regulates the minimum energy performance of the major household equipment and appliances [151]. This methodology combines both the NatHERS and MEPS standards into a whole of house energy assessment.

5.2.1 The Methodology

Although, whole-of-house energy assessment implies that the energy performance of a house is assessed based on 100% of the energy used by the building, it is not realistic to include all energy end-use. This is partly because a large number and type of energy-consuming appliances are used in the home and vary considerably across households, and as such there is insufficient data on the energy use of these appliances. Furthermore, this energy use relates to the individual characteristics of the householders, which is not transferrable to other householders. In addition, it is beyond the scope of energy assessment to regulate household energy use. Finally, the examples of other countries also showed that not all energy-consuming activities are always included in the assessment [2,3]. In this study, therefore, the basis for whole-of-house energy assessment was premised on including the major equipment and appliances that are common in most households, have a significant share on total energy consumption and have enough data available to assess.

The primary challenge of this study was to determine which appliances to include and how to estimate the energy consumption of the appliances for the assessment. For this study, the following equipment and appliances were included:

- Heating and Cooling System,
- Water Heater,
- Lighting,
- Refrigerator,
- Washing Machine,
- Television,
- Dryer, and
- Dish Washer.

While the heating and cooling system, hot water, dishwasher and lighting system are the most common fixed equipment of a house; the refrigerator, washing machine and television are the most common plug-in appliances. According to DEWHA (2008) report [152] most Australian households possess at least one refrigerator (99.9%), one washing machine (99.1%) and one television (97.66%). Dryers were included on the grounds that many washing machines come with a dryer and it is now one of the five major household appliances in Australia [153]. This study acknowledges that oven consumption should also be estimated and included, as all households possess an oven and consumes significant energy, however, since the estimations were based on the Minimum Energy Performance Standards (MEPS) database and since MEPS or any other authority does not yet regulate oven energy performance, it has been excluded.

MEPS provides the star rating, which correlates to efficiency, and estimated annual energy consumption of appliances. This energy consumption is predicted for refrigerators, dryers, dishwashers, washing machines and television, based on Australian Standards that dictate a nominal usage pattern that represents reasonable consumption behaviour. Using the metrics from NatHERS and MEPS it is possible to determine the annual electricity consumption for heating and cooling equipment. For hot water energy consumption, the most reliable method involves considering STCs which are based on hourly simulation assessments of hot water energy usage relative to a conventional electric hot water. Combining these together in terms of annual electricity consumption of certain appliances provides a basis for whole-of-house assessment. The examples shown here using this method are limited to houses with all-electric appliances.

Overall this method enabled annual electricity consumption to be compared against NatHERS and MEPS star ratings, such that a 6-star building fabric with 1-star appliances can be compared against 1-star building fabric and 10-star appliances. A separate star rating band was generated for hot water and lighting. These metrics were developed for Alice Springs and eight capital cities of the states and territories: Darwin, Brisbane, Perth, Adelaide, Sydney, Melbourne, Canberra and Hobart. Applying the examples of other countries, a reference building was identified for each city with minimum building and appliances efficiency, defined by a 6-star building fabric with 1-star appliances. The reference building was then used to conduct whole-of-house energy assessment for all cities. Note that the energy consumed by 'other' appliances is excluded for these examples, as this yet to be regulated, despite machine learning showing that this can be predicted.

Further analysis was conducted to explore and understand the impact of appliances on total household energy consumption.

5.2.1.1 Heating and Cooling Consumption

Heating and cooling consumption for this study was estimated by considering both building fabric efficiency and applying the heating and cooling equipment efficiency to determine annual electricity usage. Saman et al. [54] states that the majority of heating and cooling equipment in Australia is defined by vapour compression air conditioners. The efficiency of these systems is defined by a Coefficient of Performance (COP) for heating and an Energy Efficiency Ratio (EER) for cooling. Using the correlation for the annual thermal energy and star rating from NatHERS, the total thermal energy for heating and cooling were determined. It is assumed that new houses under this proposed scheme have a conditioned floor area of 196m^2, given that new houses typically have conditioned floor areas of about 200m^2. This area was chosen for simplicity as this resulting area-adjustment factor is 1, and this minimises the variables used in the calculations.

From CSIRO's AccuRate ratings national database, heating and cooling load percentage for Darwin, Alice Springs, Brisbane, Perth, Adelaide, Melbourne, Canberra and Hobart were identified (Table 5-2). From these values the annual heating and cooling loads (in MJ/m^2) for different building fabric efficiency were estimated for all cities based on the star rating correlation. For example, According to NatHERS, in Adelaide, a building fabric is considered to have a six-star efficiency if annual thermal load is 96 MJ/m^2 of conditioned floor area. From the database, heating and cooling load percentage for Adelaide was found as 58.9% and 41.1% respectively, corresponding to an annual, heating and cooling load of 56.5 and 39.5 MJ/m^2/year, respectively. This process was repeated for the nine Australian cities presented here, and for NatHERS star-ratings ranging from 1 to 10 stars.

Table 5-2: Heating & Cooling Load % in Different Cities (Accurate Ratings national Database)

CLIMATE ZONE	Location	Heating Load %	Cooling Load %
1	**Darwin**	0.0%	100.0%
6	**Alice Springs**	44.7%	55.4%
10	**Brisbane**	40.7%	59.3%
13	**Perth**	67.1%	33.0%
16	**Adelaide**	58.9%	41.1%
17	**Sydney**	48.1%	51.8%
21	**Melbourne**	75.0%	25.0%
24	**Canberra**	88.2%	11.8%
26	**Hobart**	95.8%	4.2%

Once the heating and cooling load with different building fabric efficiency was estimated, the total annual heating and cooling electrical energy was determined by applying the efficiency parameters associated with vapour compression air conditioners (see Equation 11).

Equation 11

$$Total\ H\ \&\ C\ Energy = \left(\frac{Total\ Annual\ Heat\ Load}{COP}\right) + \left(\frac{Total\ Annual\ Cooling\ Load}{EER}\right)$$

Where, COP = Coefficient of Performance for heating; EER = Energy Efficiency Ratio for cooling;

Equation 12

$$Total\ annual\ heat\ load = total\ cond.floor\ area(148.9m^2) \times \frac{annual\ heat\ load\ (MJ/m^2)}{COP}$$

Equation 13

$$Total\ annual\ cooling\ load = total\ cond.floor\ area(148.9m^2) \times \frac{annual\ heat\ load\ (MJ/m^2)}{EER}$$

To estimate the annual heating and cooling energy with different level of equipment efficiency, a constant COP and EER for one to ten-star heating and cooling equipment was applied based on MEPS database. Table 5-3 presents the correlation between these efficiency parameters and star rating of this appliance. Using this correlation, it was possible to determine the annual electricity consumption for heating and cooling relative for the full range of building fabric and air conditioner star ratings.

Table 5-3: COP and EER for Heating and Cooling Equipment with different Star-rating

Star Rating	COP	EER
1	3.18	3.18
2	3.43	3.42
3	3.94	3.89
4	4.34	4.32
5	4.82	4.86
6	5.46	5.38
7	5.80	6.02
8	6.25	6.36
9	6.71	6.83
10	7.17	7.31

5.2.1.2 Hot Water Consumption

For this study, annual energy consumption for hot water with different level of efficiency was estimated based on STC methodology. It is; however, worthwhile to note that only electric heater has been considered for this study.

STCs are based on the electrical energy savings of the nominated hot water system relative to an electric-element water heater. The hot water load is determined according to four different climate zones. For this study, a medium sized water heater was deemed appropriate for an average size house. According to the STC methodology, a medium size water heater with minimum efficiency will require the amount of electrical energy annually, as listed in Table 5-4.

A STC rating is awarded to a water heater if it saves at least 60% of water heating energy, in comparison to this minimum annual electrical energy. For example, a reference water heater (medium size) is assumed to consume 3,489 kWh per year in climate zone-1 [53], and therefore must save 2093 kWh/yr to receive a STC score. Consequently, the minimum rated hot water system consumes 1395.6 kWh/yr of electrical energy for climate zone 1. Therefore, if this is allowed to equate to a 1 star, then 10 stars can represent 100% saving, equating to zero electrical energy used for water heating. Consequently, a star band for each of the four Australian climate zones listed in the Australian Standard [53] was developed, based on a linear relationship. It should be stressed that these four climate zones are not related to the eight Australian climate zones listed within the NCC. The range of hot water STCs is such that savings of up to 90% are achievable and therefore assuming a 100% saving for 10 stars is a reasonable assumption. Table 5-5 summarises the annual energy consumption of water heaters in the four aforementioned climate zones, rated 1-10 stars.

Table 5-4: Annual Energy Consumption for medium sized reference water heater for different Climate Zones [53]

Hot Water Zone	Location	Electrical energy required for minimum efficiency (kWh/yr)
1	Darwin	3,489
2	Alice Springs	3,511
3	Sydney, Canberra, Adelaide, Perth, Brisbane	4,239
4	Melbourne, Hobart	4,239

Table 5-5: Assumed star bands for annual electrical energy consumption of water heating in four (AS/NZS 4234:2008) Australian climate zones

Star Rating	Hot Water (Z-1)	Hot Water (Z-2)	Hot Water (Z-3)	Hot Water (Z-4)
1	1395.56	1404.44	1695.56	1852.22
2	1240.49	1248.40	1507.16	1646.42
3	1085.43	1092.35	1318.77	1440.62
4	930.37	936.30	1130.37	1234.81
5	775.31	780.25	941.98	1029.01
6	620.25	624.20	753.58	823.21
7	465.19	468.15	565.19	617.41
8	310.12	312.10	376.79	411.60
9	155.06	156.05	188.40	205.80
10	0.00	0.00	0.00	0.00

5.2.1.3 Lighting

To estimate the lighting energy consumption, both the MEPS registered database for lamps and the maximum efficient lamps available in the market were considered to define the range between 1 to 10 stars. According to the MEPS database, for lamps, minimum lumens/watt was found as 8.5, which was considered as one-star efficiency for lamps in this study. According to IBIS World, Beacon Lighting Pty. Ltd. holds the maximum (11%) market share of Australia. From this organisation's catalogue, the maximum lighting efficacy available in the market was found as 89 lumens/watt, which was defined as a 10-star rating. All other star ratings were based on a linear interpolation between these values.

To estimate the annual lighting consumption for an average Australia house, with different levels of efficiency, the same 10 Lochiel Park house plans were used; this allowed the average area for the kitchen, Living/Dining, Bathroom, Bedroom, Entry/Stair zones to be estimated. Using the information from Table 5-6 derived from [154, 155], average Lumen-hours/day for an average house was estimated.

Table 5-6: Lux requirements for zones and assumed hours of operation

Zone	Lux (lm/m^2)	Avg Use (hrs/day)
Kitchen/Family	160	4
Living/Dining	80	3
Bathroom	80	2
Bedroom	80	1.5
Entry/Corridor/Stairs	40	1.5
Other (Daytime)	40	0
Other (Night-time)	80	1.5

From the Lochiel Park plans, average lumen-hours/day was estimated as 47,029. To estimate the annual consumption, the total lumen-hours/day (47,029) was divided by the efficacy of the lamps. Table 5-7 shows the estimated annual lighting consumption for different level of efficiency for an average house in Australia, applied in this study. These values were assumed constant across all climate zones, despite a location's latitude influencing the number of daylight hours per day, depending on season, however, it is believed this effect over a 12-month period would cancel each other out and as such, it is assumed that the overall yearly hours of required lighting is independent of climate zone (and latitude).

Table 5-7: Annual Energy Consumption for lighting fixtures across the 1-10 star range

	Star-rating	**lm/W**	**Wh/day**	**kWh/day**	**kWh/ Year**
Minimum efficacy found in registered MEPS lamp data	1*	**8.5**	5532.8	5.53	2019.49
	2*	**17.4**	2695.9	2.70	984.02
	3*	**26.4**	1782.2	1.78	650.49
	4*	**35.3**	1331.0	1.33	485.82
	5*	**44.3**	1062.1	1.06	387.68
	6*	**53.2**	883.6	0.88	322.53
	7*	**62.2**	756.5	0.76	276.12
	8*	**71.1**	661.3	0.66	241.39
	9*	**80.1**	587.5	0.59	214.42
Best Possible on today’s market (based on Beacon Lighting Group Ltd's Website)	10*	**89.0**	528.4	0.53	192.87

5.2.1.4 Other Appliances Consumption

The annual consumption for other appliances such as the refrigerator, washing machine, dryer, dishwasher and television was estimated directly from the MEPS calculator. For the estimation, an evaluation of the most common type and size was determined based on the report about whitegoods trend published by the energy efficiency program [153, 156]. The following presents a list of the assumptions used, whilst Table 5-8 summarises the estimated energy consumption, of these appliances.

- Assumptions to estimate the annual consumption of refrigerators,
- Refrigerator Type: Two-door refrigerators, according to a study [156], it accounts for 71% of all refrigerators sold in Australia.
- Fresh food Volume: 350 Litre and Freezer Volume: 100 Litre.
- Use: 24/7.
- Assumptions to estimate the annual consumption of Clothes Washer:
- Capacity: 8 kg
- Use frequency: 7 times/ week; warm wash.
- Assumptions to estimate the annual consumption of Clothes Dryer:
- Capacity: 7 kg
- Use frequency: Once/ week.
- Assumptions to estimate the annual consumption of Dish Washer:
- Capacity: 14 place setting
- Use frequency: 7 times / week.
- Assumptions to estimate the annual consumption of Television:
- Screen Size: 14 place setting
- Use frequency: 8 hours / day.

Table 5-8: Annual Consumption Estimation for different Appliances (kWh/Year)

Star-Rating	Refrigerator	Clothes Washer	Dryer	Dish Washer	TV
1	724	996	371	670	807
2	557	727	315	469	646
3	429	531	268	328	517
4	330	387	228	230	413
5	254	283	194	161	331
6	196	206	165	113	265
7	151	151	140	79	212
8	116	110	119	55	169
9	89	80	101	39	135
10	69	59	86	27	108

5.2.2 Whole-of-house Energy Assessment

With the annual electrical energy consumption for all appliances determined as a function of star rating it is possible to assess the whole-of-house energy with respect to star ratings. For Perth, Adelaide, Sydney, Melbourne, Canberra and Hobart, a 6-star building fabric with 1-star appliances was determined as the reference building, whereas, for Darwin, Alice Springs and Brisbane, a 5-star building with 1-star appliances was determined as the reference building. The variation in building efficiency requirements is due to NCC's different minimum requirements for different states and territories. The reference building was assumed to have minimum energy performance considering both building fabric and appliances. Note that in some cases 1-star rated appliances are not available for purchase. Despite this, the examples here show the importance of star rated appliances including those rated at 1-star.

The annual energy consumption for the minimum expected standard in a newly constructed reference building, for different cities, were estimated and listed below in Table 5-9. It must be noted that the total annual energy in the final column represents only an estimate of the total of considered electrical energy end uses listed, for comparative purposes, not the total household energy consumption. Furthermore, water heating energy relates to climate zones listed in the associated Australian Standard [53], rather than the NCC.

Table 5-9: Estimated energy consumption (kWh/yr) of considered electrical end-uses in reference building for each city

Location	Heating /Cooling	Hot-Water	Lighting	Refrigerator	Clothes Washer	Dryer	Dish Washer	TV	Total Annual
Darwin	5368	1396	2019	724	996	371	670	807	12,351
Alice Springs	1925	1404	2019	724	996	371	670	807	8,916
Brisbane	715	1696	2019	724	996	371	670	807	7,998
Perth	910	1696	2019	724	996	371	670	807	8,193
Adelaide	1248	1696	2019	724	996	371	670	807	8,531
Sydney	507	1696	2019	724	996	371	670	807	7,790
Canberra	2145	1696	2019	724	996	371	670	807	9,428
Melbourne	1482	1852	2019	724	996	371	670	807	8,921
Hobart	2015	1852	2019	724	996	371	670	807	9,454

The relative proportions of each end-use considered in this whole-of-house system, are shown graphically in Figure 5-7 for each city. This figure also presents specific percentages, in relation to Adelaide, for illustrative purposes. It must be noted that the proportions shown in Figure 5-7 do not relate to the total net electrical energy use of the house, but rather relate to the total for all end-uses listed in Table 5-9. The figure suggests that the proportion of energy consumed by lighting is over estimated. Furthermore, the allocation for heating and cooling appears to be underestimated. Other end-uses are similar to what is expected, therefore lighting, heating and cooling are likely to require adjustment but the overall breakdown is reasonable. These observations are based on monitored household electrical energy end-use data from South Australia, Victoria and Queensland.

The relative proportions in Figure 5-7 are based on a reference building, which is assumed to have a minimum NatHERS rating (e.g. 6-star building fabric for Adelaide) with appliances each rated at 1-star, representing the minimum energy as defined in the MEPS and STC methodologies. In reality however, household using only 1-star appliances are rare, particularly due to Government initiatives that vary across States, with many households using lamps with significantly higher performance than the minimum available efficiency. This comparative tool is still useful, because it provides information, both comparative and absolute, about the proportion of energy used by different appliances and end-uses. The intention of the methodology is justified, however like the values of energy use quoted within MEPS to which it is linked, it requires further refinement and periodic updates accordingly.

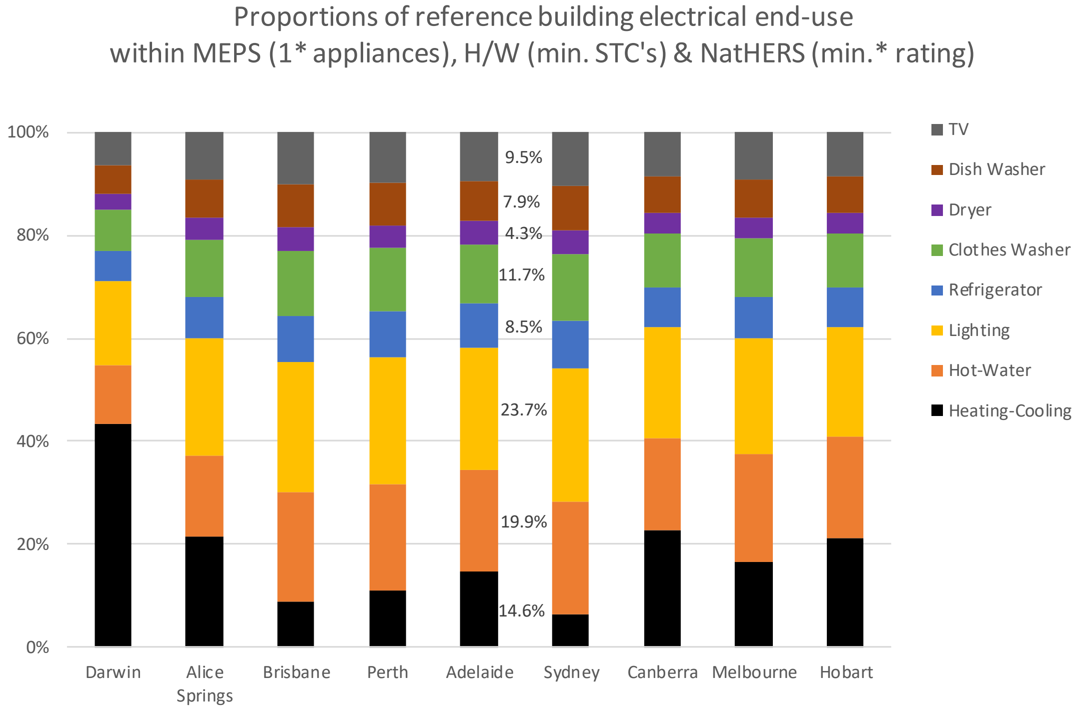


Figure 5-7: Energy Estimation for different Appliances

As seen in the USA and Canada, the performance of a house is assessed against the performance of a reference building, which is then presented on a linear scale. Since the annual energy consumption of the reference building in this study was estimated based on standardised assumptions and not based on actual consumption, the USA HERS index score system seems more appropriate for the Australian context. Hence, by following a similar principle, a house can be assessed for whole-of-house performance as presented below:

- Assign the reference building a score of 100.
- Using Equation 14, give a score to the rated building.

Equation 14

$$\text{Score of rated building} = 100 \times \left(\frac{\text{annual estimated consumption of the rated building}}{\text{annual estimated consumption of the reference building}}\right)$$

The scores then can be presented in a linear continuous scale against the reference house. For example, according to the metrics a reference house in Adelaide will consume 8,531kWh/ year. If a rated building consumes 5000 kWh energy, then the score of the rated building will be 58.6. This also suggests that the rated building is more than 40% efficient than the reference building. The representation of the results, as shown in Figure 5-8.

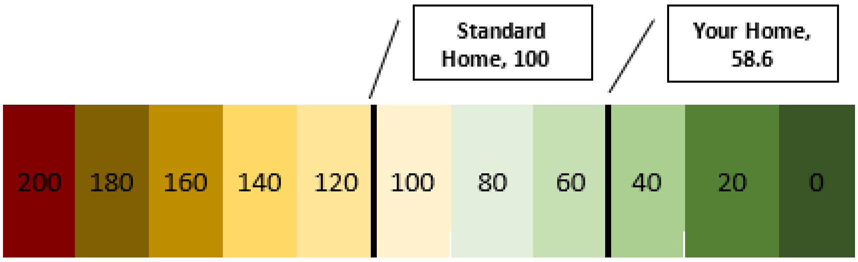


Figure 5-8: Potential Rating Scale for Australian Homes

Since in Australia building efficiency is communicated through the number of stars, a similar approach may be more appropriate in Australia to assess whole-of-house performance. Given that the current NatHERS minimum star rating in Adelaide for the building envelope is 6*, then it may be appropriate for this to be incorporated as the 1* metric for a whole of house energy rating. As such, a 1* whole of house energy rating for Adelaide would comprise a 6* NatHERS rating for the building envelope and 1* appliances. At the other end of the spectrum, a 10* whole of house energy rating would comprise a 10* NatHERS rating and 10* appliances. The range of potential whole-of-house energy ratings, in relation to the aforementioned methodology, are summarised in Table 5-10 below.

Table 5-10: Annual electrical energy consumption for proposed whole of house star-rating, Adelaide

Star-Rating	Annual Consumption (kWh/year)
1	8,531
2	7,645
3	6,759
4	5,874
5	4,988
6	4,102
7	3,216
8	2,331
9	1,445
10	559

Where a house is predicted to have an annual energy consumption of 5,431kWh, using the above table, it can be assigned to a rating of 4.5-star for the whole-of-house performance. The assessment then can be communicated through a continuous scale as following:

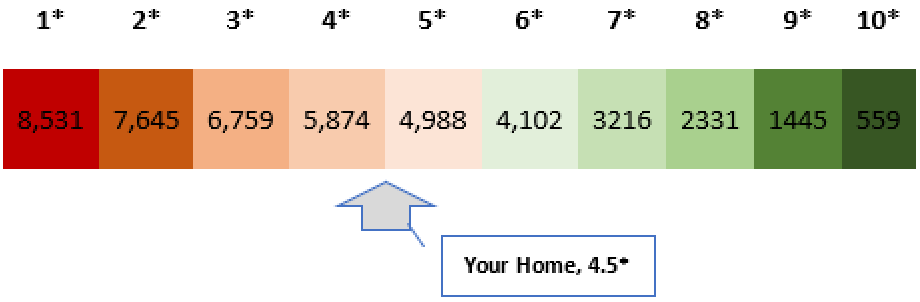


Figure 5-9: Star-Rating for a House in Adelaide

If whole-of-house energy assessment can be integrated within the tool, it can be used to provide three different ratings such as a rating for the building fabric, a rating for all appliances and a rating for the whole-of-house. This not only will assist homebuyers to make more informed decisions but also will reward the industry for installing more energy-efficient appliances.

5.2.3 Impact of Appliances

Further analysis was conducted to understand the impact of appliance efficiency on whole-of-house energy assessment. To conduct the analysis, estimated consumptions for different efficiency level were plotted for each city (Figure 5-10 to Figure 5-18). The full range of building fabric star rating was assessed across all cities. Overall, what the figures clearly show is that the impact of appliance star rating is far more significant than the star rating of the building fabric. For example, for Sydney, going from the reference building to a 10-star building fabric and 1-star appliances reduces whole-of-house energy by only 6%. For a 6-star building fabric with 10-star appliances and going to a 10-star building fabric reduces whole-of-house energy by 25%. Whereas for a 6-star building fabric going from 1 to 10-star appliances results in a reduction of 87%. This analysis should be clearly caveated by stating that there are many assumptions which exaggerate these values. Specifically, the assumed 100% saving for hot water for 10 stars, as well as the assumption that MEPS annual energy estimations are consistent with the building fabric energy estimations (Figure 5-10). However, it clearly does demonstrate that significantly more savings can be derived from applying higher appliance star ratings then building fabric ratings. This trend is consistent across all cities presented.

Therefore, the opportunity of whole-of-house assessment as a means to increase total energy efficiency can be driven through adopting higher star-rated appliances. Such an assessment process can readily generate a market for energy efficient housing, and investment in higher star rated appliances can be viewed as a far more cost-effective means of delivering a higher whole-of-house energy assessment, especially with rapid decreasing costs of energy-efficient appliances [155]. However, it should be stressed that this should not be implemented at the expense of the building fabric efficiency, but rather should be viewed to complement these.

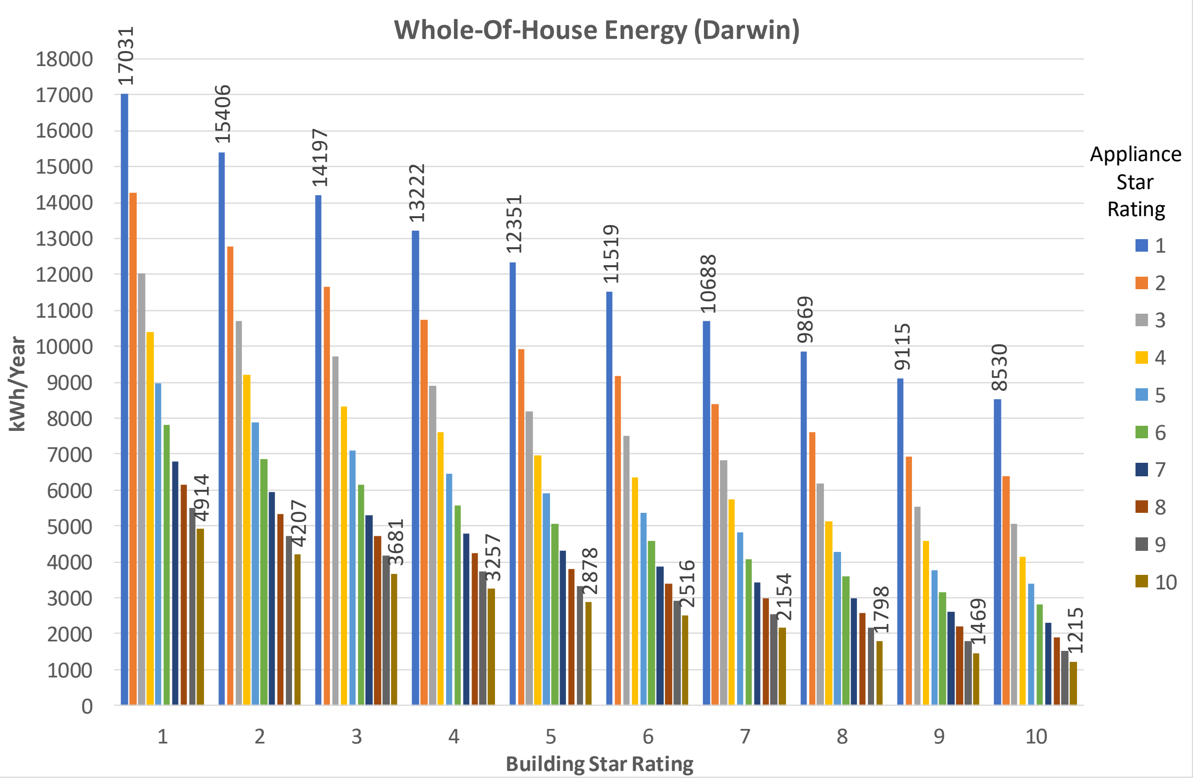


Figure 5-10: Whole-house Energy Metrics for Darwin

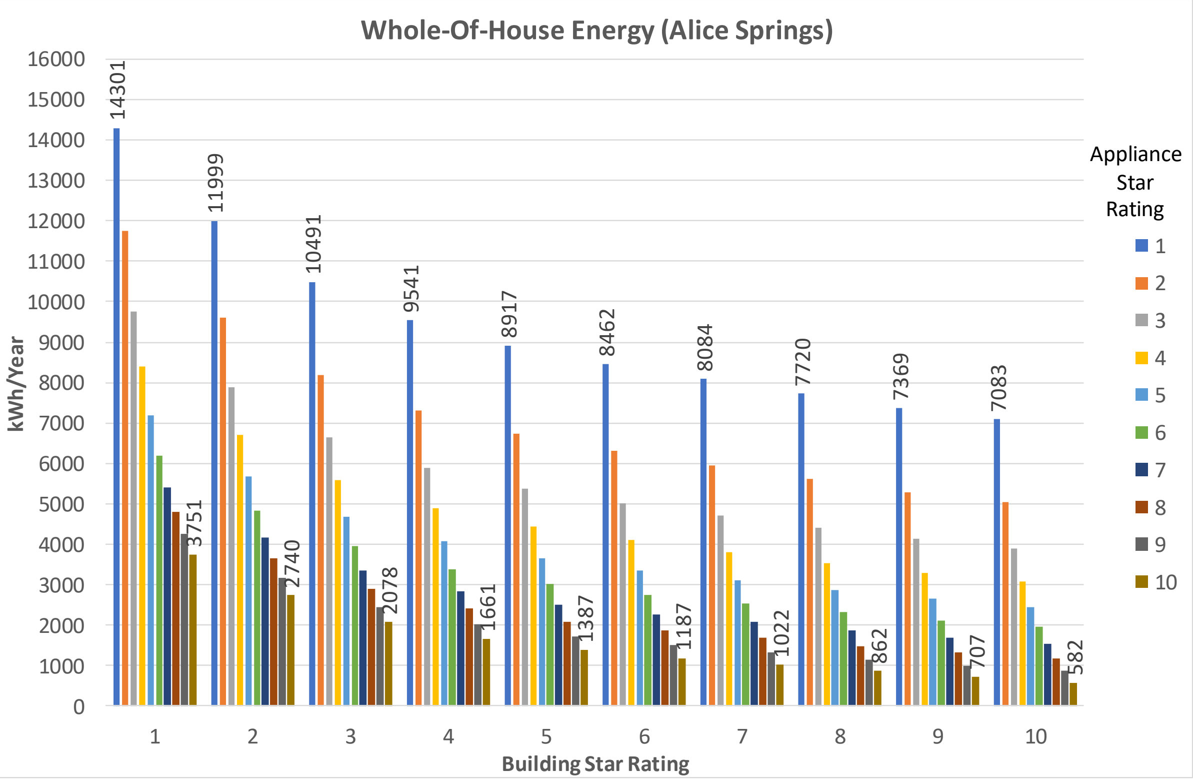


Figure 5-11: Whole-house Energy Metrics for Alice Springs

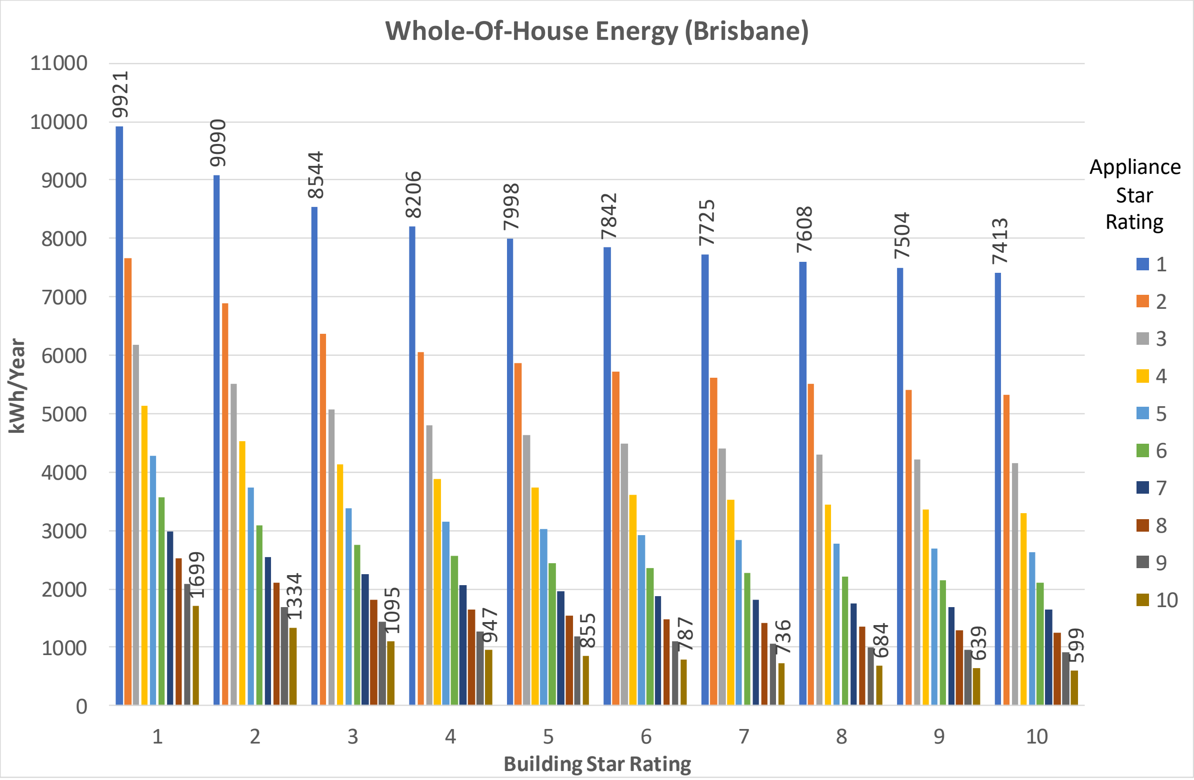


Figure 5-12: Whole-house Energy Metrics for Brisbane

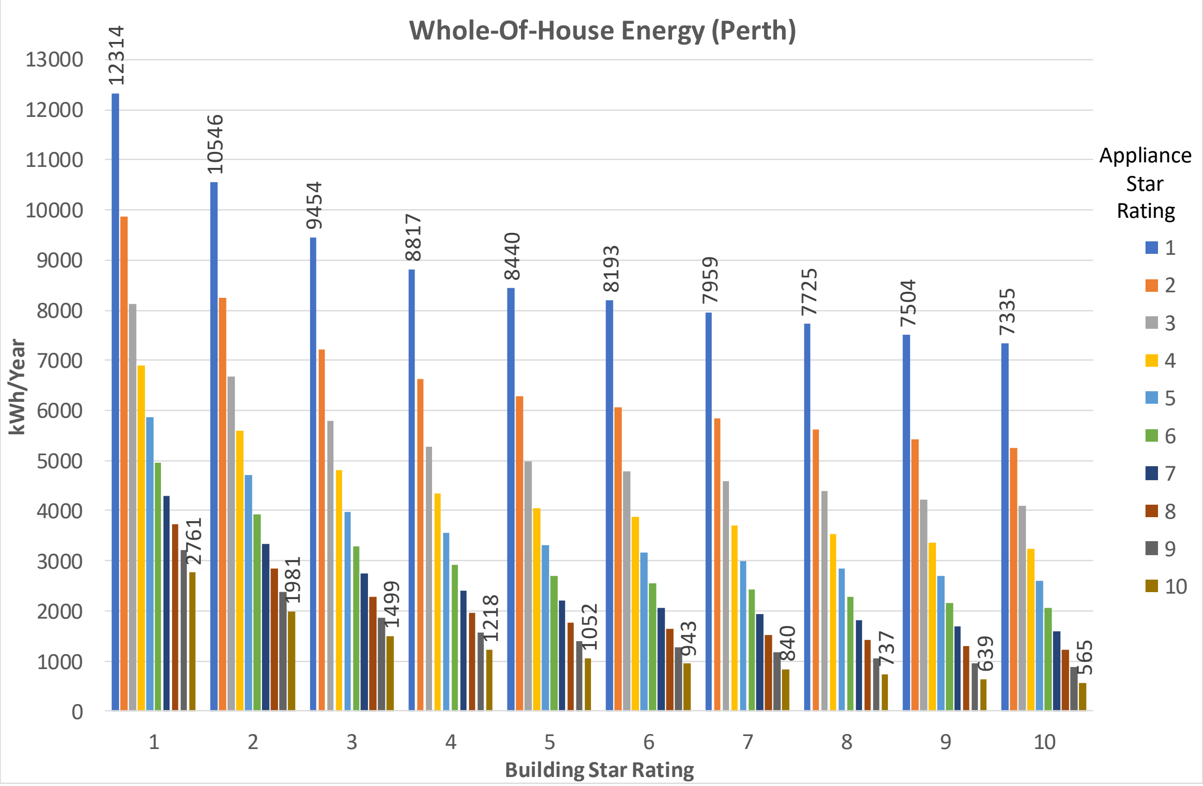


Figure 5-13: Whole-house Energy Metrics for Perth

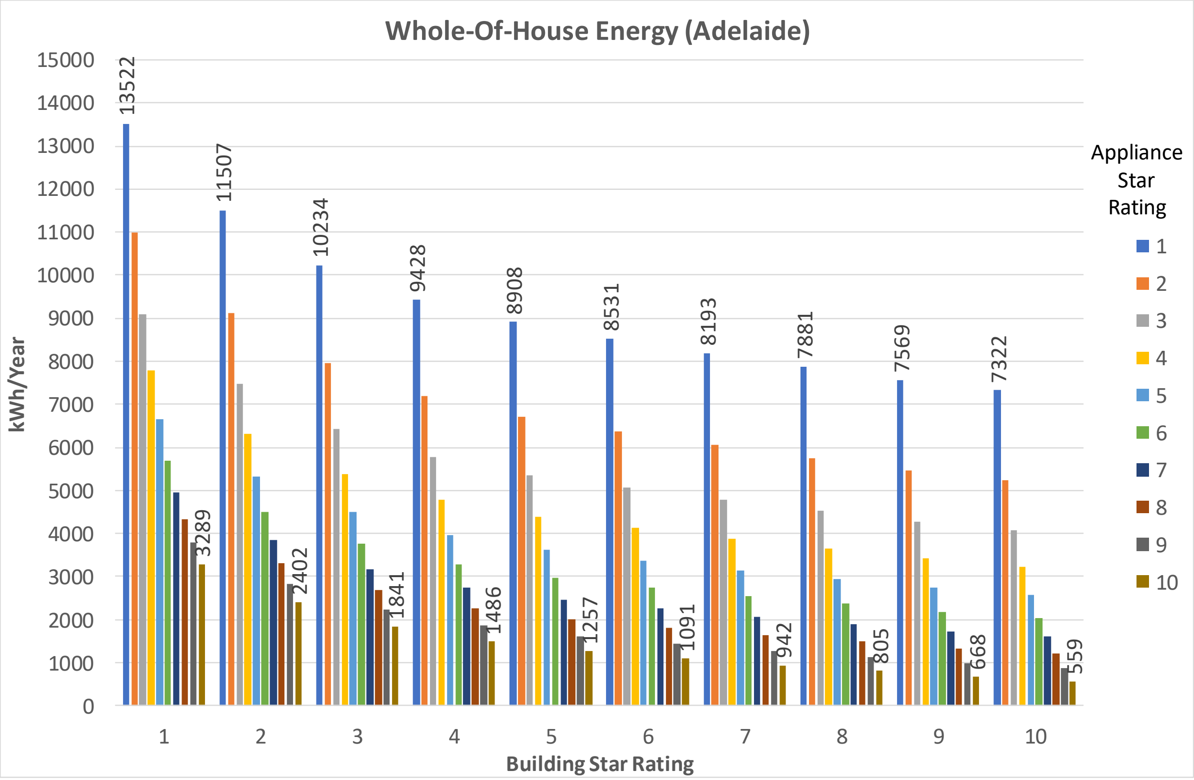


Figure 5-14: Whole-house Energy Metrics for Adelaide

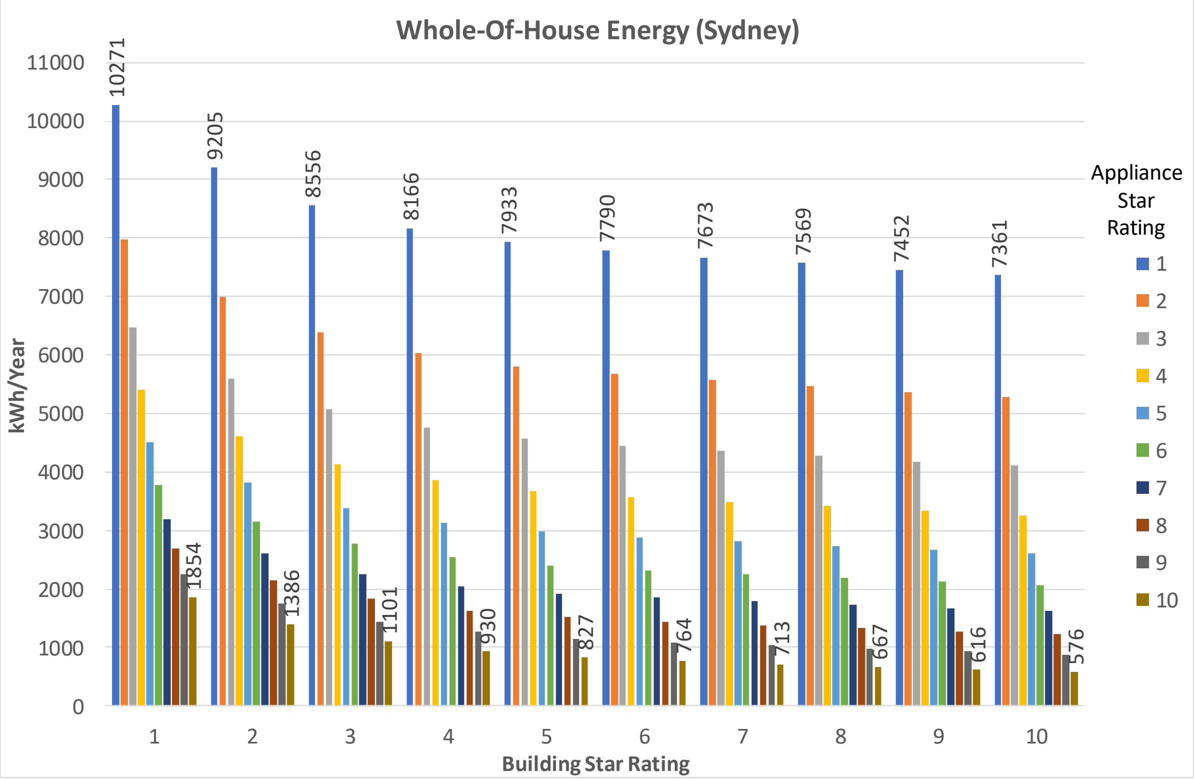


Figure 5-15: Whole-house Energy Metrics for Sydney

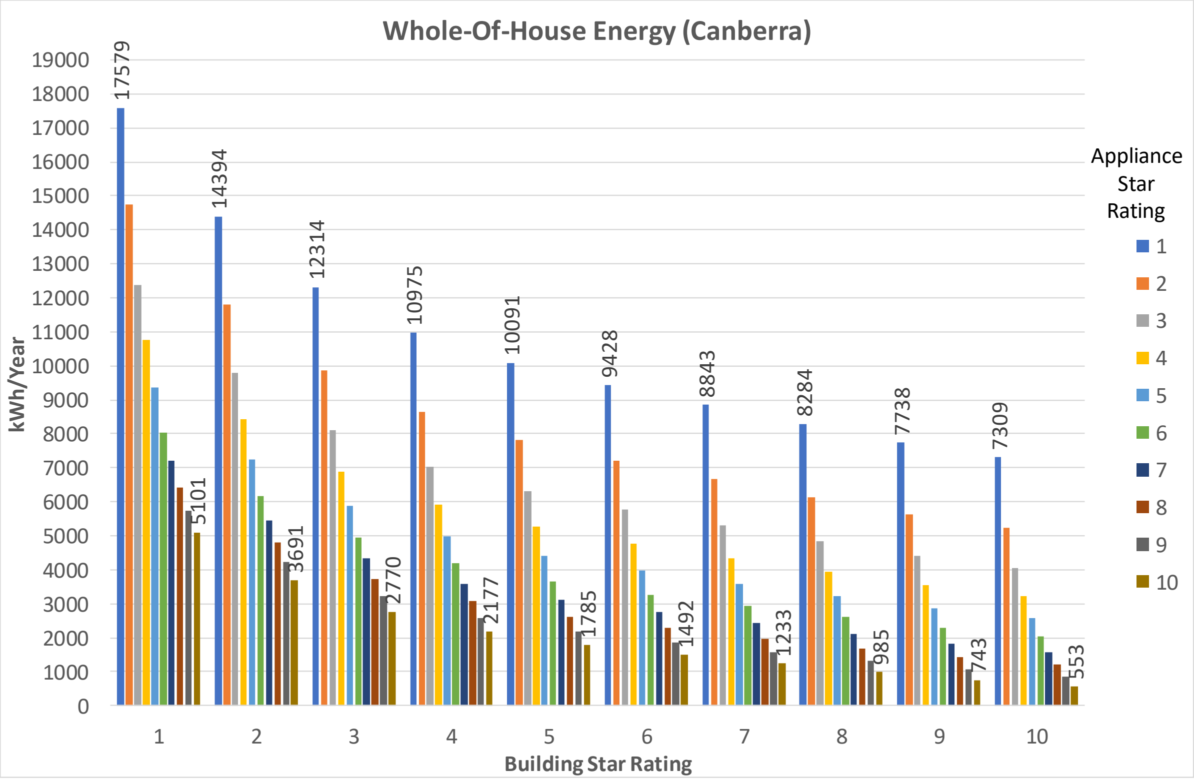


Figure 5-16: Whole-house Energy Metrics for Canberra

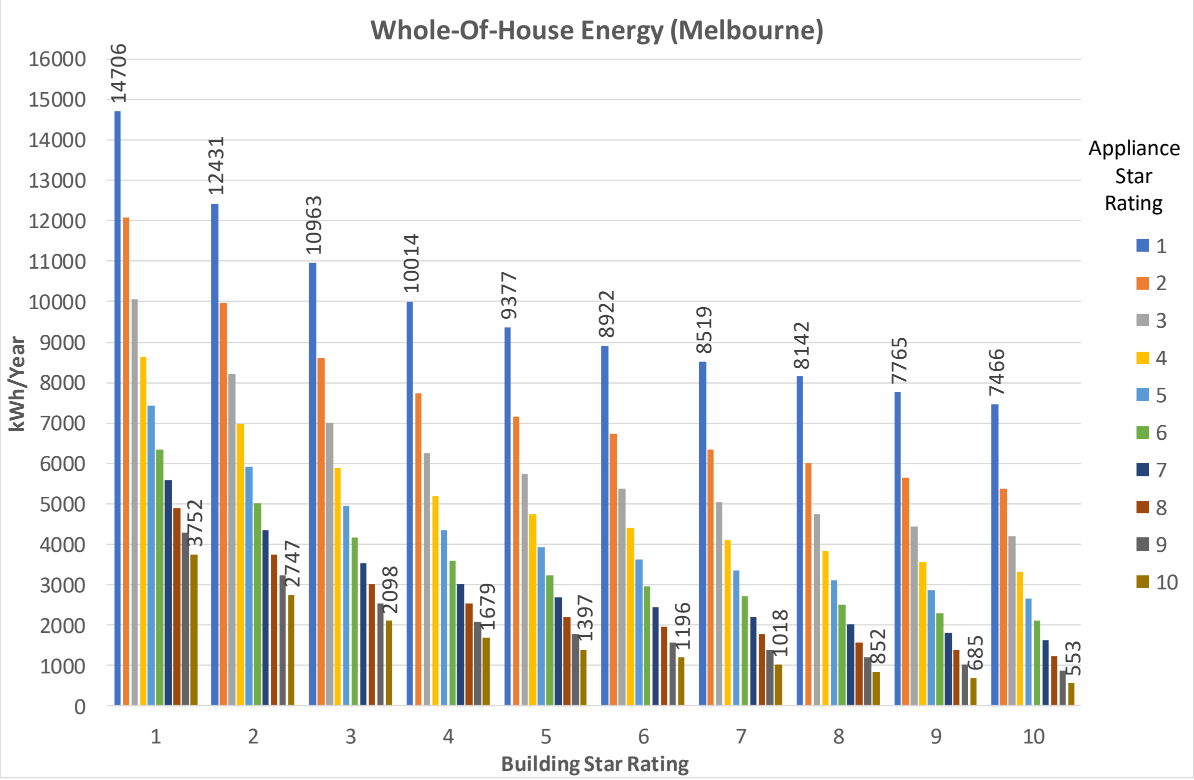


Figure 5-17: Whole-house Energy Metrics for Melbourne

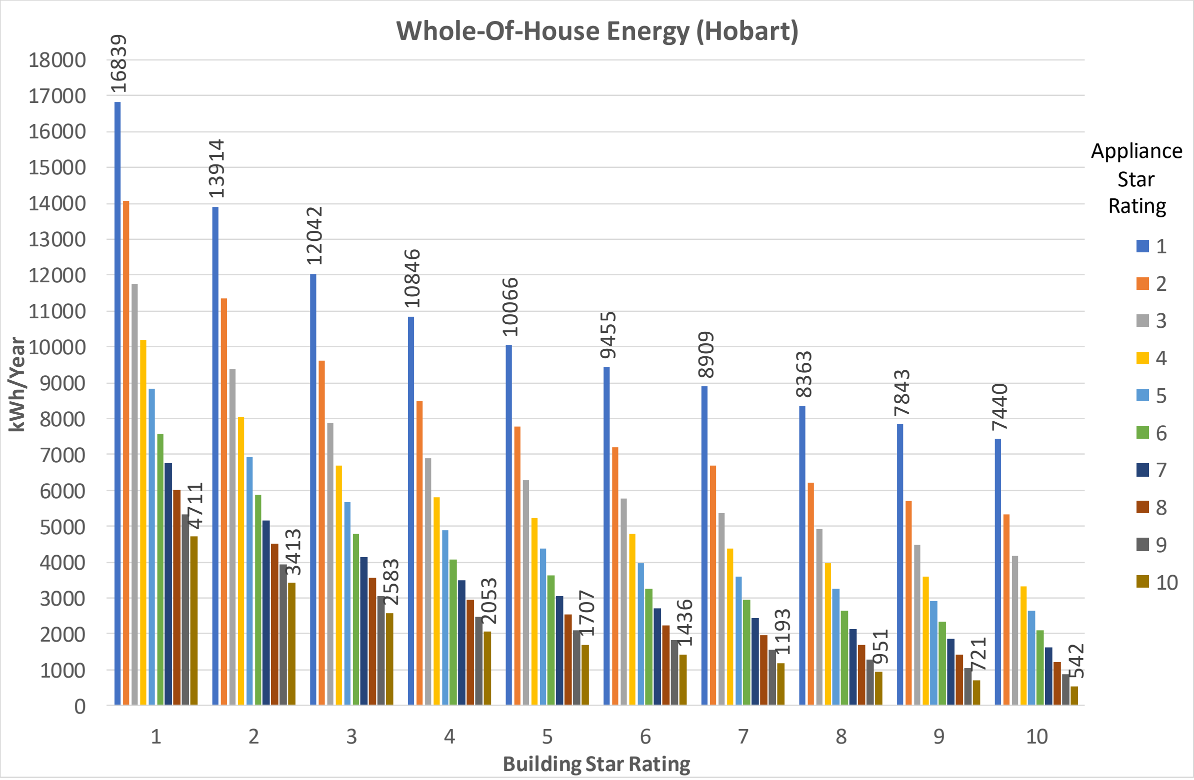


Figure 5-18: Whole-house Energy Metrics for Hobart

5.3 Photovoltaic and Battery Module

As presented in Chapter 7, the growth in on-site renewable on buildings represents a significant component of the energy used in a building. Therefore, integration of this technology within the whole-of-house energy assessment is a critical component to any future Australian assessment scheme.

5.3.1 Proposed Scheme: House Electrical Grid Impact Rating Scheme (HEGIRS)

In a similar manner towards a whole of home star rating, it is proposed to have a similar star rating for a house based on its impact on the electricity grid. Similar to the current NatHERS system, it is proposed that a house will yield a star rating from 0 – 10, based on the amount of energy purchased from the grid. For this reason, the proposed scheme is referred to hereafter as the Household Electrical Grid Impact Rating Scheme (HEGIRS). In contrast to international schemes such as in the US, the proposed scheme is based only on the energy purchased from the grid, and not energy exported to the grid. This will avoid excess solar PV being added to a house, simply to offset energy efficiency measures. Excess solar PV has complex implications for the grid and can negatively impact on GHG emissions as well as house energy costs. It is therefore only reasonable to only allow offset of imported energy consistent with energy efficiency measures. As a result, this methodology is world leading and promotes true, ‘real-time’ or ‘net’ zero grid energy houses. As such the scheme includes the impact of a storage device, such as batteries, given the consensus amongst industry that these will be the next big-ticket item to be included in newly built houses of the future.

Note that in relation to gas usage and other fuels, these can be accounted for on a primary energy basis, however, is not within the scope of this analysis. Gas usage in Australian homes is declining and will have less relevance to whole-of-house energy assessments in the future.

Therefore, once an energy assessment is conducted in relation to building fabric and inclusion of appliances, including that of '*other*' appliances that are traditionally difficult to predict yet can be easily and confidently predicted using machine learning algorithms, a household can reduce its energy purchase from the grid, through the addition of solar PV, delivering a HEGRIS star rating. This rating can be further increased by adding an energy storage device, such as battery.

The framework of the proposed HEGIRS are defined as:

- Star rating of 0 – 10 stars
- 0 stars = all electrical energy is purchased from the grid,
- 10 stars = all energy supplied independent of the grid, and effectively the house operates as a real time zero energy house.
- This star rating is to be based only the energy imported from the grid, and as such it does not factor in the amount of energy exported.

The constraints imposed on the proposed scheme are:

- The scheme will project over 20-year life consistent with the rated lifetime of most solar PV systems.
- The scheme is a projection over a 10-year period, as this corresponds to the expected life of a most battery technologies.
- Appropriate degradation rates are applied for both technologies.

The methodology to be applied involves, the following process:

- Determine household electrical load profile, accounting for estimations of air conditioning and other MEPS appliances. This can be achieved using machine learning algorithms, as successfully demonstrated in Section 4.2.
- Determine PV system energy output, based on installation parameters, such as:
- Inclination (roof pitch) angle,
- Azimuth (compass bearing) angle,
- PV system size and inverter output rating,
- DC central or micro-inverter installation (the latter can produce significantly more output energy for systems where partial shading is expected),
- Shading characteristics of house boundaries. This information can then be inputted into sun path modelling capabilities with AccuRate Sustainability, and the relevant impact on the output accounted for.
- Where a battery is included, account for round trip efficiency and apply conventional reactive control strategy, within the charge/discharge constraints of the battery.

5.3.1.1 Assumptions Regarding Energy and Storage Systems

The following assumptions are recommended regarding the energy generation and storage systems:

- A PV system's output power will degrade by 1%/year, therefore, after 20 years' service it will produce 80% of its rated output power.

- A battery:
- Will be deemed to have a 10-year life,
- Reduce its energy storage capacity by 2%/year, i.e. after 10 years' service it will only be able to store and access 80% of its original rated storage capacity.
- Should hold a minimum state of charge (SOC), typically 20% for a Lithium-Ion battery.
- Has a rated energy, charge and discharge capacity which must be inputted.
- Will be controlled by a simple reactive charge / discharge algorithm, defined as:
- Charge from excess PV energy, before it is exported to the grid,
- Discharge from the battery, before importing from the grid,
- Is assumed to have a round-trip efficiency (takes into consideration the charging and discharging efficiencies) of:
- 90%, for Lithium-Ion types. This implies the charging and discharging efficiencies are both equal to 94.9%.
- 70% for Lead-Acid types. This implies the charging and discharging efficiencies are both equal to 83.7%.
- This parameter may be adjustable to account for other types of battery technologies, such as Flow batteries, which have a round-trip efficiency of about 80%.
- This parameter may need to be account for ambient temperature

Note that the round-trip efficiency is estimated based on battery discharge / charge voltage, an example of which is shown in Figure 5-19, and technical information provided by battery representatives. An appropriate standard methodology needs to be applied to evaluate this efficiency.

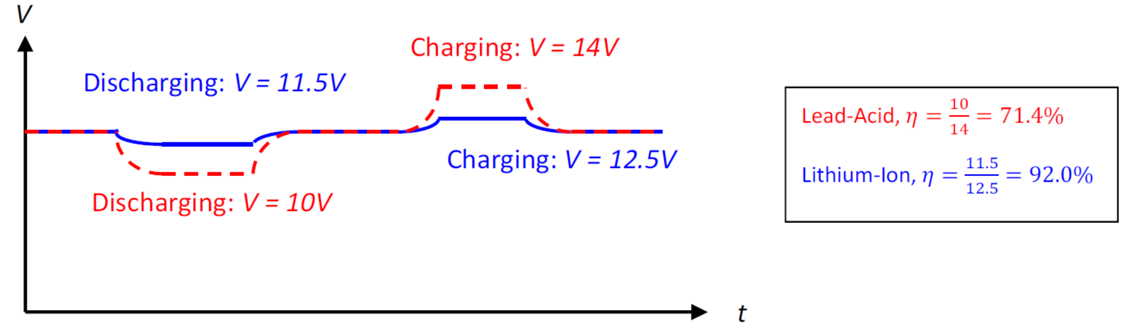


Figure 5-19: Example Voltage vs. time for a 12V lead-acid (dashed red line) and 12V lithium-ion (solid blue line) batteries, during both the discharge and charge states (for a constant current).

5.3.2 Example of Monitored Houses using HEGIRS

To demonstrate the efficacy of the HEGRIS concept, this rating scheme is applied to an all-electric house in the Lochiel Park development simulating the addition of a battery over a year of data in 2011. Monitored data has been collected every minute for the following parameters that are needed to simulate and determine the HEGIRS rating of this house:

- Gross solar PV energy generated,
- Energy imported from the grid,
- Energy exported to the grid,
- Household total energy (and power) profile.

Details of the house are shown below in Table 5-11. This analysis applies a battery capacity of 5 kWh and degradation effects are ignored.

Table 5-11: Characteristics of sample all-electric Lochiel Park house and PV system.

House Properties					**Cooling /Heating Type**	**PV System**		
Dwelling Type	**NatHERS rating**	**Floor Area (m^2)**		**Number bedroom**		**Panel Rating (kW)**	**Inverter Rating (kW)**	**Panel Technology**
		Habitable	**Conditioned**					
Detached	7.9	235.6	165.1	3	Reverse-Cycle	4.2	3.8	Mono-Crystalline

5.3.2.1 Data Frequency

Although the data collected from this house is every minute, NatHERS simulates data based on an hourly basis. These are also different to the time frequency used by retailers to generate electricity bills, which is based on 30-minute intervals. To show the effect of the data frequency on a simulated battery, Figure 5-20 and Figure 5-21 have been produced, which shows a battery State of Charger (SOC) for a sample period, over the following time intervals:

- 1 minute (original data)
- 5 minutes,
- 15 minutes,
- 30 minutes (as used by energy retailers),
- 60 minutes (as used by NatHERS).

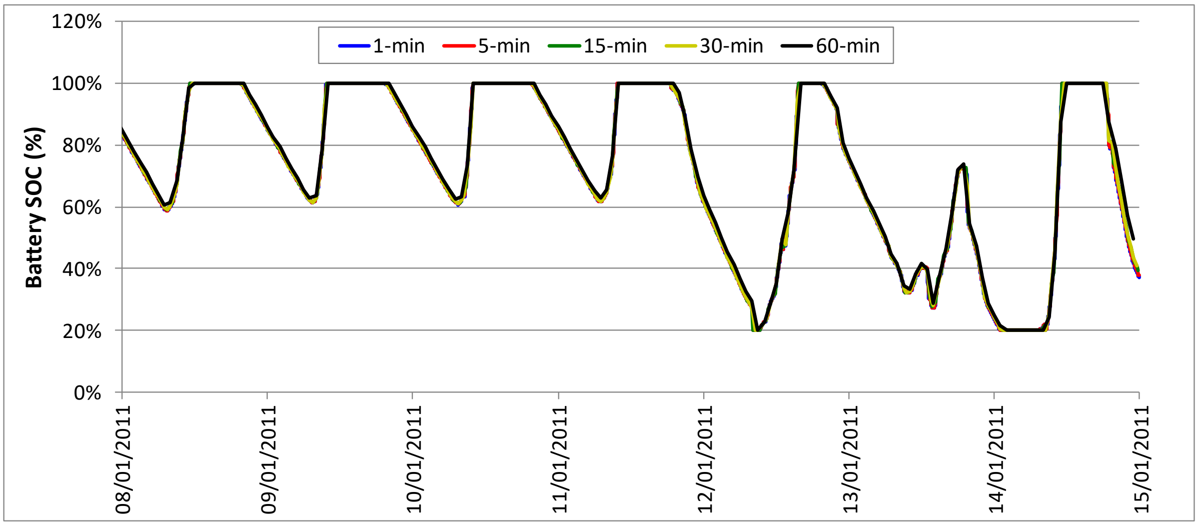


Figure 5-20: Simulated battery State of Charge (SOC) for an all-electric Lochiel Park house, showing the effect of using data at various time intervals.

Fig B: Simulated battery State of Charge (SOC) for an all-electric Lochiel Park house, showing the effect of using data at

Both Figure 5-20 and Figure 5-21, show only a small difference in the simulated battery SOC. Consequently, a time interval of 60 minutes, consistent with NatHERS, should be sufficient to accurately simulate a battery and the impact this has on the household and the electricity grid.

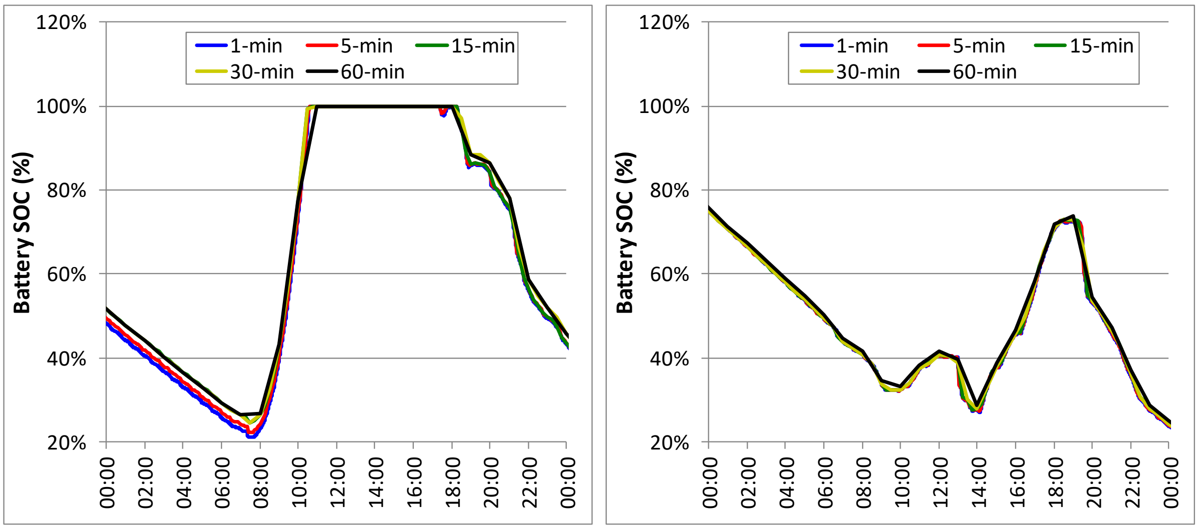


Figure 5-21: Simulated battery SOC for an all-electric Lochiel Park house, showing the effect of using data at various time intervals, for (a) 02-JAN-2011, and (b) 13–JAN-2011.

5.3.2.2 Effect of Battery Round-Trip Efficiency

The effect of the battery round-trip efficiency on the SOC is shown in Figure 5-22 and Figure 5-23, for round trip-efficiencies of 100%, 90%, 80%, 70% and 60%. The figures shows the importance of the round-trip efficiency, highlight how the amount of energy stored in the battery decreases. This is clearly shown at 7pm on 13th JAN 2011. Consider the cases where the round-trip efficiency is 90% and 70%, as these represent typical Lithium-Ion and Lead-Acid batteries, respectively. The difference in battery SOC is 14%, and this could result in the household purchasing significantly more energy from the grid, depending on the type (and hence efficiency of the battery). Consequently, including round trip efficiency is an important parameter to consider the HEGIRS rating.

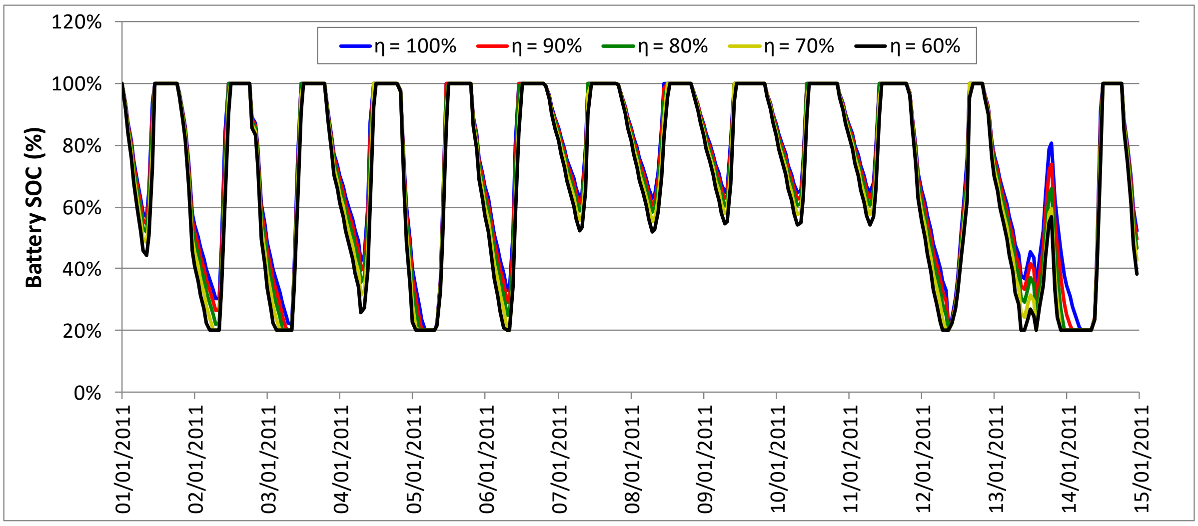


Figure 5-22: Simulated battery SOC for an all-electric Lochiel Park house, showing the effect of varying the round-trip efficiency, over a two-week period (1st – 14th JAN 2011).

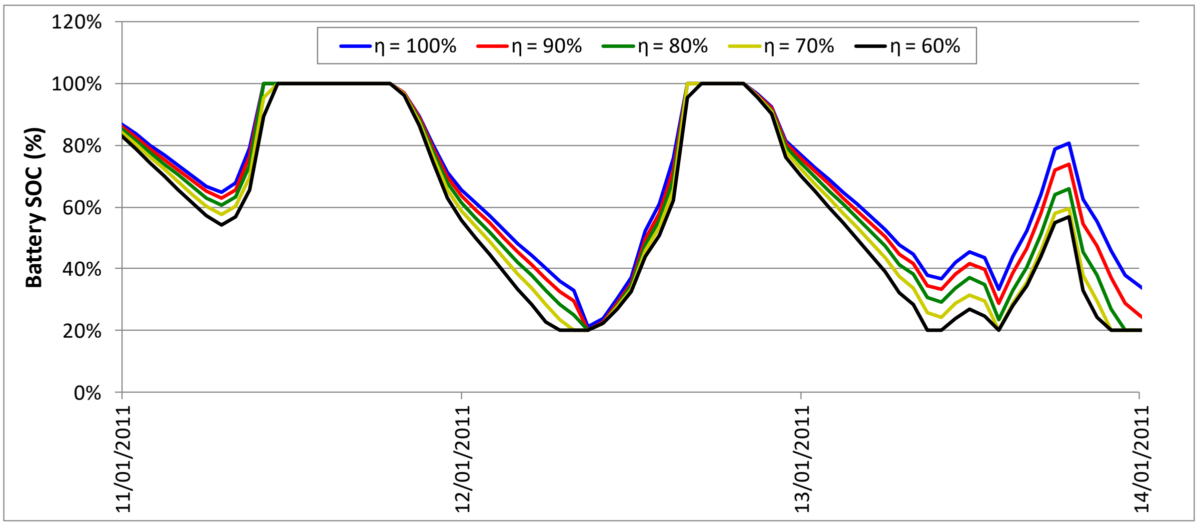


Figure 5-23: Simulated battery SOC for an all-electric Lochiel Park house, showing the effect of varying the round-trip efficiency, over a period of three days (11th – 13th JAN 2011).

5.3.3 Simulation of HEGIRS for Various Battery and PV System Sizes

The previous sections showed the impacts of simulation / monitoring time intervals and the battery round-trip efficiency. The analysis presented hereafter assumes that:

- Data is calculated over an interval of 60 minutes, consistent with NatHERS,
- A Lithium-Ion type battery, with round-trip efficiencies of 60, 70, 80, 90, and 100% are used.
- Battery sizes of 0, 5, and 10kWh are modelled.
- PV system sizes of 50, 100, and 200% of the rated capacity of 3.8 kW$_p$ are modelled (Table 5-11).

5.3.3.1 Impact of Battery Efficiency on Total Household Electrical Load

Figure 5-24 shows the impact of the battery size and efficiency, at different capacity multipliers of the PV system size on the total annual household electrical energy load. For the case of no battery, the total load does not vary, indicated by the red dashed box. When compared to the values in the green and blue dashed box there is an increase in total electrical energy, increasing with lower battery efficiency. For the largest battery, the negative impact of efficiency reduction results in an increase of 25% of total electrical energy use, comparing the most to the least efficient battery.

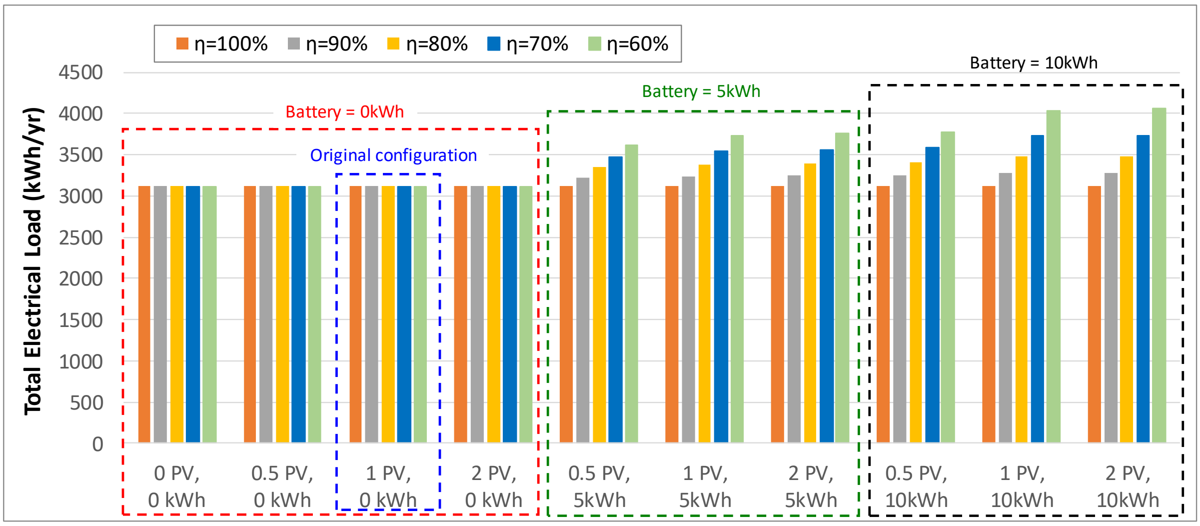


Figure 5-24: Total household electrical imported energy with varying battery size and efficiency, and PV system multiplier size of 3.8 kW$_p$.

5.3.3.2 Impact of Battery Size and PV System Size on Imported Energy

In addition to impacting on the total household electrical load, shown in Figure 5-24, adding a battery and or varying the PV system size, significantly impacts on the imported and exported amount of energy from the system.

Figure 5-25 presents the information from Figure 5-24, for a Lithium-Ion battery that has a round-trip efficiency of 90%, for various PV system sizes (0, 50, 100 and 200% of the original size), and various battery sizes (0, 5, 10kWh). The figure shows how the household can reduce imported energy with no battery by approximately 50%. However adding a battery has a far more significant impact. Note that this house has today what is classed as a small to medium solar PV system size. The average PV system size in 2010 was 1.9kW$_p$, whilst that for 2018 was 6.9kW$_p$ [157].

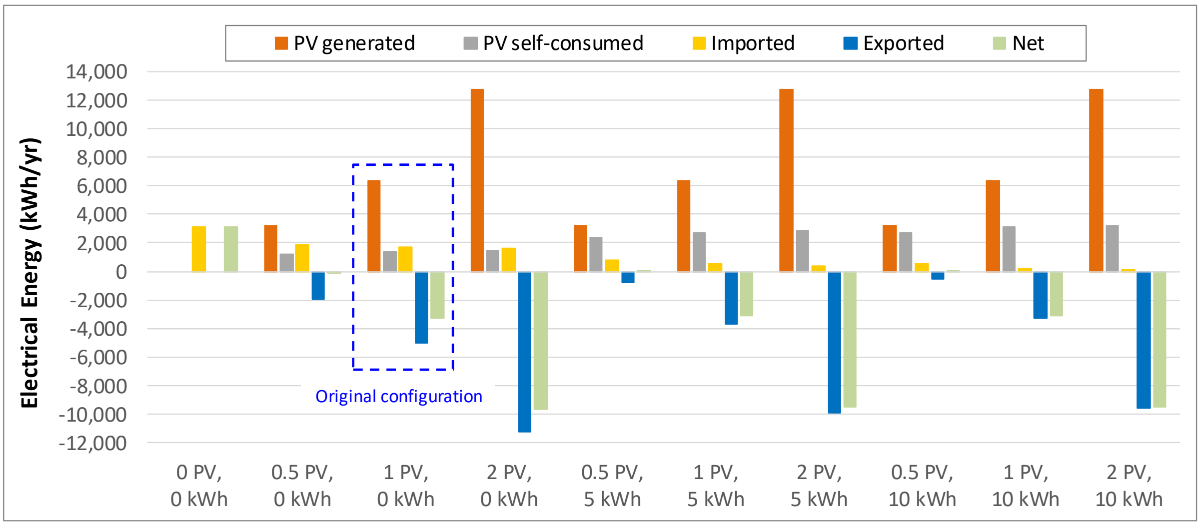


Figure 5-25: Impact of battery and PV system size on PV generated and self-consumed, and imported, exported and net energies.

The information in Figure 5-25 is summarised in Table 5-12, which shows the amount of total energy that was imported from the grid relative to the baseline case of no solar PV/battery system. Applying the star rating metric provided earlier it was possible to determine the HEGIRS star rating that this house would achieve for the cases considered. These proportions and star ratings are shown separately in Figure 5-26.

Table 5-12: Household energies and subsequent star rating under the proposed HEGIRS. Note the row lightly shaded in blue represents the original household performance, i.e. a PV system sized at 100% of the original and has no battery (0kWh).

Battery Size (kWh)	PV Size (%)	PV generated	PV self-consumed	Total	Imported	Exported	Net	Imported / Total	Star Rating
0	0	0.0	0.0	3119.2	3119.2	0.0	3119.2	100.0%	0.0
	50%	3191.0	1230.5	3119.2	1888.8	-1960.6	-71.8	60.6%	3.9
	100%	**6382.1**	**1387.0**	**3119.2**	**1732.2**	**-4995.0**	**-3262.8**	**55.5%**	**4.4**
	200%	12764.1	1496.1	3119.2	1623.2	-11268.0	-9644.9	52.0%	4.8
5	50%	3191.0	2406.7	3223.8	818.1	-785.3	32.8	25.4%	7.5
	100%	6382.1	2724.6	3242.0	518.1	-3658.2	-3140.1	16.0%	8.4
	100%	12764.1	2845.9	3244.0	398.8	-9918.9	-9520.1	12.3%	8.8
10	50%	3191.0	2688.9	3253.6	565.2	-502.6	62.6	17.4%	8.3
	100%	6382.1	3097.7	3281.2	183.9	-3284.8	-3100.9	5.6%	9.4
	200%	12764.1	3175.4	3279.1	104.0	-9589.0	-9485.0	3.2%	9.7

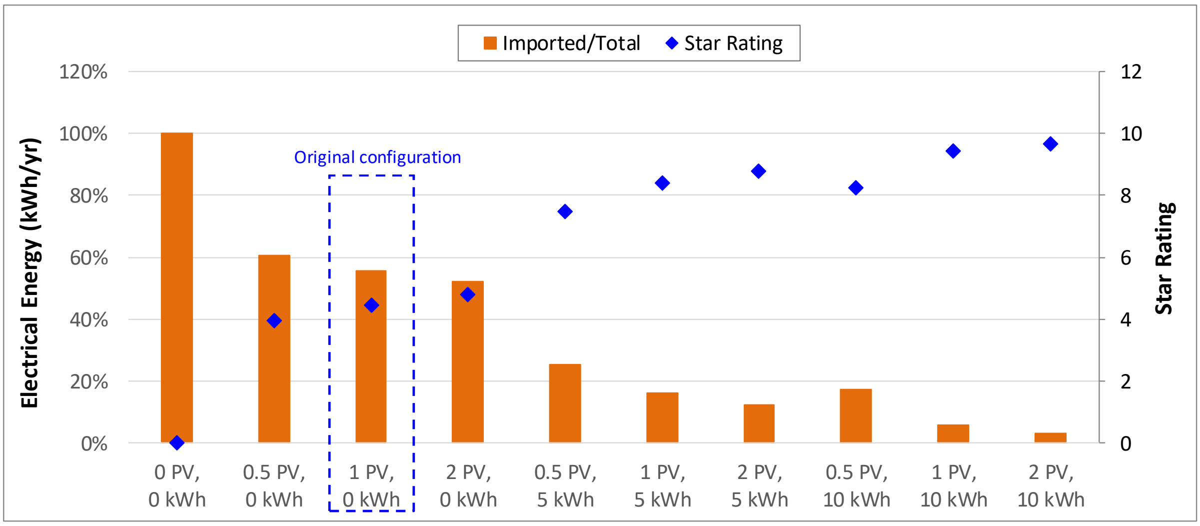


Figure 5-26: Percentage of household total energy imported form the grid, and the subsequent HEGIRS star rating, for various PV system multipliers (3.8 kW$_p$ baseline) and battery sizes.

Figure 5-26 shows how the HEGIRS star rating is dramatically increased by adding battery capacity. The case shown applies to a typical Lochiel Park house, which is representative of an efficient house consistent with the future objective of energy efficiency regulation. For the case shown, the solar PV and battery capacity can be considered typical. Under this scenario, the design nearly obtained 10 stars and ultimately become a true real time net zero energy home. Overall, this result highlights how the goal of zero emission and zero energy is readily achievable.

5.3.3.3 Impact of Battery Size and Efficiency, and PV System Size on Net Energy

The impact on the net power profile that battery and PV system size has, is shown for the house in this case-study, in Figure 5-27, Figure 5-28 and Figure 5-29, for battery sizes of 0, 5 and 10kWh, respectively. These graphs show the various levels of export that are generated, with high peaks during the middle of the day. There are concerns relating to the impact of significant amounts of solar PV exporting during this period on the stability of the distributed network. Increasing solar PV capacity can increase HEGIRS rating, but should not be encouraged at the expense of this stability. The impact of the battery is to reduce this peak export, however this benefit is not rewarded. Export limiting mechanisms do exist for solar PV systems and all new systems will require minimum control. Consideration should be given to rewarding those households who limit exports in a grid supportive approach. It is beyond the scope of this project to suggest an appropriate methodology, however, will be an important consideration for whole-of-house energy assessment with solar PV and battery systems.

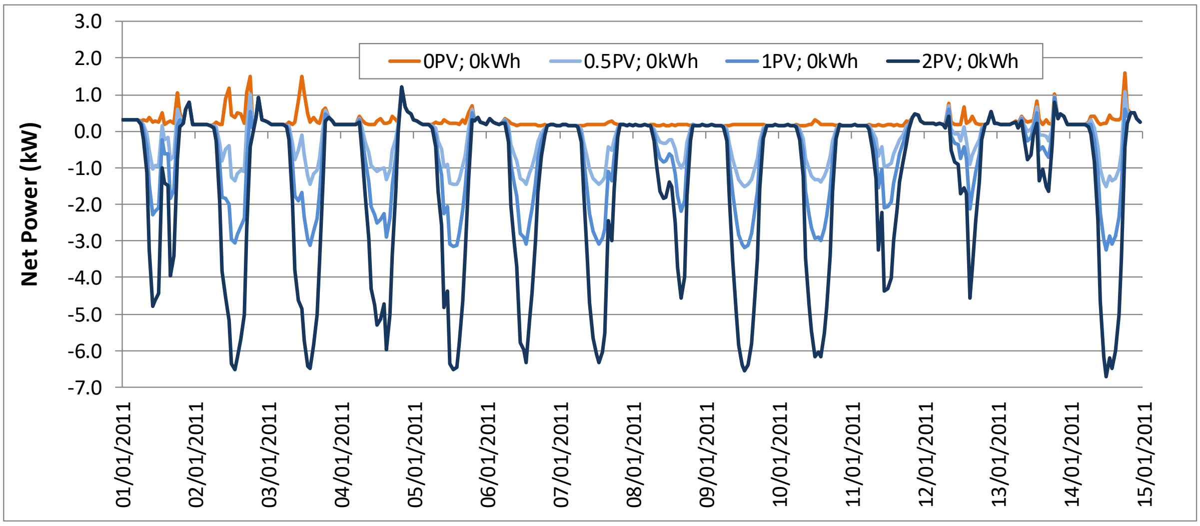


Figure 5-27: Household net electrical power profile for 01-14 JAN 2011, with no battery (0kWh).

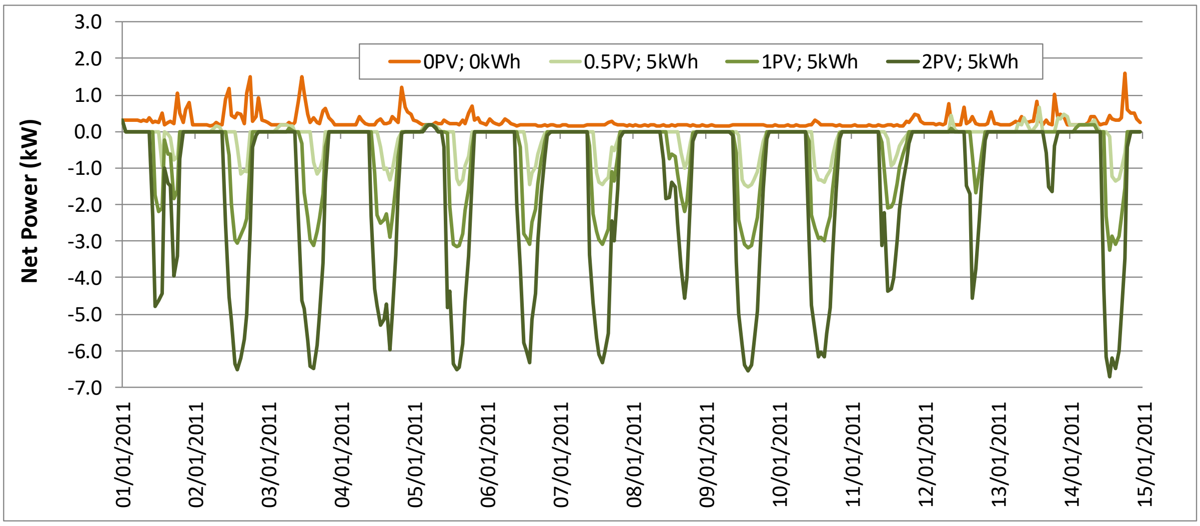


Figure 5-28: Household net electrical power profile for 01-14 JAN 2011, with a 5kWh battery. Note the orange trace represents the household's power profile without PV and without a battery, for reference.

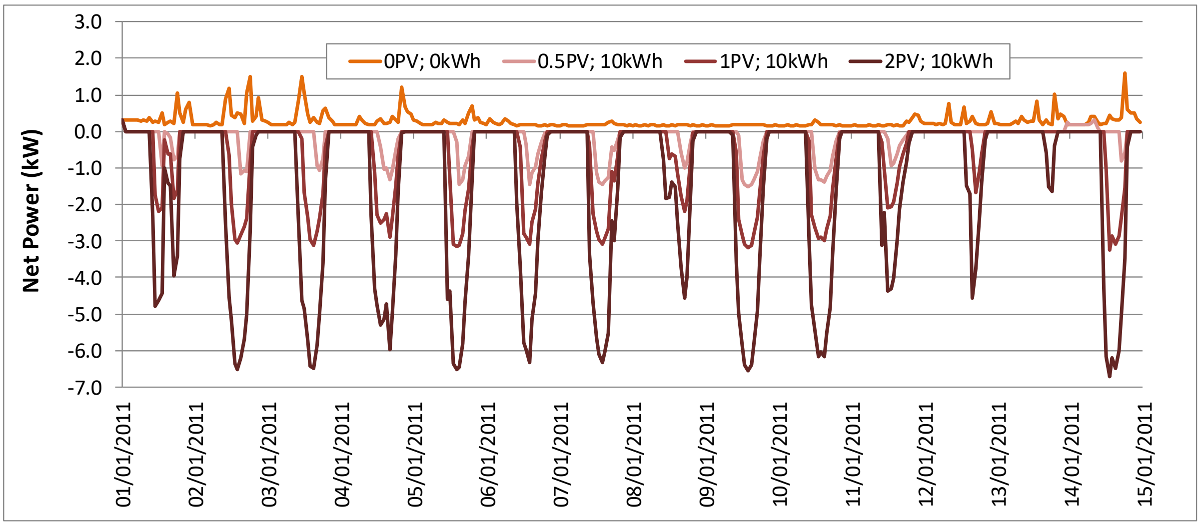


Figure 5-29: Household net electrical power profile for 01-14 JAN 2011, with a 10kWh battery. Note the orange trace represents the household's power profile without PV and without a battery, for reference.

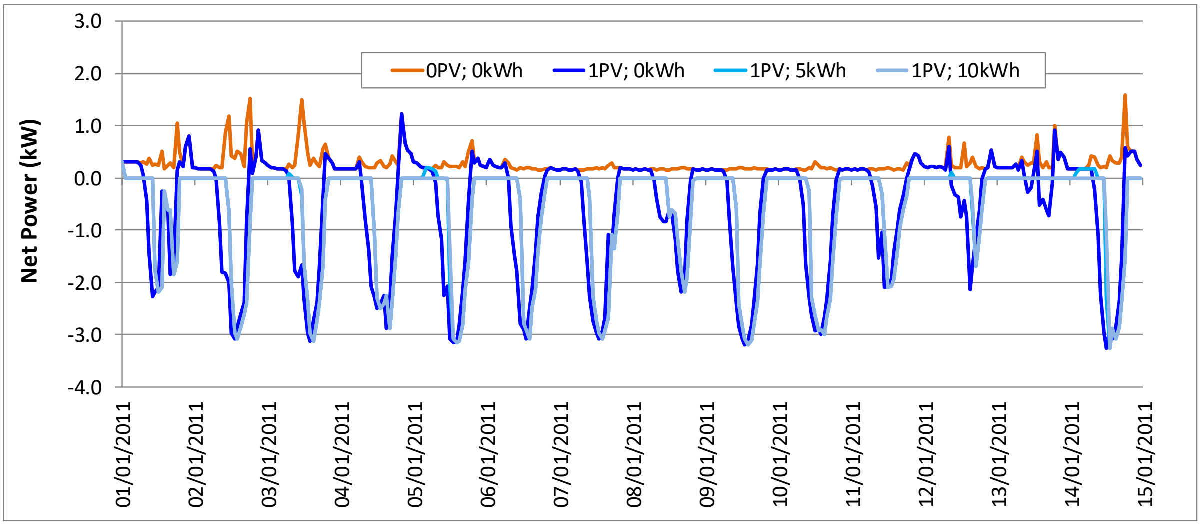


Figure 5-30: Household net electrical power profile for 01-14 JAN 2011, with a constant 3.8 kW_p solar PV and different battery capacities. Note the orange trace represents the household's power profile without PV and without a battery, for reference.

5.3.4 Conclusions

A new household electrical grid impact rating scheme has been proposed, based on the amount of energy that is required to be purchased from the grid. In cases where no onsite energy generation system exists, all of the household electrical energy is purchased from the grid, which corresponds to a HEGRIS star rating of 0. In contrast, if a household does not need to purchase energy from the grid, i.e. it can self-consume all of the PV energy generated, using batteries, then this is equivalent to a 10-star HEGRIS rated house.

The simulation results presented here show the impact of both a PV system and a battery, on reducing the energy purchased from the grid. The results of the simulations highlighted:

- Having a PV system between 50% and 200% of the household's original size, and not having a battery, yielded a HEGIRS star rating of 3.9 – 4.8 stars.

- Having a PV system between 50% and 200% of the household's original size, together with a 5kWh battery, yielded a HEGIRS star rating of 7.5 – 8.8 stars.
- For a house with an existing PV system, the HEGIRS star rating could be increased from 4.4 stars, to 8.4 and 9.4 stars by adding a battery with storage capacities of 5 and 10kWh, respectively.

These outcomes demonstrate how increasing a PV system alone can increase the HEGIRS rating, however the addition of a battery is far more effective, given that this significantly reduces the energy demanded from the grid. Consequently, this scheme is able to support the use of batteries reflecting the growing need for better management of household renewable electricity. This scheme can readily be integrated into a whole-of-house energy assessment scheme. The case study investigated showed that a truly real-time net zero grid energy home is achievable, and that ignoring the impact of household batteries is illogical given the predicted future uptake of these, and the significant impact of reducing a household's HEGIRS star-rating.

5.3.5 Future Work

The HEGIRS concept can be expanded to include demand management techniques, to reduce the impact on the grid. In addition to reducing demand during critical periods such as heatwaves, techniques which reduce exports include:

- Activating air conditioning for managed pre-cooling of the home,
- Diverting energy to a water storage tank, using a resistive electric element or heat pump. This could also be integrated into the MEPS rating of hot water systems.
- Appliances, such as dishwashers, washing machines, refrigerators and pool pumps, which can communicate with a PV system or use solar forecasting algorithm to smartly control themselves.

The analyses presented here did not include the effects of PV output power and battery storage capacity degradation, power charge/discharge limits or system lifetime limitations. To analyse a house (and the HEGIRS) properly, the final star rating would need to consider these effects. Furthermore, it is recommended that, like many other electrical appliances and end-uses, PV and battery systems should be included in existing Greenhouse and Energy Minimum Standards (GEMS) Act 2012 legislation, along with subsequent incorporation into Australian and New Zealand MEPS. During the process of adoption of PV and battery storage system performance into MEPS, it is also recommended that processes allowing the determination of onsite compliance and expected minimum energy generation also form part of the regulatory framework for such systems.

6 Compliance and Metrics

This chapter discusses the items to be disclosed in the universal certificate and the process by which these key and critical house construction and operational aspects are delivered appropriately, in terms of contractual specifications and legislative requirements, to building owners and/or occupants. It is envisaged that the process by which confirmation of whether these critical aspects and components of a building have been successfully delivered, will be undertaken as part of an independent building inspection process. This process must be conducted by an independent professional with appropriate training and associated experience, such as a building inspector with several years of demonstrated practical experience and membership of an associated professional organisation. The process by which a large number of building characteristics are confirmed will require an inspector to make a number of visits to the building, throughout different stages of construction, whilst maintaining regular ongoing communication between the inspector and builder, project manager and client. Compliance of built and installed components and systems with design specifications will be determined, in accordance with the specifications listed in documentation that has been obtained from builders and, wherever possible, approved by relevant government agencies (e.g. local council, Clean Energy Regulator, etc.). Any documentation used to assess building compliance will be known as an Approved Building Reference Document (ABRD) and will include documents such as unamended, local council approved construction plans, site elevations, glazing schedules and supplier and appliance manufacturer specifications. A building inspector will be required to record an installation quality rating for key components of a building, as appropriate, represented by a number between zero and five, as defined in Table 6-1.

Table 6-1: Quality rating system for installation of appliances and building fabric components and systems

Construction & Installation Quality Rating	Definition	Description
0	UNACCEPTABLE (documentation required)	Contravenes NCC requirements and/or intention of manufacturer, in terms of installation and/or operability. Rectification and associated reporting essential, prior to habitation.
1	POOR	Barely acceptable, based on minimum NCC requirements or intention of manufacturer, with rectification recommended.
2	OK	NCC compliant, whilst having attributes that could be improved, with no significant adverse impact on operability.
3	GOOD	NCC compliant and overall quality is sound, in line with the intention of the manufacturer.
4	VERY GOOD	NCC compliant and overall quality is high, in line with the intention of the manufacturer, enhancing operability.
5	EXCELLENT	NCC compliant and overall quality is exceptional, likely exceeding expectation of the manufacturer, optimising operability.

For the purposes of performing their role, each inspector will also require a minimum set of specialised equipment, which is expected to comprise the list contained in Table 6-2. Furthermore, where third party tests have been performed these must be provided to the inspector for confirmation.

Table 6-2: Suggested minimum set of specialised equipment for building inspector

Building Inspector Equipment List (Minimum)	Purpose
Documentation Device (e.g. Tablet or Notebook)	Recording observations, preferably a tablet utilising applications that optimise the efficiency of data recording
Acoustic/dB Meter	Air-conditioner operational noise level
Camera with Thermal Imaging capability	Recording installation quality and issues
Portable Lighting (*e.g.* 'Head Torch')	Visibility, especially in roofspace
Height Visibility Access Assistance Device (*e.g.* Drone, Large Articulated Endoscope, Ladder (>900mm discouraged), *etc.*)	Viewing inaccessible building spaces, including upper-storey roof, attic and upper external walls of building envelope
Enclosed Space Visibility Assistance Device (*e.g.* Slim Flexible Endoscopic Camera, *etc.*)	Improving visibility access to otherwise hidden areas (*e.g.* inaccessible wall cavities, raked ceiling spaces, ductwork, *etc.*)
Air Leakage Detection Device (e.g. Smoke Pen)	Identification of miscellaneous sites of air leakage
Orientation Tool (e.g. Compass)	Confirming specified azimuth of building
Third party blow door test reports and ducting leakage assessment	Confirming that infiltration rates through building and ducting are within specified limits.
Approved Building Reference Documents (ABRD) (e.g. Unamended Council Approved Construction Plans, Deemed To Satisfy Documentation, Site Elevations, Blower Door Test Results, NatHERS energy rating and building reports etc.)	Facilitating clear and unambiguous identification of all locations, within a building and associated site, which are referred to within all associated reporting documentation
NatHERS model, as appropriate	Confirming building specifications and identifying associated discrepancies

It is important that appropriate training of inspectors is conducted to maximise the positive impact of the associated compliance inspection process and prevent undue burden on the builder, homeowner and other stakeholders. Developing a familiarity with NatHERS software and the NatHERS Assessor Handbook should, for example, form a part associated training. Many of the requirements and processes will, however, also require appropriate judgement, to ensure the intent of the requirement is achieved, as opposed to merely achieving procedural compliance. This allowance for accepting judgements, based on experience, should be built into the process and would be revealed through the recording of 'installation quality'.

The requirements and suggested inspection techniques will also require ongoing refinement to maximise their benefit, whilst always aiming to minimise the burden on all process stakeholders. It is recommended that a prescriptive set of requirements are developed, which correspond to the required inspection outcome, to minimise ambiguity and confusion. For example, if a ducting leakage test requires < 10% leakage, then this is identified by a measurement or if the insulation installation quality is based on a visual inspection, then a corresponding sample photograph should be included. This will provide an evidence base for any subjective judgements made by an inspector and should minimise ambiguity associated with interpreting the intent of a given requirement.

Finally, it is recommended that a review and auditing process be developed, to allow information collected by a building inspector to be scrutinised, where this is deemed appropriate by a suitable governing body (e.g. Local Council, Planning Authorities, etc.). This review and auditing process would allow significant objections to specific information, collected in relation to building compliance, to be addressed and rectified, where appropriate.

6.1 Parameters to be included in Universal Certificate

It has been established, through the instigation of this project, that a demonstrated need exists for improved compliance processes and tools, in relation to the residential sector. Specifically, there are a number of significant components and characteristics of a dwelling, in terms of both the building fabric and installed systems and appliances, which should be included in the Universal Certificate, soon to be known as the NatHERS Certificate. This Universal Certificate represents a critical and complementary extension of the existing output of NatHERS software, such as AccuRate Sustainability, which currently lists the predicted space heating load, space cooling load and associated star-rating for a building. The Universal Certificate should extract the relevant heating and cooling load information from NatHERS, along with additional information relating to materials used in construction of the building envelope and associated characteristics, including: insulation; glazing; penetrations; installed fixed appliances, including HVAC equipment, dishwasher, dryer, washing machine, and lighting; infiltration and natural ventilation; and thermal performance during critical peak climactic events. Additional information that is recommended to be added to the Universal (or NatHERS) Certificate was determined based on a number of information streams. This information related to experience of researchers working on the project and colleagues in related fields, literature review and industry engagement, especially communications with highly respected forensic building inspectors, contacted throughout the course of the project. This information will be described in detail, throughout the following sections.

6.1.1 Insulation

A number of different types of insulation can potentially be incorporated into the building fabric, such as wall (external and internal), ceiling, roof and floor/edge insulation. Insulation can also be incorporated into components of appliances and associated systems, such as the pipework of water heating systems. Insulation that forms part of a HVAC ducted system will be discussed in a later section.

The NCC of Australia contains numerous references to the characteristics and requirements of various types of insulation, regarding installation within Australian buildings. This has arisen partly as a result of many identified cases of failure to install sufficient insulation in a manner that facilitates improved building performance. Due to the fact that most buildings and many major appliances rely heavily on the performance of insulation to contribute to the thermal comfort and economic wellbeing of occupants, it is important to recognise this significance and ensure compliance with associated NCC requirements. Part of this recognition should involve the characteristics of all types of insulation that are specified for use within a building, to be listed on the Universal Certificate. The characteristics of each different type of insulation, which are to be recorded as part of the building inspection process, are listed in Table 6-3 below. Information that must be included in the Universal Certificate is highlighted in yellow, whilst the remaining un-highlighted information is included mostly for the purpose of legislative compliance confirmation.

Table 6-3: Insulation characteristics to be included in the Universal Certificate

Insulation Type	**Insulation Material**	**Insulation Thickness**	**Rated R-Value**	**De-rated R-Value (NCC)**	**Thermal Bridging (steel framed)**	**Installation Quality Rating (0-5)**	**Observations**	**Photograph/s**
External Wall	✓	✓	✓	✓	✓	✓	✓	✓
Internal Wall	✓	✓	✓	×	✓	✓	✓	✓
Ceiling	✓	✓	✓	✓	✓	✓	✓	✓
Roof	✓	✓	✓	×	✓	✓	✓	✓
Floor	✓	✓	✓	×	✓	✓	✓	✓
Slab (Base)	✓	✓	✓	×	×	✓	✓	✓
Slab (Edge)	✓	✓	✓	×	✓	✓	✓	✓
Hot Water Pipework	✓	✓	✓	×	×	✓	✓	✓
Air-cond. Pipework**	✓	✓	✓	×	×	✓	✓	✓

** excluding ducting

6.1.2 Fenestration

Fenestration, comprising of building components including glazing, skylights and roof windows, represents a substantial capacity for a building to impact occupants, through factors such as thermal comfort, economic sustainability and overall amenity. It is especially difficult to distinguish between different types of glazing, especially following installation within associated fenestration systems, based on a lack of associated markings and constraints inhibiting visible and physical access. Important factors, such as the U-Value and Solar Heat Gain Coefficient (SHGC) of a fenestration system, must be specified in construction documentation. These values are often especially difficult to confirm, given that systems can be assembled on site and therefore do not incorporate labelling from a manufacturer, with regard to assembled fenestration system performance. Currently, onsite testing of the U-Value and/or SHGC of a particular fenestration system element, or assembled fenestration system, is difficult and impractical. High performance glazing and fenestration systems may include etched markings on the glazing, which can be used to confirm performance, however this is uncommon in most buildings. The characteristics of each fenestration system, which are to be recorded as part of the building inspection process, are listed in Table 6-4 below. Information that must be included in the Universal Certificate is highlighted in yellow, whilst the remaining un-highlighted information is included mostly for the purpose of legislative compliance confirmation.

Table 6-4: Glazing characteristics to be recorded, with those highlighted to be included in the Universal Certificate

Fenestration System Type	**Location (Reference to ABRD)**	**U-Value**	**SHGC Value**	**Overall Glazing Thickness**	**Orientation**	**Installation Quality Rating (0-5)**	**Observations**	**Photograph/s**
Single Glazing	✓	✓	✓	✓	✓	✓	✓	✓
Double Glazing	✓	✓	✓	✓	✓	✓	✓	✓
Skylight	✓	✓	✓	×	✓	✓	✓	✓
Roof Window	✓	✓	✓	✓	✓	✓	✓	✓

6.1.3 Penetrations and Gaps

There are countless penetrations made through the building fabric, between external and other internal spaces. Penetrations introduce the potential for unwanted ingress and outgress of air and moisture, which can have significant negative impacts, in terms of the effect on occupant health and wellbeing, thermal comfort and associated energy efficiency of the building. All penetrations in a building that may allow ingress of unwanted moisture/water into areas, such as ceiling spaces, wall cavities and sub-floor spaces, can both introduce and promote the growth of organisms, such as fungi, as well as cause building materials to degrade and decay. In turn, organisms such as fungi, may adversely impact indoor air quality, for example by introducing a sustained source of potentially neurotoxic by-products into the internal environment of a building. The characteristics of each designed penetration to a building, which are to be recorded as part of the building inspection process, are listed Table 6-5 below. Information that must be included in the Universal Certificate is highlighted in yellow, whilst the remaining un-highlighted information is included mostly for the purpose of legislative compliance confirmation.

Table 6-5: Penetration characteristics to be included in the Universal Certificate

Penetration Type	**Location (Reference to ABRD)**	**Function of Penetration**	**Sealing System Type/IP Rating**	**Sealing System Life Expectancy**	**Consequence of Failure**	**Installation Quality Rating (0-5)**	**Observations**	**Photograph/s**
Roof	✓	✓	✓	✓	✓	✓	✓	✓
External Wall	✓	✓	✓	✓	✓	✓	✓	✓
Floor	✓	✓	✓	✓	✓	✓	✓	✓
Window frames	✓	✓	✓	✓	✓	✓	✓	✓

6.1.4 Building Membranes, Infiltration and Natural Ventilation

The importance of air-quality in a building, including moisture control, becomes more critical with decreasing availability of passive natural ventilation through gaps, as the overall level of building sealing increases. Building membranes have a highly significant potential to significantly impact critical factors of building performance, including thermal performance, moisture control and air infiltration. The characteristics of all building membranes, including building wraps and reflective foils, which are to be recorded as part of the building inspection process, are listed in Table 6-6 below. Information that must be included in the Universal Certificate is highlighted in yellow, whilst the remaining un-highlighted information is included mostly for the purpose of legislative compliance confirmation.

Table 6-6: Building membrane characteristics to be included in the Universal Certificate

Building Membrane Type	**Location (Reference to ABRD)**	**Manufacturer (as appropriate)**	**Function (e.g. Vapour Control, RFL)**	**Functional Life Expectancy**	**Consequence of Failure**	**Installation Quality Rating (0-5)**	**Observations**	**Photograph/s**
Foil	✓	✓	✓	✓	✓	✓	✓	✓
Moisture Control Membrane	✓	✓	✓	✓	✓	✓	✓	✓

6.1.5 Installed and Fixed Appliances and Systems, Including HVAC Equipment

Installed and fixed appliances that will be considered for the purposes of the Universal Certificate include HVAC equipment, such as: reverse cycle air-conditioners and associated ductwork for space heating and cooling; mechanical ventilation systems aimed at maintaining indoor air-quality; exhaust fans for extraction of moist air from wet areas; range-hoods; and ceiling fans. Other appliances that will be considered either as part of the building inspection process or for the purposes of the Universal Certificate include: dishwashers; fixtures associated with the installation of washing machines and clothes dryers; ovens; lighting systems.

Saman et al. [54] presents research which shows that installed ducted systems through poor insulation and installation causing leakage nearly double the energy used by the air conditioner, which adversely affects total cooling energy as well as presents overheating risks during heatwaves. In SA, a ducting inspection process is a component of the ducting replacement opportunity under the Renewable Energy and Energy efficiency Scheme. This inspection process involves the use of a modelling rating tool. However, a simple low cost option could involve requiring a leakage balance testing using a flow-hood as is currently done in the commercial air conditioning sector to ensure minimum leakage. This could be incorporated within any blower door testing program.

Information relating to installed and fixed appliances, which is to be recorded as part of the building inspection process, is listed in Table 6-7 below. Information that must be included in the Universal Certificate is highlighted in yellow, whilst the remaining un-highlighted information is included mostly for the purpose of legislative compliance confirmation.

Table 6-7: Characteristics of installed appliances and systems to be determined and recorded

Installed Appliance/ System Type	Description of Characteristics to be Determined
HVAC Equipment	Confirmation of all installed system and component details (e.g. type, model no., capacity, ductwork R-value, etc.), as specified in ABRD
	Adequate space for ventilation provided around air-conditioner condenser units, as appropriate
	All refrigerant pipework, as appropriate, correctly insulated
	Confirmation of correct location of supply and return ducts, as appropriate, relative to ABRD
	Measurement of operational acoustic/noise levels, as appropriate
	Confirmation that all air extraction systems are ducted outside of building envelope, as appropriate
	Confirmation of adequate leakage test and test result of ducted system
	Confirmation of rated R value of ducting insulation conforms to NCC
	Confirmation that all mechanical ventilation systems are installed and configured in accordance with all specifications listed in ABRD
	Installation quality rating (0-5) associated with all HVAC equipment and systems
Water Heating Systems (All)	Confirmation of installed system details (e.g. star rating, type, model no., capacity, etc.), as specified in ABRD
	Estimated maximum distance travelled by heated water
	Installation quality rating (0-5) associated with all water heating systems
Solar Water Heating Systems	Orientation (azimuth and altitude) and location of solar collectors, relative to ABRD
	Insulation of all circulation system pipework
	Correct operation of circulation pump and other control system components
Lighting Systems	Confirmation of installed lighting system details (e.g. type, model no., capacity, etc.), as specified in ABRD
	Location and estimated area of insulation affected by each lighting system and/or luminaire, as appropriate, relative to ABRD
	Installation quality rating (0-5) associated with all lighting systems
Dishwashers	Confirmation of installed system details (e.g. MEPS star rating, type, model no., etc.), as specified in ABRD
	Hot water connection present, as required
	Installation quality rating (0-5) associated with all dishwashers
Ovens	Confirmation of installed system details (e.g. type, model no., etc.), as specified in ABRD
	Installation quality rating (0-5) associated with all ovens
PV Energy Generation Systems	Confirmation of installed system details (e.g. type, model no., capacity, etc.), as specified in ABRD
	Orientation of solar panels, relative to ABRD
	Installation quality rating (0-5) associated with all PV systems
	Monitoring system allowing comparison between actual and theoretical daily output power
Fixtures	Presence of insulated hot water connection for installation of appliances, including dishwasher and clothes washer, as appropriate
	Presence of penetration and associated ductwork to outside of building envelope for clothes dryer installation, and extraction of associated moist and/or hot exhaust air, as appropriate
	Presence of drainage pathway for condenser type clothes dryer, as appropriate
	Installation quality rating (0-5) associated with all fixtures considered

6.2 Methodology and Metrics for Building and Universal Certificate Compliance Check

The methodology for collecting data, which are required for the purpose of confirming compliance against the various specifications relating to a building, are detailed in Table 6-8. Data collected throughout this process, along with data that is recommended to be collected for informative purposes, could also be relevant to related subsequent processes, including auditing of a building inspection outcome or report.

Table 6-8: Metrics to be inspected for compliance of construction or renovation

Component/ Characteristic	Requirement	Methodology	Alternative
Insulation Systems (General)			
External Wall Insulation	Verify and document agreement with construction specifications, following installation, but prior to plasterboard installation and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, measure thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other distinguishing characteristics, especially the potential for thermal bridging. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging, where visual inspection was not undertaken at the appropriate stage of construction, with written and photographic documentation.
Internal Wall Insulation	Verify and document agreement with construction specifications, following installation, but prior to plasterboard installation and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, measure thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other distinguishing characteristics, especially the potential for thermal bridging. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging, where visual inspection was not undertaken at the appropriate stage of construction, with written and photographic documentation.
Ceiling Insulation	Verify and document agreement with construction specifications, following installation and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, measure thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other distinguishing characteristics, especially the potential for thermal bridging. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection not carried out at appropriate stage and no longer possible (e.g. flat rooves, raked ceilings), with written and photographic documentation.
Roof Insulation	Verify and document agreement with construction specifications, following installation and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, measure thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other distinguishing characteristics. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection not carried out at appropriate stage and no longer possible (e.g. flat rooves, raked ceilings), with written and photographic documentation.
Floor Insulation	Verify and document agreement with construction specifications, following installation and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, measure thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other distinguishing characteristics. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection not carried out at appropriate stage and no longer possible (e.g. flat rooves, raked ceilings), with written and photographic documentation.

Slab (Base) Insulation	Verify and document agreement with construction specifications, at the earliest possible stage, e.g. prior to pouring slab and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, record rated R-Value, measure insulation thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other significant visible and distinguishable characteristics, especially the potential for thermal bridging. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging, as appropriate, with written and photographic documentation.
Slab (Edge) Insulation	Verify and document agreement with construction specifications, at the earliest possible stage, e.g. prior to pouring slab and rate quality of installation.	Visually inspect installed insulation and associated purchasing information, record rated R-Value, measure insulation thickness and document photographically. Assess associated likelihood of compliance based on purchasing documentation, thickness, appearance, texture and any other significant visible and distinguishable characteristics, especially the potential for thermal bridging. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging, as appropriate, with written and photographic documentation.
Hot Water Pipework Insulation	Verify and document agreement with specifications, following installation and rate quality of installation.	Visually inspect installed hot water pipework and associated insulation, including all solar loops, measure and document thickness, appearance and any other distinguishing characteristics and assess associated likelihood of compliance. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection not carried out at appropriate stage and no longer possible (e.g. after plasterboard installed), with written and photographic documentation.
Air-Cond. System Pipework Insulation	Verify and document agreement with manufacturer specifications, following installation and rate quality of installation.	Visually inspect installed refrigerant pipework and associated insulation, measure and document thickness, appearance and any other distinguishing characteristics and assess associated likelihood of compliance. Record installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection not carried out at appropriate stage and no longer possible (e.g. after plasterboard installed), with written and photographic documentation.
Glazing	Verify and document agreement with glazing specifications, following installation and rate quality of installation.	Visually inspect all installed glazing and associated purchasing information, measure thickness as required and document photographically. Assess associated likelihood of compliance based on purchasing documentation, etched markings, thickness (as appropriate), appearance and any other distinguishing characteristics. Record installation quality rating and provide brief written and photographic observations.	
Infiltration	ATTMA accredited blower door test and associated report.	Blower door testing in accordance with ATTMA recommendations. Assess associated mechanical ventilation requirements, based on reported results. Need for follow-up operational assessment of installed mechanical ventilation system.	
Natural Ventilation	Assess the appropriateness of controlled and uncontrolled natural ventilation, relative to the associated climate zone.	Where blower door test results yield ACH<5, ensure that an appropriate mechanical ventilation system has been adequately specified and is properly installed.	

Building Membranes	Assess the appropriateness and installation of building membranes, such as wraps and foils, relative to the associated climate zone.	Visually inspect membrane surface, especially at joins, document each type and associated orientation (i.e. inward and outward facing side) and identify sites of likely or potential moisture and/or air leakage. Document installation quality rating at each location, assess likelihood of design performance and provide brief written and photographic observations.	Blower door testing may provide evidence, in relation to air-leakage of building wraps, however obtaining retrospective evidence of moisture leakage would be far more difficult.
Penetrations and Gaps	Locate and document any potential sites of water ingress and air leakage throughout the building envelope and rate quality of installation.	Visually inspect all building envelope penetrations for weaknesses, e.g. improperly installed building systems such as flashing, penetrations due to installation of appliances, plumbing and electrical work and all other potential sites and sources of water ingress or air leakage. Assess likelihood and potential source or cause of water ingress and/or air leakage along with associated installation quality rating at each location and provide brief written and photographic observations.	Testing, including blower door, thermal imaging, water spray and other testing, as required, with written and photographic documentation. Verify that issues have been addressed with photographic evidence, or updated blower door test results / thermal images.
Installed and Fixed Appliances	Verify and document agreement with appliance specifications and peak thermal requirements (as required) and rate quality of installation.	Visually inspect all fixed appliances and associated purchase documentation. Assess likelihood of performance to design specifications, record installation quality rating and provide brief written and photographic observations of associated issues.	
Ducting Systems (General)			
Space Heating Ducting	Verify and document agreement with specifications relating to both heating appliance and ductwork and rate quality of installation.	Visually inspect installed ductwork and purchasing documentation. Measure and/or assess likelihood of leakage and associated level of performance, utilising flow-hood measurements to a level of < 10%. Record appropriate dimensional measurements, installation quality rating, brief written and photographic observations.	Thermal imaging where visual inspection was not carried out at appropriate stage and no longer possible (e.g. flat rooves, raked ceilings), with written and photographic documentation.
Space Cooling Ducting	Verify and document agreement with specifications relating to both cooling appliance and ductwork and rate quality of installation.	Visually inspect installed ductwork and purchasing documentation. Measure and/or assess likelihood of leakage and associated level of performance, utilising thermal imaging technology, as appropriate. Record appropriate dimensional measurements, installation quality rating and provide brief written and photographic observations.	Thermal imaging where visual inspection was not carried out at appropriate stage and no longer possible (e.g. flat rooves, raked ceilings), with written and photographic documentation.
Ventilation Systems (General)			
Mechanical Ventilation Systems	Verify and document agreement with system and associated installation specifications and rate quality of installation.	Visually inspect installed mechanical ventilation systems and purchasing documentation. Measure any relevant characteristics and assess the likelihood of performance to design specifications, in parallel with follow-up blower door testing. Record installation quality rating and provide brief written and photographic observations.	Where inaccessible, assess ducting pathway using camera or other appropriate tools, with written and photographic documentation.

Exhaust Fans and Range-hoods	Verify and document agreement with appliance and installation specifications and rate quality of installation.	Visually inspect installed exhaust fans and associated purchasing documentation, ensure that they are adequately sealed whilst not operational and ducted outside the building envelope (as appropriate). Record installation quality rating and provide brief written and photographic observations.	Where inaccessible, assess ducting pathway using camera or other appropriate tools, with written and photographic documentation.
Ceiling fans	Verify and document agreement with appliance and installation specifications and rate quality of installation.	Visually inspect ceiling fans and purchasing documentation. Measure diameter, assess their likelihood of achieving design performance, record installation quality rating and provide brief written and photographic observations.	

6.3 Sample Universal Certificate

A number of additions and modifications to the Universal Certificate, soon to be known as the NatHERS certificate, are required in relation to metrics that have been recommended for inclusion, as listed throughout this section.

Additional information, to incorporate recommendations made in Section 6.1.1 relating to insulation, is contained in Table 6-9. It is recommended that this table be included in the updated Universal (NatHERS) Certificate. This table shows the “Building Element ID”, building “Element Type”, “Insulation Material”, “R-Value”, insulation “Thickness”, as listed in AccuRate Sustainability, along with, as-built, thermal bridging locations and installation quality rating (IQR) for all types of insulation employed in construction.

Table 6-9: Universal (NatHERS) Certificate additional information relating to insulation characteristics

Insulation characteristics						
Building Element ID	**Element Type**	**Insulation Material**	**R-Val.**	**Thickness (mm)**	**Thermal Bridge Location**	**IQR**
Cust-BV-123-Ac	Ext Wall	Rockwool	R2.5	83	Living North	2
Plasterboard-on-Studs-R3.0	Int. Wall	Glassfibre	R3.0	99	Kit/liv, Br1, Br2	1
Plasterboard-on-Studs-R4.0	Ceiling	Glassfibre	R4.0	176	Br1, Br3, Bath	1
Roof(Insulated)	Roof	Cellular	R0.14	7	None	4
Floor-Insul-R1.5	Floor (Upper)	Polyurethane	R1.0	28	Br1, Br3	1
300mmWafflePod-85mm-Concrete	Floor (Slab)	Polystyrene	R0.79	31	None	4
300mmWafflePod-85mm-Concrete	Floor (Edge)	Polystyrene	R1.0	28		2
Hot Water Pipework	Pipework	Polyurethane	R0.3	13		4
Air-cond. Pipework	Pipework	Polyurethane	R0.3	13		3

Additional information, to incorporate recommendations made in Section 6.1.2 relating to fenestration systems, is shown in Table 6-10. The addition of an installation quality rating for each window is recommended to be included in the updated Universal (NatHERS) Certificate, constituting a slight amendment to the window schedule table already included in the Universal Certificate.

Table 6-10: Universal (NatHERS) Certificate additional information relating to fenestration system characteristics

Fenestration system characteristics							
Window ID	**Window no.**	**Height (mm)**	**Width (mm)**	**Orientation**	**Zone name**	**Outdoor Shade**	**IQR**
ALM-001-01 A	001	2100	1000	SSE	Kit/liv	No	2
ALM-001-01 A	002	2100	1000	SE	Kit/liv	No	1
ALM-001-01 A	003	2100	1000	E	Br1	Yes	1
ALM-001-01 A	004	1500	1000	WSW	Br2	Yes	4
ALM-002-01 B	005	1500	1000	N	Br3	No	1
ALM-002-01 B	006	1200	1500	N	Ensuite	No	4
ALM-002-01 B	007	900	1200	N	Bath	Yes	2
ALM-003-25 A	008	900	1200	W	Living	Yes	4
ALM-003-25 A	009	900	1200	V	Living	Yes	3

Additional information, to incorporate recommendations made in Section 6.1.3 relating to building penetrations, is shown in Table 6-11. It is recommended that this table be included in the updated

Universal (NatHERS) Certificate. This table shows the building "Element Type", "Zone" and building element "ID no.", as listed in AccuRate Sustainability, along with, as-built, penetration or gap "Location", the "Function" of or "Reason" for the penetration or gap, the "System" used or ingress protection "Rating" of a specific sealing system or methodology used, the "Life" expectancy of the system and installation quality rating for sealing systems employed in construction, relating to all penetrations and gaps.

Table 6-11: Universal (NatHERS) Certificate additional information relating to characteristics of penetrations, gaps and associated sealing systems and methodologies

Penetrations, gaps and associated sealing systems and methodologies

Element Type	Zone	ID no.	Location	Function/Reason	System/ Rating	Life (yr)	IQR
Roof	Roofspace	N/A	PV Panel	Electrical wiring to meter	IP66	50	4
Roof	Roofspace	N/A	Solar H/W	Pipework to storage tank	IP66	50	5
Ext Wall	Kit/liv	2	Sink	Plumbing - sink	Gland	30	4
Ext Wall	Bath	1	200 AFL	Plumbing – bath/basin	Gland	30	4
Floor	Bath	1	Sink	Drainage - sink	Silicone	25	4
Floor	Ensuite	1	Sink	Drainage - toilet	Silicone	25	4
Window Frame	Kit/liv	001	Lower L/R	Improper flashing	IP65	0	0
Window Frame	Kit/liv	002	Upper L	Incomplete seal	IP65	0	0
Window Frame	Br1	003	Mid R	Brick/mortar cracked	IP65	1	1
Window Frame	Br3	005	Mid R/L	Incomplete seal	IP65	0	0

Additional information, to incorporate recommendations made in Section 6.1.4 relating to building membranes (or wraps), is shown in Table 6-12. It is recommended that this table be included in the updated Universal (NatHERS) Certificate. This table shows the building "Element" type, as listed in AccuRate Sustainability, along with, as-built, the "Manufacturer", the "Function" of the building membrane, the "Life" expectancy of the membrane and installation quality rating for all building membranes employed in construction.

Table 6-12: Universal (NatHERS) Certificate additional information relating to building membrane characteristics

Building membrane characteristics

Element	Manufacturer	Function	Life (yr)	IQR
Roof	Eg9Corp. Inc.	Reflective cellular membrane to control heat flow	50	4
Ceiling	Eg9Corp. Inc.	Intelligent membrane for building envelope moisture control	50	4
Ext Wall	Eg9Corp. Inc.	Intelligent membrane for building envelope moisture control	50	5
Floor	Eg9Corp. Inc.	Concrete slab moisture control	50	3

Additional information, to incorporate recommendations made in Section 6.1.5 relating to installed equipment and systems, is shown in Table 6-13. It is recommended that this table be included in the updated Universal (NatHERS) Certificate. This table shows the building "Equipment Type" along with a number, "(No.)" to identify the specific item of equipment or system under consideration, the "Sub Type" of the equipment or system under consideration, the "Manufacturer" and "Model No." of the equipment, the "Zone Name" where the equipment is installed (in accordance with AccuRate Sustainability), critical specifications and installation quality rating for the equipment. The samples of "Critical Specification" information shown in Table 6-13 include: the rated COP and EER of heating and cooling systems; the R-Value of insulation used in ductwork and pipework of various systems; measured values of noise emanating from installed HVAC equipment; confirmation (Y or N) of whether installed equipment meets the specifications listed in ABRD, including whether exhaust air is ducted outside the building (i.e. “Outdoor”); the area of insulation penetrations relating to various installed equipment; the number of STC’s applied to the installed water heating system; the orientation of solar collectors; the maximum length of heated water pipework; and the rated power of lighting fixtures and PV system components.

Table 6-13: Universal (NatHERS) Certificate additional information relating to installed equipment and system characteristics

Installed equipment and system characteristics					
Equipment Type (No.)	**Sub Type**	**Manufacturer/Model No.**	**Zone Name**	**Critical Specification**	**IQR**
HVAC (1)	Heat Pump A/C	Eg1Corp. Inc./RC2000	All Cond.	COP/EER(4.2/3.9)	4
HVAC (1)	Ducting	Eg2Corp. Inc./RD101	All Cond.	R1.5	3
HVAC (1)	Noise	N/A	N/A	45dB(A)	2
HVAC (1)	Ventilation/Clearance	N/A	N/A	Min(200mm)	2
HVAC (1)	Pipework Insulation	Eg3Corp. Inc./PWI102	N/A	R0.5	2
HVAC (2)	Mech. Vent. System	Eg4Corp. Inc./MV102	All Cond.	Y	4
HVAC (3)	Range Hood	Eg4Corp. Inc./RHX102	Kit/Liv	Y	3
HVAC (3)	Ducting	Eg2Corp. Inc./RHD102	Roofspace	Outdoor	4
HVAC (4)	Exhaust Fan	Eg4Corp. Inc./EFX103	Laundry	Y	4
HVAC (4)	Ducting	Eg2Corp. Inc./EFD103	Roofspace	Outdoor	3
HVAC (4)	Insul. Penetration	N/A	Laundry	0.112m^2	4
HVAC (5)	Exhaust Fan	Eg4Corp. Inc./EFX103	Bath	Y	4
HVAC (5)	Ducting	Eg2Corp. Inc./EFD103	Roofspace	Outdoor	4
Hot Water (1)	Solar Gas Inst. Boost	Eg5Corp. Inc./SHW104	N/A	STC(43)	5
Hot Water (1)	Pipework Insulation	Eg3Corp. Inc./PWI102	N/A	R1.2	4
Hot Water (1)	Orientation	N/A	N/A	WSW	1
Hot Water (1)	Pipe Length	N/A	N/A	Max(9.5m)	3
Lighting (1)	LED Fixtures	Eg6Corp. Inc./LED106	Various	3.2W	4
Lighting (1)	Insul. Penetration	N/A	Kit/Liv	0.401m^2	3
Lighting (1)	Insul. Penetration	N/A	Living	0.327m^2	3
Lighting (1)	Insul. Penetration	N/A	Br1	0.112m^2	3
Lighting (1)	Insul. Penetration	N/A	Br2	0.301m^2	3
Lighting (1)	Insul. Penetration	N/A	Br3	0.110m^2	3
Lighting (2)	CFL Fixtures	Eg6Corp. Inc./CFL107	Various	7.5W	4
Lighting (2)	Insul. Penetration	N/A	Laundry	0m^2	3
Lighting (2)	Insul. Penetration	N/A	Bath	0m^2	3
Lighting (2)	Insul. Penetration	N/A	WC	0m^2	3
PV System (1)	PV Panels	Eg7Corp. Inc./PVP108	N/A	1500W	4
PV System (1)	Orientation	N/A	N/A	NNW	4
PV System (1)	PV Inverter	Eg7Corp. Inc./PVI108	N/A	2000W	3

7 Beyond NatHERS

7.1 Achieving Reliable Energy Efficiency in the Future

AccuRate Sustainability has the capability to incorporate the relevant characteristics of current Australian buildings, enabling it to effectively reflect the energy efficiency of the building. Chapter 3 has demonstrated how going through the AccuRate Sustainability rating process, the measured energy efficiency of the building envelope can dramatically increase, taking designs from 4 stars to around 7 stars, resulting in meaningful energy savings associated with heating and cooling equipment. This is fundamentally demonstrated in the reduction of energy needed during extreme periods of cold and hot conditions.

Recommendations have been made to improve the building energy efficiency on a cost-effective basis, which highlight opportunities based on increasing air tightness, improvements in building fabric and the use of solar PV [158]. However, this study did not emphasise how benefits are more difficult to obtain without stricter regulation. The report presented herein has recommended changes to the assumptions and parameters used within AccuRate Sustainability under NatHERS which can support increasing star ratings requirements more reliably. However, it is critical to stress that as regulations are considered to improve the energy efficiency of buildings beyond 7 stars, it is resolving of the weaknesses and inconsistencies within the assumptions which drive the actual improvement in energy efficiency, rather than the regulated star rating itself. Many of the recommendations presented in this report and by others have been envisaged and previously identified, over a decade ago. This is in contrast to the previous decade where NatHERS had undergone a radical transformation and was advancing consistent with international trends. It is again important to highlight how the gap relative to international standards is widening. This is reflected in the need to consider how improved energy efficiency improvements can conflict with other factors and constraints.

Air infiltration represents a significant energy loss and moves to introduce blow door testing as a compliance mechanism, represents an effective strategy to improve the as-built energy efficiency of a building [158]. However, in line with international experience, without adequate ventilation requirements, ‘sick building syndrome’ can be experienced. Given that residential air conditioning regulations do not require ventilation, ventilation becomes window opening driven. This provides an interesting conflict for households on how to identify the most appropriate amount of window opening to balance ventilation and energy efficiency requirements. How then will the assumed operation within NatHERS deviate from the actual? The ideal solution is controlled ventilation, as experienced in the EU. Delivering controlled ventilation, often with heat recovery, without compromising energy efficiency, manages this conflict. This is currently not being considered in regulatory changes.

With a sealed building, moisture control becomes much more critical, as it becomes the principle driver of condensation. Regulation and practice associated with moisture and prevention in mould growth in the Australian building sector, until very recently, attracts a significant low level of attention compared to the EU and US environments (Section 7.1.1). Should insulation be exposed to condensation, this will ultimately degrade the energy efficiency of the building? Moisture control represents a further conflict that needs resolution as energy efficiency design decisions may conflict moisture control requirements. Effective assessment is needed and NatHERS, providing a numerical simulation of the building, offers an ideal platform for integrating this assessment. Current changes in the NCC, although positive still substantially lag best practice approaches. Since moisture condensation has serious impact on health and building structure, it seems more appropriate not to increase the star rating of buildings substantially until this issue is resolved effectively.

Acoustic control is a critical requirement for well-being and appropriate selection of building materials, particularly in apartment buildings requires careful assessment. As an example, introduction of double glazing in the EU as a retrofit program resulted in increased noise transmission between apartments. This presents a further conflict to resolve. There may be benefits in linking acoustic requirements to energy as in the Australian context, with more dense housing, noise from outdoor air conditioners can represent a major concern. Furthermore, insulation and selective double glazing can improve household privacy.

Natural daylighting has demonstrable health and well-being benefits. Higher star rated homes have resulted in smaller windows and less access to the outdoor environment. With increased energy efficiency of the building fabric this is likely to increase, conflicting with the desire for natural daylight.

With regards to appliances the interaction with these factors also needs consideration. Until the recent NCC changes, there was currently no ventilation requirements to vent bathroom, laundry and kitchen moisture to the external environment. Venting into the roof space is a common practice with potentially disastrous effects, which at the very least degrades the insulation, reducing energy efficiency. It is critical that this regulated ventilation of moisture be quality assured. Moisture generation from dishwashers, steam ovens, cooktops and so on should be appropriately considered in any moisture and ventilation analysis.

Overall, what is clear is that as improvements in energy efficiency regulations are implemented to higher levels, how these regulations conflict with health and well-being requirements and expectations of householders becomes critical to the efficacy of those regulations.

7.1.1 Review of Moisture Control Regulation in Australia

Recent research has found that up to 40% of all Australian homes constructed in the last 15 years have visible internal formation of condensation [159]. The same group of researchers also documented the impact of moisture on building fabric and the extent of mould due to moisture in new Tasmanian homes [159, 160].

The health risk of mould-growth is clear. Acute mould exposure can result in nasal stuffiness, eye irritation, wheezing, flu-like symptoms, rashes, nosebleeds, dry, hacking cough and behavioural changes, on the other hand, chronic exposure can cause chronic sinus infections, fever, nose or throat irritation, shortness of breath or asthma, headaches, respiratory infections, dizziness, inability to concentrate and fatigue [161]. According to the World Health Organization (WHO), the occurrence of asthma has been increased in Australia in recent times and residential dampness is associated with 50% of this increase [162]. In 2016, a total of 26 deaths due to asthma were recorded in Northern Territory, Australian Capital Territory and Tasmania [163].

Furthermore, the 2018 Condensation risk mitigation for Tasmanian housing report estimated that per day, a person generates about 8 litres of water vapour due to various human activities in a residential building [164]. If this vapour is not released, moisture accumulates, which can expose the building structure to serious risk of decay due to continuous moisture absorption by materials [165]. Building fabric decay caused by moisture accumulation, may take up to 10 years to become noticeable, and therefore, a latent issue can become serious if not addressed correctly.

It has been argued that the inclusion of energy efficiency requirements in the national regulations without considering its impact on condensation is contributing to excessive condensation and mould-growth problems in contemporary homes [163, 166]. R-value requirements of building elements have been increased substantially from 2003 to 2016 to improve building energy efficiency resulting in more sealed and insulated buildings [166]; a cross section of typical external walls for Australian homes is shown in Figure 7-1. Consequently, inadequate ventilation combined with inadequate vapour control results in accumulation of unwanted condensation, driving this impact.

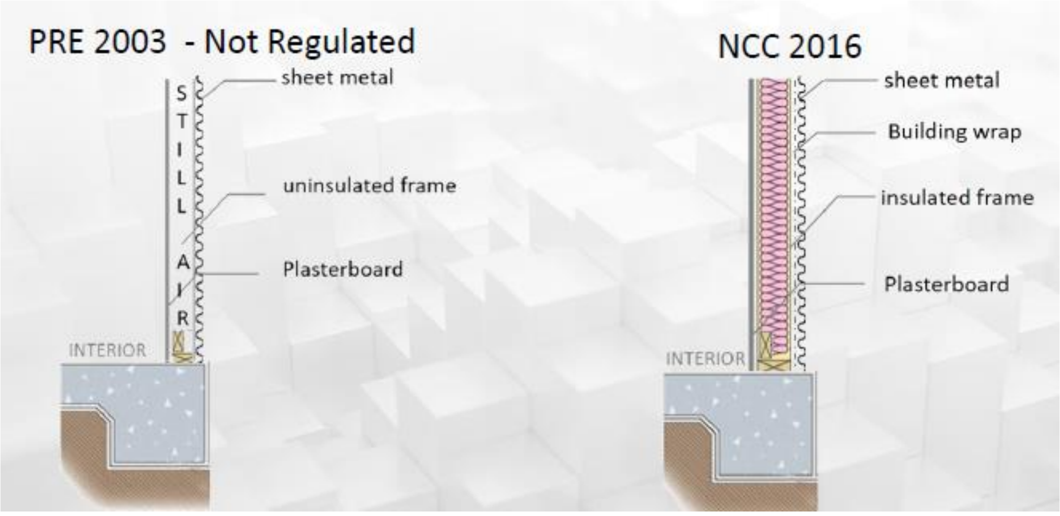


Figure 7-1: External Wall of a typical Australian Home [166]

While EU and USA already have effective moisture control regulations, Australia is the only developed country without any comprehensive building regulation for moisture control and mould to date. In EU and USA, it is already established that effective moisture control is decisive to obtain energy efficient, healthy and durable buildings. Energy efficient buildings are very sensitive to insufficient air-tightness or ill-conceived moisture control design and good design achieves an optimum between moisture control and energy efficiency [167].

The NCC is now providing moisture control regulation, which will be in effect from May 2019. This is detailed through DTS provisions which require appropriate permeability of correctly located barriers. Of more value it highlights the opportunity to use a verification tool as a separate pathway. WUFI (Wärme Und Feuchte Instationär) is the leading assessment tool developed at the Frauhoffer Institute in Germany, capable of simulating the moisture flow through building elements. WUFI conducts numerical transient simulation to ensure that moisture holding capacity of building elements is not exceeded and condensation and associated mould growth is avoided. However, the upcoming NCC 2019 does not include all climate zones for moisture control regulations. All climate zones will be included in NCC 2022 along with seven more recommendations. In 2025, four more recommendations will be added [168]. Hence, moisture control regulations will not be fully matured until 2025.

7.2 Separation of Rating and Design in AccuRate Sustainability

Fundamentally, although AccuRate Sustainability (rating mode) is used as a rating tool, the tool is also used to make design choices which can achieve the minimum star rating at minimum cost. This characteristic is the basis for using this modelling approach to improved energy efficiency as opposed to the Deemed to Satisfy pathway in the NCC. O'Leary et al. show that different approaches can be applied to the assessment of thermal performance and what passes the compliance test using one method in some cases may not (at least in current design) achieve a pass in an alternative method [169]; this was shown for 2 houses in a case study comprising of 7 South Australian houses.

O'Leary continues by stating that "*using thermal simulation to model thermal energy characteristics to predict energy use for comfort is a powerful way to improve energy efficiency but also gives some flexibility over the 'all or nothing' elemental DTS method.*" [169]. Ultimately this minimises the full versatility of AccuRate Sustainability (rating mode) in the industry as regulatory changes are far behind improvements in international best practice. AccuRate Sustainability (non-rating mode) and the more recently developed AusZEH design, attempts to address this, however there are still numerous missing assumptions relative to the global standard of EnergyPlus through its varied interfaces such as Aecom and Design Builder. Furthermore, with a lack of continuous improvement in the modelling depth and range, the gap between international tools widens, and in the long term fundamentally will degrade the credibility of AccuRate Sustainability in both rating and non-rating mode.

Clearly changes in AccuRate Sustainability (rating mode) require a Regulatory Impact Assessment, however without a forward-looking AccuRate Sustainability it is difficult for regulators, assessors, builders, component suppliers to anticipate what could be regulated. For example, the current push for blow door testing is being conducted without AccuRate Sustainability having this feature in it for the industry to assess the consequences of sealed buildings on their designs. Rather the industry relies on static reports of studies, which although reliable and credible, do not enable individual builders to dynamically respond considering their own constraints and designs. For example, now that thermal bridging is included in AccuRate Sustainability, forward looking businesses could use this to evaluate their building designs against their competitor designs and show customers the improvement they can offer. Risk adverse businesses can assess the risk to any regulatory change. In either case there is a step-wise approach to industry transformation.

It is proposed that AccuRate Sustainability can be advanced into an internationally benchmarked design tool, decoupled from AccuRate Sustainability as a rating tool. This new design tool can readily adopt a continuous improvement strategy based on the leading software tools, international standards and practices. Consequently, AccuRate Sustainability or its equivalent, can be used to ultimately provide robust star rating options as it is now able to adopt best practice modelling. This would enable energy efficiency rating for housing to become more consistent with MEPS star rating which does deliver a credible point of difference with customers. Active encouragement of more homes to achieve higher star ratings beyond the minimum required will further support regulatory changes into the future. This is consistent with the aims of the EU/US housing energy efficiency programs which focus on providing a market for energy efficiency houses relying on a robust assessment (Chapter 5). These programs focus to encourage energy efficiency homes with a scaled rating scheme which operates well beyond just compliance. This process drives down the costs of energy efficiency improvements. Ultimately this approach produces a virtuous cycle within the building sector, in which energy efficiency improvements reduce in cost as it is implemented in higher rated homes driven by market demand. However, this cycle can only be achieved with a robust assessment process.

With such a design tool in the Australian context, it will provide the platform by which optional future regulatory changes can be trialled. These options can be graded into near, mid and long-term proposals. This would provide the industry with a clear opportunity to expose themselves to these potential regulatory changes, and fairly evaluate the risks and corresponding opportunities. Fundamentally this would avoid the stop/start approach to regulatory change and encourage steady positive change.

7.3 Cost Comparison Between New Houses in Germany and Australia

A major limiting argument associated with enhancing the energy efficiency of buildings relates to the increase in capital costs to the homeowner.

German regulations and building practice already account for infiltration minimization, quality control, adequate ventilation and moisture control. A comparative capital cost analysis has been conducted to identify the cost gap between a minimum standard German house, with these regulatory requirements and a minimum standard Australian house, which does not have these requirements.

In Germany, the Energy Saving Ordinance (EnEV) decides the minimum energy performance standards for all new and refurbished (major) buildings. The first EnEV minimum requirements were introduced in 2003 with further upgrades in 2007, 2009 and 2014. The 2014 EnEV will further be upgraded in 2019 [149, 150, 170]. From 2016 onwards, EnEV 2014 standards are to be followed with much stricter requirements reducing energy by approximately 25% compared to EnEV 2009. Therefore, over the last decade the maximum primary energy demand has been reduced from 70 kWh/m^2/year (according to EnEV 2009) to about 50 kWh/m^2/year in 2016 (according to EnEV 2014) [170, 171]. The impact of these changes on primary energy consumption is presented in Figure 7-2, which includes high performance housing systems such as Passivhaus, the globally recognized ultra-efficient building system developed in Germany.

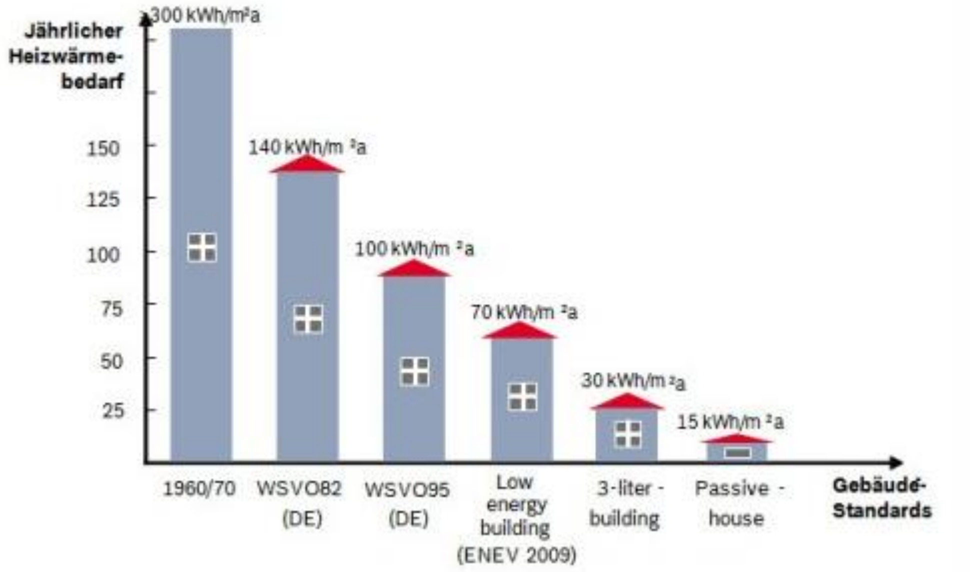


Figure 7-2: *Impact on primary energy regulation of homes in Germany*

EnEV also specifies the maximum values of the specific heat loss factors (U-value) of the building envelope for new buildings and refurbished buildings. Every new and refurbished building must meet this requirement in addition to the minimum energy requirements regarding building envelope and heating and hot water plant efficiency.

Table 7-1 compares some the U-value requirements of different building elements in Germany and the U-value of the same elements found in the sample 6-star house provided in NatHERS. The U-value comparison confirms that German standards are more stringent than Australian standards, particularly when considering that thermal bridging is excluded in the Australian assessments.

Table 7-1: A comparison between EnEV 2014 minimum U-Value requirements [171] for different elements and the U-Value found for equivalent elements in AccuRate Sustainability Demonstration house (6 in Victoria)*

Element	EnEV max allowed U-value	NatHERS Sample House- Total U-Value
External Wall (with insulation)	0.24	0.32
Window	1.30	5.4
Pitched roof (with insulation)	0.24	n/a, roof is not insulated
Top floor Ceiling	0.24	0.25
Exterior Door (i.e. Entrance Door)	1.8	2.12

As part of EnEV 2014 regulations, every building (old or new) must have an energy certificate with a label, which classifies the property according to their energy efficiency level. There are nine classifications in total from A+ to H with A+ being the most energy efficient, encompassing Passivhaus. Depending on the building types, newly constructed buildings meeting the EnEV 2014 standard mostly fall into the classes between A+ and B. The classification is based on the annual final energy demand shown in Table 7-2.

Table 7-2: Primary energy usage energy efficiency class for EnEV 2014 regulation in Germany.

Energy Efficiency Class	Final Energy (kWh/m^2/year)
A+	less than 30
A	between 30 & 50
B	between 50 & 75
C	between 75 & 100
D	between 100 & 130
E	between 130 & 160
F	between 160 & 200
G	between 200 & 250
H	more than 250

Table 7-3 presents the costs of construction associated with A+ to B rated prefabricated homes built in Germany for a range of finished quality [172]. This range translates to 1300 - 3800 \$/m^2. For on-site constructed heavy mass homes, this range changes to €1000-€1700 (\$1600-\$2600)/m^2. Corresponding data is presented in Table 7-4 across Australian capital cities [173, 174]. On average the costs range from 1700 to 3500 \$/m^2. This range is consistent with the costs in Germany with the budget design being 20% lower cost than the equivalent Australian design.

Clearly this is a preliminary cost assessment and further analysis is needed to ensure a true comparison cost can be determined. However, when comparing within each market, according to [175], in Germany, a Passivhaus is about 3-8% more expensive compared to an EnEV standard building, whereas in the UK Passivhaus represents a cost increase of about 15-20% on standard designs in the UK [176]. Both these increases can be considered small relative to the variation in prices experienced in the Australian market.

Therefore, higher energy efficiency which is quality controlled can be effectively implemented at manageable costs within Australia. An important consideration to highlight is that the cost variation experienced in each market relates to the cost and quality of internal finishings. It can be argued that quality-controlled energy efficiency measures are in of themselves a quality improving finishing. This can be further argued if these measures enhance the general health and well-being parameters of the building.

Table 7-3: German house, for pre-fabricated houses, price/m^2 for prefabricated houses of varying finished quality [172]

Type of Construction	Price/m²	
	Euro €	$ AUD
Basic	800	1280.50
Average	1000	1600.62
Middle-range	1400	2240.87
Good	1800	2881.12
Luxurious	2400	3841.50

Table 7-4: House construction costs across Australian cities [173, 174].

Location	Price/m²	
	Low-Budget	High-Budget
Sydney	$1,780	$5,100
Melbourne	$1,720	$3,300
Adelaide	$1,580	$3,450
Brisbane	$1,800	$4,000
Canberra	$1,700	$3,400
Darwin	$1,800	$2,800
Perth	$1,400	$2,700
Average	$1,683	$3,536

7.4 Greenhouse Gas Emissions Context

It is impossible to ignore the changing context into which AccuRate Sustainability (rating mode) and energy efficiency regulation in general exist in Australia.

The energy efficiency regulations in the NCC, and as defined by the Greenhouse and Energy Minimum Standards (GEMS) Act 2012, have a focus on reducing greenhouse gas emissions, which was a clear opportunity a decade ago. The Australian electricity sector is transforming rapidly towards renewable energy with planned renewable energy generation expected to meet 45% of the National Electricity Market (NEM) by 2030 [177]. This report dated Sep-17 stated that the number of large renewable energy generator connection requests were 11 GW of wind power and 11 GW of solar power. Today this request is at 16 GW of wind power and 23 GW of solar power. Adding 10 GW rooftop solar PV estimated to be achieved by 2030 (Figure 7-4), highlights that renewable energy generation will likely be the dominant energy source in the NEM. The emissions intensity factor for the NEM in 2018 was 0.8 kg/kWh reflecting around 18% renewable energy contribution [178]. Should the planned projects be achieved, this number will more than halve by 2030.

The general trend of predictions in the Australian renewable energy space is to over-achieve predictions, as experienced in SA. The impact on gas usage in homes will also be dramatic with fuel switching occurring and also the planned transition to renewable gas as outlined in the Gas vision document [179] by 2050. Collectively, this presents a fundamental challenge to the purpose of energy efficiency regulations based on emissions. On this basis energy efficiency regulation returns to the focus as presented after the 1970s oil crisis, driving energy productivity for the householder. In such a case, the relevance of solar and battery installations becomes a major competitor relative to other efficiency measures. Figure 7-3 presents the forecasts and breakdown of electricity usage in the residential sector from the Australian Electricity Market Operator (AEMO) [177], and Figure 7-4 presents the current and forecast production of residential rooftop PV [178]. In 2017, the estimated production from rooftop PV represents approximately 13% of total residential electricity consumption. The average Australian house is defined by a star rating lower than 5. In Lochiel Park, where gas usage is small relative to electricity usage, the solar PV production represents more than 50% of the electricity used for the house. Therefore, as emissions become less a factor, energy productivity more relevant, and solar PV being a dominant factor, the basis for energy efficiency regulation under the current framework becomes more difficult to justify.

Ultimately, energy efficiency assessment must be based on total imported grid electricity (assuming all locally generated electricity is renewables based). Any whole of house assessment should provide the flexibility to households to achieve minimum grid electricity imported applying the full spectrum of options ranging from being highly efficient with minimum on site renewable energy, right through to minimum efficiency and a high level of on-site renewable energy generation, consistent with the strategy suggested in Chapter 5.

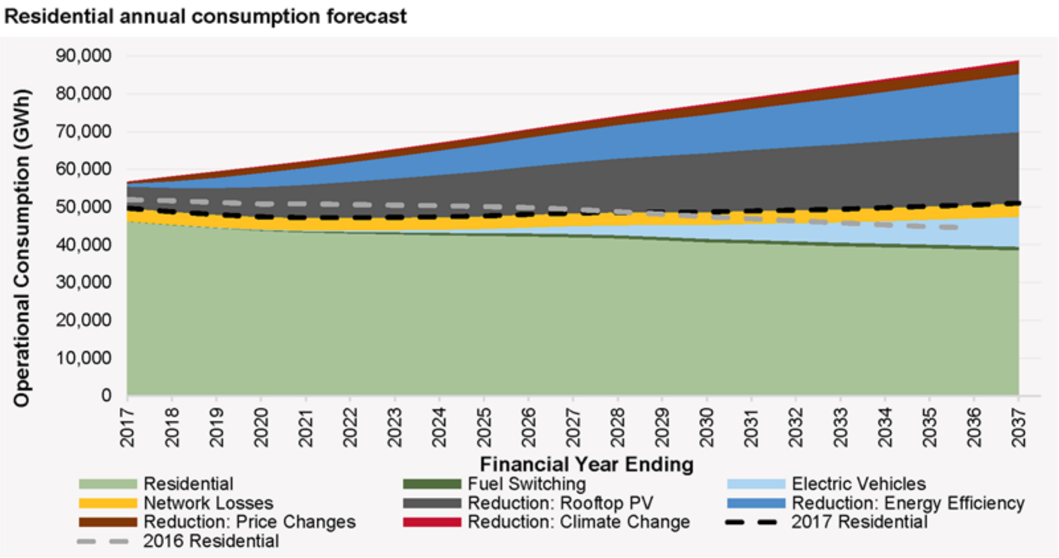


Figure 7-3: Electricity usage and forecast in the residential sector of the National Electricity Market.

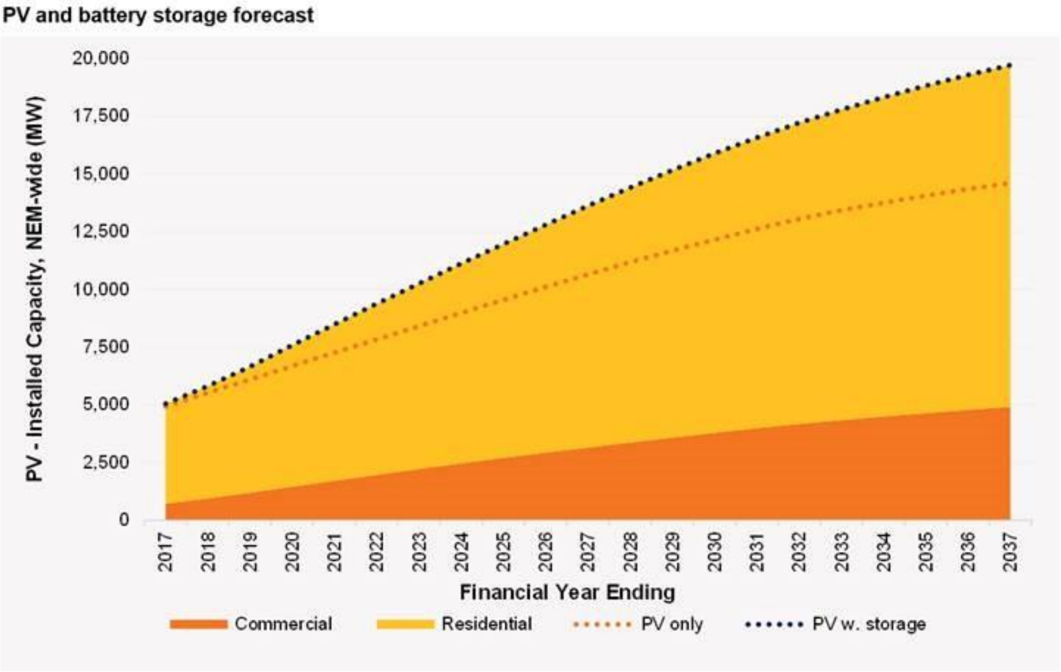


Figure 7-4: Existing and forecast rooftop solar PV installations in the National Electricity Market.

7.5 Regulation is Key

This report has document many assumptions regarding the current rating scheme, NatHERS, as well as proposing other schemes, such as HEGIRS and whole-of-house approaches. The key to the success of any rating scheme is regulation. It is known that many of the elements of this report are currently regulated, whilst some are planned to be regulated in the future. However, some of the contents discussed here are not planned to be regulated, yet could be, and could have a significant impact on the future Australian house rating scheme. Table 7-5 below, summarises the elements discussed in this report, along with the relevant section / subsection number, and specifies whether these: are currently regulated, if they are planned to be regulated, or if they could be regulated in the future.

Table 7-5: Summary "what is currently", "what is planned to be", and "what could be regulated?".

Element of report	**Regulated?**		
	Currently	**Planned to be**	**Could be**
AccuRate Design (allow AccuRate to perform as a design tool)			✓
AccuRate Design to link to International Standards / best-practice			✓
AccuRate Design to link to Quality Assurance			✓
Adaptive thermal comfort to be included		✓	
Adjustment of COP assumptions in AC modules		✓	
Blower door testing / impact of air leakage on rating and moisture		✓	
Construction Material assumptions (windows etc.)	✓		
Impact of Climate-changed RMY input weather files			✓
Impact of R-value degradation			✓
Impact of Thermal-bridging (in rating mode)			✓
Occupancy patterns		✓	
Quality Assurance - Rigorous / thorough (no frills) inspection			✓
Quality Assurance - Universal Certificate		✓	
Rating scheme to include health and wellbeing			✓
Thermostat setpoints assumptions	✓		
Whole-of-house method 1, i.e. building and appliance star-ratings		✓	
Whole-of-house method 2 (HEGIRS), i.e. PV, battery, machine learning			✓

7.6 Conclusions

It can be argued that a shifting emphasis from the current paradigm of reducing GHG towards more of a focus on health and well-being represents a more cohesive approach to energy efficiency regulation of the building, consistent with best practices internationally. The costs associated with implementing robust energy efficiency measures, which consider broader health and well-being factors are not excessive and well within the range of Australian construction costs. At its lowest common denominator energy efficiency delivers reduced energy costs which are of significant public benefit. However, as highlighted in Chapter 5, focusing on appliances together with including solar PV/battery options, could deliver a more cost-effective value proposition in improving whole of house energy efficiency in the short term. This would provide time for improvements in the AccuRate Sustainability building modelling engine and regulations to incorporate these other health and well-being factors. Ultimately, consideration of improved thermal comfort, privacy through acoustic benefits, indoor air quality, prevention of mould growth and consideration of natural daylighting, potentially represents a far greater value for the householder and the public generally, then energy productivity in isolation.

Incorporating these health and well-being factors into an effective design tool which can be primarily used to support better design is likely to represent a far more productive use of the effective capabilities built into AccuRate Sustainability. Ultimately this would shift the AccuRate Sustainability engine beyond just rating and become actively used to lead the building industry towards enhanced housing.

8 Conclusions and Recommendations

Through NatHERS, AccuRate Sustainability provides a popular pathway to meet energy efficiency compliance regulations within the NCC, through the use of building simulation. The assumptions and methodologies applied within this software require regular review and update to ensure the energy efficiency objectives of NCC regulations are achieved. This study aimed to inform the next generation of the software with a view to increasing energy efficiency compliance requirements in the future. Furthermore, consideration of not just the building envelope but other major energy usage appliances was investigated. Finally, information concerning compliance metrics was developed, to support quality assurance measures being considered.

A detailed review of the assumptions applied in the software in relation to the building envelope is presented in Appendix A of Section 10. The review showed many assumptions are out of date or do not match world's best practice. More detailed analysis of some of these assumptions have been analysed in Chapter 4, with a summary of recommendations provided in Section 4.5. These recommendations include a more realistic occupancy profile accounting for weekend/weekday differences. Accounting for thermal bridging in rating mode is proposed, which becomes more significant in higher star-rated homes. Recommendations are made to evaluate the performance of the building during simulated heatwaves, avoiding poor designs which risk increasing heatwave related deaths. More accurate thermostat settings and on/off set point correlations for air conditioning were investigated. The potential for applying adaptive thermal comfort evaluation measures was evaluated and verified. Overall, aspects requiring further upgrades and improvements include: heating and cooling thermostat temperatures; triggering temperatures for heating and cooling; the cooling effect of air movement; and occupant window operation rules. It is noted that existing understandings are still limited. Considering the importance of thermal comfort and air conditioning operation in house energy efficiency regulation development, it is recommended that further research is needed to validate and improve the understanding in both occupants' thermal comfort and air-conditioner operation behaviours in Australian residential houses.

Research, based on measured air conditioning usage, has shown that a higher-star rating does correlate with reduced air conditioning annual energy usage, as shown in Chapter 3. This correlation is stronger for cooling than for heating and also during months of climatic extremes when heating and cooling is most needed. These results demonstrate that the star rating mechanism is effective at increasing the envelope efficiency from lower star ratings up to 7.5 stars. However, beyond these high star ratings, the current software and regime of assumptions is unlikely to achieve the same positive correlation, as this relationship becomes more sensitive to the accuracy of the assumptions involved.

Given the historically long delays associated with upgrading the software due to the need for regulatory impact assessment processes, it is not possible to sustain a robust software in line with international best practice, and therefore it is recommended that AccuRate Sustainability be reformulated to allow for the separation of compliance and design, as presented in Chapter 7. It is within this design mode that a mechanism for continuously upgrading and enhancing the accuracy, efficiency and robustness of the software can be achieved in line with software that is considered international best practice. This will also provide a more granular and dynamic process by which industry can test and evaluate proposed future changes to compliance regulations.

The review and recommendations summarised in Appendix A of Section 10 also considered the appliance modules within AccuRate Sustainability. Many specific recommendations to changes in assumptions are presented. Essentially, it is proposed that evaluation of appliances should better integrated with existing energy efficiency ratings mechanisms used through GEMS, MEPS and industry standards, particularly for gas appliances, and through the Clean Energy Regulator for hot water system performance assessments. Proposed changes will better facilitate whole-of-house energy assessments.

A review of whole-of-house energy assessments in other jurisdictions highlighted how these regulations are primarily driven not only to provide a compliance pathway, but to encourage and support an energy efficiency housing solutions market. This approach, if applied to AccuRate Sustainability, would be best facilitated through the inclusion of a design mode, which could be continuously upgraded to implement best practice assumptions and methodologies, without being hampered by delays associated with regulatory impact statements required for rating mode. It is only through a rigorous evaluation methodology, incorporating quality assurance, that such a market can be generated. This is consistent with international systems, where higher rated buildings are valued, and subsequently attract financial support, because the evaluated and actual performance are likely to be consistent.

A whole-of-house energy assessment methodology was presented for Australia, integrating current energy efficiency rating mechanisms (Chapter 5). It was identified that there is a significantly greater opportunity for positive impact of energy efficiency improvements in relation to appliances, rather than with the building envelope. A novel methodology was developed for the integration of solar PV and battery technology into the whole of house energy assessment. International systems operate on annual net energy usage, whereas the proposed system focuses on rating a renewable energy system on total imported energy, discouraging export focused solar PV installations, in favour of greater self-consumption through energy storage and demand management.

Currently there are no effective quality assurance requirements within energy efficiency compliance regulations of the NCC. Proposed compliance metrics and methodologies have been presented in Chapter 6. These approaches require further development and refinement, however focus on ensuring a robust assessment. Specifically, an inspection process is recommended to ensure those elements which have a strong impact on energy efficiency, as specified in the rating process, are installed as specified and the quality of that installation is assessed. Where quantitative assessments of installation quality are possible, such as blow door testing, these are also recommended.

The original basis for energy efficiency regulations in the NCC is to reduce greenhouse gas emissions. This basis is inconsistent with the rapid transition to renewable energy in the Australian energy system, which habitually exceeds expectations. As presented in Chapter 7, it is recommended that a transition towards a focus on assessing the total energy imported, within a framework of occupant health and well-being, should be set in motion. This framework should consider imported energy limits on the basis of thermal comfort, economic benefits to the householder, moisture control, indoor air quality, acoustics, daylighting and other factors which deliver improved householder amenity. This framework is critical, as any future increases in energy efficiency requirements introduce a likelihood to create conflicts between energy efficiency and occupant health and well-being.

Overall, this study has attempted to inform the next generation of tools associated with energy efficiency regulation in the existing context. However, this context is changing, and the efficacy of the existing tool is limited, without improvements. Shifting towards a whole-of-house approach with a design tool subject to continuous improvement, which is benchmarked against international best practice, within a health and wellbeing framework, will enable a more robust framework capable of delivering enhanced housing for the community, in a world transitioning to renewable energy systems.

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10 Appendices

Appendix A: Review and recommendations of NatHERS and AccuRate Sustainability Module assumptions

The reader can easily navigate to relevant sections / subsections of this report, by clicking on the Section number (embedded hyperlink).

Table 10-1: Summary of recommendations from Review of NatHERS assumed settings.

Element of AccuRate Sustainability	Section	Review / recommendation
Summary of Thermostat settings for All Climate Zones	2.1.1.3	The assumptions regarding thermostat settings / trigger temperatures, need to be updated in AccuRate Sustainability, based on evidence gathered by CSIRO from rigorous monitored data. This is further discussed in Section 3.1.
Effect of Air Movement on Comfort Temperature	2.1.1.4	It is recommended that the applicability of Equation 2 should be re-examined.
Cooling and Heating Operation Assumptions	2.1.1.5	Occupants generally do not open their windows as they are assumed to be, in AccuRate Sustainability. In reality, people do not ventilate and take advantage of any potential cooling effect due to air movement. As such, windows remain closed most of the time in many houses for various reasons, which is critical to calculate the heating and cooling load. It is highly recommended that mechanical ventilation systems should be considered when designing a house and that these are incorporated into AccuRate Sustainability. It is also recommended that air leakage tests (blower door test results) need to be carried out when windows are open, such that this can be included in the building model. It is also highly recommended that the assumptions regarding ventilation, and the subsequent potential cooling effect, be revisited and updated to reflect reality.
Occupancy and Associated Heat Gains of Zone Types	2.1.1.6	Zoning assumptions are too simplified / generalized, and are not based on rigorous or monitored data. For example, only one zoning type can be assumed for all bedrooms. The occupancy and associated heat gains of multiple bedrooms can vary dramatically, especially if one is a spare bedroom and rarely occupied. Occupancy duration for different zones are overestimated, such as living room and bedrooms that are assumed to be occupied for 17 hours per day even, albeit at different times of the day. Zoning assumptions need to be improved, i.e. more zoning types need to be established along with more realistic occupancy patterns, based on rigorous monitored data.

Internal Heat Load	2.1.1.7	The assumptions used regarding dwelling size and the number of occupants, are based on statistical data from the 1990's. As these are outdated and family arrangements are tending to be less 'nuclear', AccuRate Sustainability needs to address these assumptions. In addition, these should be periodically updated every time a national Census is carried out. The internal heat loads are outdated and unrealistic, and these calculations need to be better aligned with ASHRAE reference values. As moisture is becoming important, it is highly recommended that the internal latent load, as well as moisture producing appliances and processes, such as dishwashing, clothes washing and showers, need to be factored into the internal latent heat load calculation. Finally, there is a mismatch between heating/cooling operation time and the occupancy heat gain times assumed in AccuRate Sustainability. It was seen that heating/cooling operation was assumed when occupancy was not. This inconsistency needs to be addressed.
Thermal Mass	2.1.1.8	It is highly recommended that future versions of AccuRate Sustainability, and the other accredited rating tools, need to be updated such that the effects of internal thermal mass that does not form part of the building envelope on building thermal energy modelling are incorporated into the software. Where this is already incorporated into the software, this should be clearly indicated in the associated documentation.
Construction Materials	2.1.2.1	The current material library is suitable to cover major typical construction practices in Australia; however, it lacks new, innovative and energy-efficient materials that are the results of the latest technology, such as 'smart glass', structural insulated panels, 'cool roofing' and phase change materials. It also does not provide some material choices for green or sustainable construction, such as straw bales, green wall or plant-based materials. Although many materials can be simulated using specified resistance values to mimic known properties, their specific inclusion within the construction materials database may be advantageous. This could serve to indirectly promote the use of sustainable materials, especially where AccuRate and other NatHERS tools are used as an integral part of the building design process. This could improve the quality of the tool and effectively reward innovative design and construction, therefore it is recommended that new materials are incorporated as part of a regular update of the construction materials database. While specifying the materials for a construction, thickness of the materials can be modified manually; however, there is no upper limit for the material thickness, which means a concrete block's thickness can be set at 100,000 mm. The upper limit for material thickness should be restricted to a reasonable limit to reduce the chance of accidental not s during data entry. Only the R-value and U-value of the materials are considered. Other properties such as moisture content of the materials are not included. This should be included to enhance the accuracy of the tool. The material properties utilised in the materials database are independent of temperature, however the properties of many insulation materials commonly used in construction vary considerably with temperature, therefore this can affect the accuracy of results. It is particularly a problem in peak summer. To avoid iteration in the modelling, a nominal average of temperature between sol-air and room-air should be considered.

Window (Glazing System) Materials and Properties	2.1.2.2	Given the number of glazing system products with U-value / SHGC ranges that are not covered by AccuRate Sustainability, it is <u>highly</u> recommended that a custom glazing system option be incorporated into the next version of the rating tool. This is suggested, as opposed to a regularly updating the Default library (every 12 months) and dispersing the updated library to registered accredited rating tool users, as this task is a more cumbersome and time costly exercise. Regularly updating the Default library is deemed a <u>medium</u> priority recommendation. In addition, it is also recommended that where custom glazing systems parameters are allowed to be entered in manually (without the need for updating the Default library), a dialogue box is created that allows the assessor to either: - attach a PDF copy of glazing system test performance results, or - add a URL to a product that exists in the WERS website / database.
Surface Colours, Solar Absorptance and Emissivity	2.1.2.3	The term solar absorptance needs to be renamed to total solar reflectance (TSR) consistent with industry terminology. In addition, the skylight framing options should be expanded to include new products available on the market.
Thermal Bridging	2.1.2.4	Thermal bridging is available only in the non-rating mode. Since thermal bridging can have significant impact on the thermal performance of a building, to ensure accurate assessment, it is highly recommended that this should also be included in rating mode. AccuRate Sustainability only considers thermal bridging due to framing. The tool should be updated to consider other forms of thermal bridging, such as the extended floor of a balcony. The number of Thermal bridging materials provided in the tool are limited. For complex construction systems, allowance should be made to include measured R-values from accredited testing bodies. Thermal bridging calculations should follow best practice international standards.
Air Leakage and Infiltration Assumptions	2.1.3.1	It is highly recommended that AccuRate Sustainability is updated to allow the assessor to manually enter the air infiltration rate, based on an approved blower door test.
Building Shape and Orientation Customisability	2.1.3.2	The existing software interface does not allow an assessor to accurately calculate the impact of ventilation of a building that is non-rectangular, e.g. circular or curvilinear. It is recommended that AccuRate Sustainably is updated to address this limitation.
Number of User-Defined Zones	2.1.3.3	It is recommended that the maximum number of user-defined zones is increased beyond 50, as this will allow assessors to model larger buildings.
Slab-on-Ground Construction	2.1.3.4	Given possible contradiction with the NCC regarding edge insulation and termite control regulations, it is highly recommended that AccuRate Sustainability be modified such that an associated error or warning message is displayed to the assessor as they are building the model. This will allow the assessor to take action to facilitate consistency with other regulations.
Complex Roofs Modelling	2.1.3.5	It is recommended that the user interface of AccuRate Sustainability is modified to allow an assessor to quickly build complex roof space models, without assuming one roof for each roof space.
Opaque Louvres	2.1.3.6	It is highly recommended that the assumptions regarding open opaque louvers, including solar radiation of zero, are further investigated and any new information regarding dollar radiation are updated in AccuRate Sustainability.

Area Adjustment Factor	2.1.3.7	Although we cannot provide comment on methodology of the area-adjustment factor assumed by AccuRate Sustainability, we have heard from industry experts that large houses (above $250m^2$) are penalised more than they should be. It is hence recommended that the area-adjustment factor is reviewed periodically, e.g. every five - ten years and adjusted where empirical evidence is gathered and shown to contradict the current assumptions.
Lighting Module: Zone Characteristics	2.2.1.1.1	It is unlikely that either the kitchen or living components of the kitchen/living zone will be square. This could have a significant adverse impact on the accuracy of calculated, required lighting levels. The impact of this assumption must therefore be determined and, as necessary, any associated errors should be identified and rectified. As with other aspects of AccuRate Sustainability, this could simply be addressed through the addition of instructional text describing ways to maximise accuracy, through approximation of certain specific values.
Lighting Module: Minimum selectable luminaire wattage	2.2.1.1.2	This minimum wattage represents an outdated value, especially for LED based luminaires, the most efficient of which have rated power of less than 2 Watts. Based on recent advances in technology, the minimum lighting wattage available for selection within the Lighting module should be reduced to a more realistic number, e.g. 1Watt. A periodic review process should be scheduled to ensure that outdated or outlawed lighting technologies, such as conventional incandescent globes, are removed and that the likely characteristics of currently available and near future lighting technology can be entered.
Lighting Module: Seasonal variation in assumed lamp usage	2.2.1.1.3	The lack of variation between lamp usage during times of year with vastly different daylight hours and associated times of daylight is questionable. This is highlighted when comparing lamp usage in winter months, when days are shorter to that in summer months, when days are longer in addition to the influence of daylight saving in affected areas. It is recommended to investigate the inclusion of different assumptions for lamp usage, especially between periods of the longest summer and shortest winter days.
Hotwater Module: Hot Water System Efficiency	2.2.1.2.1	The upper (highest) values for efficiency contained in both the software manual and the Hotwater Module itself are, using current technology, impossible for all of the system types listed in Table 2-11. Furthermore, the logic associated with allowing values of up to 15, which indicate an efficiency of 1500%, is highly questionable. The maximum efficiency of gas instantaneous, gas storage, oil-fired and solid fuel hot water systems should be less than one in all cases, where no renewable system is in operation.
Hotwater Module: Hot Water System Control System Wattage	2.2.1.2.2	The default value of zero for control system wattage in the Hotwater Module represents a highly unlikely value associated with almost all hot water system types. The default value for control system wattage of all systems in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being commonly applicable to many different types of system, e.g. 2.13W for highly efficient, very common gas instantaneous system.
Hotwater Module: Hot Water System Startup Loss Per Firing	2.2.1.2.3	The default value of zero for startup loss per firing in the Hotwater Module represents a highly unlikely value associated with gas fired hot water systems. The default value for startup loss per firing in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being applicable to the most popular gas instantaneous system.

Hotwater Module: Hot Water System Maintenance Rate	2.2.1.2.4	The default value of zero for maintenance rate in the Hotwater Module represents a highly unlikely value associated with almost all hot water system types. The default value for maintenance rate of all systems in the Hotwater Module should be changed to a value greater than zero. This new default value could be chosen based on it being commonly applicable to many different types of system, e.g. 2.13W for highly efficient, very common gas instantaneous system.
Hotwater Module: Assumed Temperature Difference Between Hot Water and Indoor Air	2.2.1.2.5	This assumption could be relatively accurate in older houses where hot water delivery temperature could be set to 60°C, however for all new houses, hot water delivery temperature is set no higher than 50°C to comply with requirements of AS/NZS 3500.4:2018 to avoid scalding of vulnerable occupants. The aforementioned assumed temperature difference would therefore assume an indoor temperature of 10°C, which is unacceptably low. It should also be noted that, as discussed in section 2.2.1.2.6, the associated accuracy of this assumption is further compromised where a hot water delivery temperature control panel is utilised. The value for assumed temperature difference between hot water and indoor air temperature should be reduced to a much lower value, e.g. 30°C, to account for the impact of legislated regulations associated with hot water delivery temperature.
Hotwater Module: Treatment of Hot Water Delivery Temperature Control Panels	2.2.1.2.6	It is generally accepted that considerable savings can be facilitated through the use of hot water delivery temperature control panels, specifically where water heaters can be set to deliver hot water to zones at temperatures of as low as 37°C. These types of systems tend to avoid heating water to unnecessarily high temperatures before most often reducing this temperature significantly at the faucet, which can otherwise result in considerable unnecessary heat loss. Analogous to the way the Lighting Module treats the existence of dimmer switches, the Hotwater Module should treat the existence of hot water delivery temperature control panels, in terms of their potential to achieve water heating energy savings. This could be achieved through the incorporation of a factor that simply reduces the water heating energy attributable to any zone where such a controller exists.

<u>Hotwater Module:</u> Solar Hot Water System Energy Consumption	2.2.1.2.7	Table 2-12 indicates that the available values for solar collector inclination (altitude) are 0°, 20°, 40°, 60°, 80° and 90°, which do not include many of the most common roof pitches and optimal inclinations of collectors in most Australian latitudes. Available values for solar collector azimuth range from 270° to 90°, which represent acceptable to optimal values and therefore do not account for sub-optimal orientation of solar collectors due to compromised solar access or inferior design and installation. Furthermore, some of the collector non-ideal orientation factors listed are questionable, especially the values associated with 90° inclination, which represent systems that absorb practically no solar radiation throughout the summer months. The fixed value of solar fraction, listed in Table 2-13, which is dependent only on the systems collector and circulation type, omits the fact that all solar water heaters sold in Australia are required to achieve a solar fraction of at least 60% (0.6). Furthermore, there is a large variation in the solar fraction achieved by the various systems currently available in Australia, which are all listed in the CER list of solar water heaters, some of which achieve solar fractions of greater than 0.90. The most critically important point about water heater energy rating is that solar hot water systems, including their conventional boosting hot water systems and components, are all tested and modelled using a well-established system that is accepted as being acceptably accurate by the Australian Federal Government. This system is described in AS/NZS 4234:2008 and currently, all but a few solar hot water systems and a large proportion of conventional hot water systems and associated components have been tested and their energy consumption has been modelled for the purposes of this system. It is recommended that the system for calculation of energy consumption of heated water systems described in AS/NZS 4234:2008 replaces the existing Hotwater Module. This recommendation is based on the fact that this system is already in use for legislative purposes, its accuracy has been tested and accepted by the Australian Federal Government and it utilises far fewer questionable assumptions than the existing Hotwater Module, which is currently incorporated into AccuRate Sustainability. The STC's for a given system (STC_{system}) can be easily converted to solar fraction, by dividing by the maximum achievable number of STC's for the given system type. i.e. Solar Fraction = $STC_{system}/STC_{max\ achievable}$ It should be noted that $STC_{max\ achievable}$ is determined by the size of the system and relates to the energy consumed by a similarly sized reference system to which the solar hot water system is being compared for the sake of calculating associated energy savings (see AS/NZS 4234:2008). It should also be noted that the current version of the Hotwater Module utilises a significantly different reference system for the sake of comparison, which should also be brought into line with the methodology described in AS/NZS 4234:2008. Lastly, it must be mentioned that the assumed relationship between Solar Fraction and the SHW coefficient utilised in the existing Hotwater Module is as follows: Solar Fraction = 1- SHW

Space Heating Module: Ducting Loss Model	2.2.1.3.1	The very basic methodology for estimating delivery efficiency appears to ignore the complex nature of ducting losses. The option to utilise a much more complex methodology is mentioned in the AccuRate Sustainability (v.2.3.3.13) Software Manual (see equation below), however the complexity of this makes its use impractical for the vast majority of Accurate users. It is recommended that a more comprehensive ducting loss model be incorporated into the Space Heating Module of AccuRate Sustainability, whereby a simple list of variables to be entered and selected is incorporated.
Space Heating Module: Heating System Prioritisation	2.2.1.3.2	It appears that the prioritisation of older and inefficient oil, gas and wood fired space heating systems over highly efficient heat pumps is counterintuitive, therefore it is recommended that prioritisation is informed by the efficiency of all systems. It is recommended that the Space Heating Module prioritises the use of appliances, based on their efficiency, where the highest efficiency appliances are given the highest priority for utilisation.
Space Heating Module: Emission Factors	2.2.1.3.3	The emission factors associated with the burning of a given fuel in a given location should be identical. These values must be aligned so that all modules utilise the same emission factor for the same fuel source and associated physical process (e.g. burning fuel to generate heat) in a given location.
Space Heating Module: Reverse Cycle Space Heating System Rated Efficiency	2.2.1.3.4	In practice, the efficiency of a reverse cycle space heating system is highly likely to vary as the outdoor temperature varies, in addition to variations according to age and other factors. The rated value will likely be correct at an outdoor temperature of approximately 7°C. The treatment of values of efficiency as being fixed is therefore, in most cases, an erroneous assumption and will most likely adversely affect the accuracy of associated calculations of the Space Heating Module. It is recommended that the Space Heating Module varies the value of rated efficiency, obtained from the energy rating website, according to Figure 2-4.
Space Heating Module: Space Heating Module Versus Existing MEPS Methodology	2.2.1.3.5	The MEPS legislative instrument represents a mature system that is used to evaluate critical aspects of the energy consumption of space heating appliances, which is currently accepted and utilised by the Australian federal government. Values for space heating energy, obtained using the MEPS system are known to be conservative estimates and almost always differ considerably to those obtained through use of AccuRate's Space Heating Module, for a number of reasons. Despite the variety of legitimate influences that contribute to this apparent discrepancy, such a discrepancy represents a source for users and the community to develop considerable mistrust of each separate system. It is recommended that a thorough investigation is conducted into the ways in which the methodologies utilised within the MEPS instrument can be aligned to those used within the Space Heating Module of AccuRate Sustainability to avoid mistrust and synchronise the inputs and outputs of two potentially complementary systems.

Space Cooling Module: Determining the Efficiency of a Space Cooling System	2.2.1.4.1	The aforementioned button, which is supposed to be linked to the relevant section of energy rating website, does not currently navigate to a suitable web page. Furthermore, the current default value of 2.9, which is listed and used by the Space Cooling Module, is applicable only to very large space cooling systems with capacity exceeding 39kW and is also therefore likely to be incorrect for the purposes of most users. The inconsistent language between the Space Cooling Module text and that of the energy rating website introduces the potential to confuse the user. It is recommended that the energy rating website link associated with the button in the Space Cooling Module is updated to navigate to a page containing all information that is relevant to the performance of a specific space cooling system. This button should also allow determination of the relevant minimum energy performance requirements from the appropriate standard (i.e. currently AS/NZS 3823.2:2013, pg. 20).
Space Cooling Module: Reverse Cycle Space Cooling System Rated Efficiency	2.2.1.4.2	In practice, the efficiency of a reverse cycle space cooling system is highly likely to vary as the outdoor temperature varies, in addition to variations according to age and other factors. The rated value will likely be correct at an outdoor temperature of approximately 35°C. The treatment of values of efficiency as being fixed is therefore, in most cases, an erroneous assumption and will most likely adversely affect the accuracy of associated calculations of the Space Cooling Module. It is recommended that the Space Cooling Module varies the value of rated efficiency, obtained from the energy rating website, according to Figure 2-5.
Space Cooling Module: Performance of Evaporative Space Cooling Appliances	2.2.1.4.3	The default value of performance for evaporative cooling systems is significantly high. This is most likely based on the relatively low energy consumption associated with the relatively high effective cooling capacity that can be achieved within an optimal range of combined outdoor temperatures and humidities. It must be noted however that, outside the optimal range of combined outdoor temperatures and humidities, most evaporative space cooling systems cannot effectively achieve thermal comfort within any zone during times where a space cooling load is present. Evaporative space cooling systems may not achieve thermal comfort for occupants where outdoor dry-bulb temperatures exceed 35°C, given that most standard systems do not achieve a temperature reduction of greater than 10°C in most climatic conditions experienced during the cooling season. Furthermore, as relative humidity increases above 50%, the ability of these systems to reduce indoor temperature and achieve thermal comfort for occupants diminishes considerably. For buildings where natural infiltration rates have been significantly reduced, the additional internal moisture load introduced by direct evaporative cooling systems is also a concern, in terms of the health and wellbeing of occupants and the impact on structural components of the house. It should be noted that currently, an Australian Standard is currently being drafted to allow the performance of evaporative space cooling and similar appliances to be evaluated. This draft standard was scheduled to be implemented before the end of the year 2019, however due to significant industry objections, the future of this document is unknown and may result in it becoming an informative publication, rather than a legislative instrument. It is recommended that, where possible, the rated efficiency of evaporative cooling systems is used within the space cooling module. Accordingly, it is also recommended that where a trend towards a common range of efficiencies for such systems is identified, then this should be used to modify the default value for evaporative space cooling systems, if significantly different to the existing default value.

Space Cooling Module: Combination of Evaporative and Refrigerative Space Cooling Appliances	2.2.1.4.4	The modelling of both a direct evaporative and a refrigerative space cooling system operating concurrently in one or more zones would theoretically, according to the Module, constitute the availability of a very large cooling capacity, based on the way that the weighted EER is calculated for a given zone. It must be noted, however, that if operated within the same zone, each of these two different types of system would drastically reduce the performance of the other i.e. they would 'fight' each other. This relates to the incompatible mechanisms by which each type of system achieves a cooling effect, where evaporative systems maintain a constant large volume throughput of air with a high relative humidity whilst refrigerative systems maintain a relatively very low throughput of air with much lower levels of relative humidity, in comparison to that achieved by evaporative systems. It is recommended that, where both evaporative and refrigerative type systems exist in a house, that the Space Cooling Module generates warnings associated with the potential negative impact of using such systems concurrently within the house. Furthermore, it is recommended that the cooling module does not allow modelling of the cooling effect of both systems concurrently, preferably within the entire house, but at least within each serviceable zone.
Space Cooling Module: Age Based Performance Degradation	2.2.1.4.5	It is unclear whether the two age-based performance reduction techniques for space cooling systems should be used consecutively or separately. If used separately, the accuracy of these systems is questionable, however when used together they appear to generate expected levels of efficiency, based on previous, in-house, research consultancy. It is recommended that, where the rated performance of a system is unknown, all possible factors are applied in order to most accurately reflect the systems actual performance.
Space Cooling Module: Space Cooling Module Versus Existing MEPS Methodology	2.2.1.4.6	The MEPS legislative instrument represents a mature system that is used to evaluate critical aspects of the energy consumption of space cooling appliances, which is currently accepted and utilised by the Australian federal government. Values for space cooling energy, obtained using the MEPS system are known to be conservative estimates and almost always differ considerably to those obtained through use of AccuRates Space Cooling Module, for a number of reasons. Despite the variety of legitimate influences that contribute to this apparent discrepancy, such a discrepancy represents a source for users and the community to develop considerable mistrust of each separate system. It is recommended that a thorough investigation is conducted into the ways in which the methodologies utilised within the MEPS instrument can be aligned to those used within the Space Cooling Module of AccuRate Sustainability to avoid mistrust and synchronise the inputs and outputs of two potentially complementary systems.
CO_2 Emissions Factor	2.2.1.5	As emissions factors are updated regularly, it is highly recommended that a mechanism be introduced to AccuRate Sustainability that allows the user / assessor to adjust CO_2 emission factors.