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The Evaluation of the 5-Star Energy Efficiency Standard for Residential Buildings

Final Report

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December 2013

A Report to the Department of Industry

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Contents

Part 3 Supporting data 104

Part 4 - Appendices 147

Figures

Tables

Appendix Figures

Appendix Tables

Acknowledgments

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- Envirovision Australia Pty Ltd (supply, installation and maintenance of the energy monitoring systems)
- Association of Building Sustainability Assessors (quality control of the energy re-rating process)

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Executive summary

BACKGROUND

In 2006, the Building Code of Australia (BCA) set a new residential building energy efficiency standard of 5 stars, as rated by software tools accredited under the Nationwide House Energy Rating Scheme (NatHERS). To reach the 5-star energy efficiency standard, architects and builders could choose from a large variety of options, such as increasing insulation in ceilings, walls and floors; using double glazing; and redesigning house layout and orientation.

The Regulation Impact Statement (RIS) on the 5-star standard analysed its likely impact on the energy efficiency of new houses relative to the previous standard. The RIS estimated that the 5-star standard would reduce heating and cooling energy costs, as well as greenhouse gas emissions. In 2012, to assess whether the new standard was achieving its goals, the Australian Government asked CSIRO to:

i) find out whether the 5-star standards have actually reduced heating and cooling energy use of houses compared with those built to the earlier 3.5 to 4-star standard; and

ii) determine the actual benefits and costs of meeting the 5-star standard

To undertake this task, CSIRO studied 414 houses in the principal centres of population of three BCA climate zones over a winter and summer period.

KEY FINDINGS

This report details CSIRO's response to the above questions. In this report, 5-star (or above) houses are referred to as higher-rated houses, while houses less than 5-stars were referred to as lower-rated houses.

The findings should be regarded as preliminary, because research work and monitoring is ongoing and relevant only to the houses that were included in this study (i.e. detached houses built in the last ten years in Brisbane, Adelaide and Melbourne). Several factors have made it difficult to draw robust conclusions about the differences in energy use between lower-rated and higher-rated houses that could be applied to other such houses across Australia. Some of the factors causing this uncertainty are briefly described below.

- The uneven distribution of houses across star rating values in the data set means that the sample size restricts the conclusions that we can make.
- The small sample size causes uncertainty about how representative the data set is of Australia's households, particularly in relation to household type, occupancy patterns and user behaviour.
- The above-average temperatures during the summer period make it likely that air-conditioning appliances were operating at full capacity, regardless of star rating, making it difficult to detect differences between lower and higher-rated houses.
- The higher-rated houses were generally constructed more recently than the lower-rated houses, and further investigation is needed to check whether this caused any inherent bias. For example, the newer, higher-rated houses were more likely to contain younger children, have someone home all day, and identify themselves as high energy users.

- The expected energy ratings of the houses in our sample have not increased in line with the changes in building regulation. The reasons for this, as well as the quality of build compliance issues raised by the study, needs to be further examined.

Increased monitoring of houses across Australia will help to provide a clearer picture of the impact of increasing star ratings on household energy consumption. Data collected through this analysis should also be compared with alternative data sources to provide a more robust understanding of house performance.

Essentially, our main findings are as follows.

- The 5-star standard significantly reduced the energy needed to maintain house temperatures in winter in the houses we studied. As well as saving energy, higher-rated houses were on average held at a temperature around 1 °C higher than lower-rated houses during winter. It is not clear if this was because the occupants had set the temperature higher, or whether it was an innate property of the control system or a result of increased thermal insulation. We estimate in Section 10.2 that if the temperatures had been the same in both groups (thus comparing on a like-for-like basis), then the average energy per unit of conditioned floor area saved in the winter season in the post-2006 cohort of higher-rated houses would have been:
    - 0.4 kWh m^{-2} electricity in Brisbane (climate zone 2): 20% reduction (10.2.1)
    - 2.7 kWh m^{-2} electricity in Adelaide (climate zone 5): 39% reduction (10.2.2)
    - 29 kWh (104 MJ m^{-2}) gas in Melbourne (climate zone 6): 56% reduction (10.2.3).

  Without compensating for the increased warmth of higher-rated houses, the observed average energy saving for winter was:
    - negligible in Brisbane (climate zone 2) (10.2.1)
    - 1.3 kWh m^{-2} electricity in Adelaide (climate zone 5): 19% reduction (10.2.2)
    - 25 kWh m^{-2} (86 MJ m^{-2}) gas in Melbourne (climate zone 6): 50% reduction (10.2.3).
- The average cooling energy use in summer was greater in the higher-rated houses in Brisbane and Melbourne. However, it is not clear whether this was due to the 5-star standard, the make-up of the house occupancy of higher-rated houses with more children and higher rates of full-time occupancy, or other behavioural factors. These include the extent of window opening and closing during summer, and the scale of heat loads from other home appliances and equipment (Chapter 3). There was also no difference in the temperature between the lower and higher-rated houses. CSIRO is continuing measurement and statistical analysis on the houses included in this study.
- Greenhouse gas emissions were reduced in winter in higher-rated houses in all cities (Table 9-1). However, summer emissions increased in higher-rated houses in all cities (Table 9-2). Overall, greenhouse gas emissions were still reduced by 7% for the higher-rated houses over the year, despite the summer season increase.
- Heating costs were reduced and cooling costs increased in higher-rated houses (Table 9-1 and Table 9-2). The net annual impact was that Brisbane costs were greater in higher-rated houses, whereas Adelaide and Melbourne costs were lower for the higher-rated houses (Table 9-3). The reductions in Adelaide were small, but in Melbourne the reduction was a significant (37% or $194 per year).

- The higher-rated houses cost at least $5000 less in Adelaide and Melbourne for those elements of the building related to energy efficiency than lower-rated houses, and up to $7000 less in Brisbane. Increases in the amount of insulation and an apparent shift to more rectangular house design were the most influential aspects observed in the shift to higher-rated houses.

We conclude that the 5-star standard has produced significant savings in heating energy use in the sample. However, we need to improve our understanding of summer-time house cooling energy efficiency. The smaller-than-expected value of the temperature difference between the interior of the house and the outside environment suggests that additional variables are affecting house cooling compared with house heating. The relatively small sample size used in analysing some cohorts, particularly in Brisbane, may have also affected our ability to draw firm conclusions. Identifying and evaluating these variables will enable architects, building sustainability assessors and equipment designers to provide more thermally efficient house cooling, as well as advise the public about improving thermal comfort and reducing summer energy bills. Further analysis of the massive dataset that CSIRO has produced will help to reveal these areas of potential energy efficiency gains for housing.

PROJECT METHODOLOGY

To provide the data required to answer the questions presented in the Background section, we recruited and surveyed 414 volunteer households of different star ratings across three cities, in three different BCA climate zones: Brisbane (Zone 2), Adelaide (Zone 5) and Melbourne (Zone 6). We re-rated each house, measured inside and outside temperatures, and obtained household energy bills over the study period. We then selected 209 of these houses to further measure the amount of energy used by heating and cooling appliances. The study ran from June 2012 (winter) to the end of February 2013 (summer).

We calculated the average energy consumption of two cohorts of houses in each climate zone: those less than 5 star and those that were 5 stars or greater. To generate meaningful sample sizes for all later comparisons, the approach taken for clustering houses by star rating was to round up the re-rated star rating by up to half a star. That is, houses have been deemed to be 5 stars or above if their re-rated star rating was greater than 4.5 stars. We also used statistical methods to find out how the overall summer and winter energy use for heating and cooling related to the houses' star ratings. While the energy savings quoted above are from the statistical assessment, they are consistent with the averaged measurements from the two cohorts. Results from both analyses are given in the body of the report.

HEATING AND COOLING ENERGY USE

We analysed the data from the volunteer households to ask whether the 5-star standard actually reduced heating and cooling energy use in houses compared to those built to the earlier 3.5–4-star standard. In other words, are higher-rated houses more energy efficient than lower-rated houses?

The type of heating and cooling equipment varied among the houses in the study. Reverse cycle air-conditioning (heat pumps) were the dominant heating system in Brisbane and Adelaide, whereas gas heating was dominant in Melbourne. In Brisbane and Adelaide, heat pumps were the dominant cooling system. In Melbourne, 40% of houses used evaporative cooling, 40% used heat pumps, and the remaining 20% had no cooling system. As the star rating system does not take into account the type of heating or cooling appliance, we separated houses into cohorts with the same appliance type when performing statistical analysis.

Winter heating energy use

Regardless of climate zone or heating system, we found that the higher-rated houses had slightly higher temperatures than lower-rated houses in the main living area: typically from 0.6 to 0.9 °C higher. This was unexpected, because we anticipated that temperatures would be the same in all houses. The higher temperatures could be due to human behaviour, greater insulation, or an innate property of the control system.

The measurements and statistical analysis provided us with enough information to calculate, at 95% significance, how much energy was being saved (actual savings), as well as how much additional energy (inferred savings) could have been saved if the higher-rated houses had been operating at the same temperature as the lower-star rated houses. From the statistical analysis, the actual and inferred energy saving in winter for a higher-rated house (compared with a lower-rated house) are given below:

- Brisbane: 20% potential savings, if temperatures were kept at the same level as for the lower-rated houses
- Adelaide: 19% actual saving, with an additional 21% potential saving due to the increased temperature in the higher-rated houses
- Melbourne: 50% actual saving, with an additional 6% potential saving due to the increased temperature in the higher-rated houses.

Summer cooling energy use

Energy consumption was increased in summer in houses with higher star ratings in Brisbane and Melbourne, while the test results from Adelaide were not statistically significant for a 95% confidence level. These summer results may have been confounded by the following two factors:

i) cooling equipment running at full capacity during the particularly hot 2012–13 summer months (if this was the case, then the measured energy consumption is merely an indicator of the installed capacity of the air conditioners, rather than a measure that can be used to assess the effect of star rating)

ii) it was not possible to reliably assess the levels of ventilation being used in the houses.

More measurements and a more detailed analysis are needed to resolve these two issues.

Comparing summer cooling and winter energy use

The difference between interior and exterior house temperatures in summer was relatively low compared with winter. In contrast, heating energy consumption in winter did an effective job of warming the house above the ambient temperature. This difference between winter heating and summer cooling may be because houses contain substantial internal sources of heat that place an additional load on cooling in summer, but assist heating in winter. These might include heat loads, such as ovens, standby[1] power, televisions and computers; or ambient heat and solar heat that has entered the house and been stored. Another factor making analysis of these results difficult was the wide variety of cooling methods, such as ventilation, shade, fans and air conditioners.

BENEFITS AND COSTS

Possible benefits arising from higher-rated houses could include improved occupant comfort, reduced electricity and gas costs, and reduced greenhouse gas emissions. We analysed each of these by comparing the difference between the inside and outside temperature, analysing energy bills, and measuring the energy used by heating and cooling appliances to determine greenhouse gas emissions, respectively.

In winter, the increased temperature of 0.6–0.9 °C in the higher-rated houses may have improved occupant comfort. However, a greater energy saving benefit may be realised by householders in higher-rated houses if their winter-time thermostat settings were lower and closer to the value in lower-rated houses.

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[1] Standby is now one of the largest individual electrical end uses in the residential sector (~10%) and is probably equivalent to the energy consumption of refrigerators and freezers. (Energy Efficient Strategies, October 2006)

When considering whole-of-house energy consumption, cost reductions were observed in Adelaide and Melbourne for higher-rated houses, with a 3% reduction in costs in Adelaide and a 13% reduction in Melbourne. Brisbane houses effectively remained the same (Table 8-3).

When considering heating/cooling appliance energy consumption, we did not see a reduction in electricity costs in higher-rated houses compared with lower-rated houses. It is possible that energy saved from heating higher-rated houses was used elsewhere, for example, to maintain higher temperatures in the house. In houses with gas heating, the gas consumption was 52% less in higher-rated houses than in lower-rated houses (Table 9-1).

In winter, average greenhouse gas emissions from heating appliances were reduced in higher-rated houses compared with lower-rated houses: by 50% in Melbourne, 9% in Adelaide and 13% in Brisbane. In summer, preliminary (not statistically significant) results suggest that greenhouse gas emissions may be increased for the higher-rated houses in all cities: by 37% in Melbourne, 11% in Adelaide and 28% in Brisbane. The result in Melbourne was affected by the high emission factor of brown coal-fired power stations.

As well as the measured energy saved due to the 5-star rating, there were also potential savings to be made due to the increased temperatures in higher-rated houses. Overall, the improved insulation in higher-rated houses appears to have the potential to save energy and greenhouse gas emissions in winter, but makes little difference in summer.

In the RIS, the costs of meeting the 5-star standard were expected to be more than for lower-rated houses. However, our results show that based on the sampled house designs, it has actually been less expensive to meet the 5-star standard than the previous standard. The average cost for those elements of a building that are related to achieving the star rating were $7,500 less in Brisbane, $5,500 less in Adelaide and $5,000 less in Melbourne. This was mainly because of an observed shift to more rectangular floor plans; leading to a larger floor area per unit of wall and glazing (the window-to-wall area ratio was similar). Although the cost of insulation rose, this was outweighed by the savings made on walls and windows. The cause for these changes in design may be due to factors unrelated to the star rating, but their inclusion affects the star rating and the cost of the building.

RECOMMENDATIONS FOR FURTHER WORK

Overall, this research has shown that a great deal of further measurement and analysis is required to enable effective decisions about the future of house cooling energy efficiency in Australia. We have amassed an extremely large data set, which has so far been only partially analysed. More research is required to unlock learnings from this data.

For example, the current study focused on averaged seasonal data sets, rather than on what happens in specific circumstances. Analysing subsets of data from particular time periods under particular search conditions may help to reduce uncertainty by eliminating irrelevant data. It would also help answer a range of additional questions. For example, under what conditions do people turn on their air conditioners? What room temperatures are being achieved when the air conditioner is switched on?

More contextual data may also need to be gathered from the sample houses and occupants to better understand the key drivers of heating and cooling energy use. Maintaining the existing cohort of houses presents Australia with the opportunity to create a register of monitored test houses for future studies.

More research is also required to compare the energy performance of individual houses using the Chenath thermal modelling engine, which forms the basis of the rating tools accredited under NatHERS. Predictions from the Chenath engine should be done under *as-occupied* assumptions, rather than rating assumptions. This would help to further validate the NatHERS benchmark calculation engine and provide a basis for identifying key house design sensitivities.

The data should also be used to explore a range of industry issues, such as:

- quantifying the impact of thermal loads, such as cooking appliances, entertainment and home office electronics, standby loads and human metabolism, which may favour heating efficacy in winter over cooling efficacy in summer
- identifying the variety of human behaviour (e.g. opening windows) and thermal comfort factors (e.g. thermostat settings) affecting energy consumption, and informing the Australian public about improving thermal comfort and saving energy in their houses
- using this information to better understand which house design solutions are most appropriate for summer cooling-dominated climates
- identifying the relationship between the peak cooling demand predicted by the Chenath engine and air-conditioner sizing, and informing the residential air-conditioning industry of opportunities for improving energy efficiency and reducing costs

Part I Background and methodology

1 Assessment approach

1.1 Background

In 2011, the Department of Climate Change and Energy Efficiency (subsequently abolished, with its energy efficiency functions transferred to the Department of Industry) commissioned the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to ascertain the actual benefits and costs resulting from the introduction of the 5-star energy efficiency standard for housing from 2006 in the Building Code of Australia (BCA). In particular, this study addresses two research questions:

1. How effective has the standard been in reducing actual (not simulated) conditioning energy use (heating and cooling) relative to houses constructed to earlier energy efficiency standards, specified as between 3.5–4 stars in the 2003–2005 releases of the BCA?
2. What are the actual benefits and associated costs of the 5-star standard relative to the 3.5–4 star standard, in terms of construction costs, avoidable energy costs, heating and cooling appliance costs, and total lifetime costs?

1.2 Scope

The impact of the Nationwide House Energy Rating Scheme (NatHERS) rating on energy consumption was assessed by comparing NatHERS star ratings against measurements of energy consumed by heating and cooling appliances in 209 households across Melbourne (BCA climate zone 6), Adelaide (BCA climate zone 5) and Brisbane (BCA climate zone 2). An additional 205 houses were assessed for supporting information using NatHERS ratings, energy bills and surveys. This report covers the assessment's methodology, assumptions, results and key outcomes. It also makes recommendations for ongoing work and suggestions to further improve the standard.

This assessment was carried out across 414 houses in climate zones 2, 5 and 6. It took into account the following parameters:

- building design, construction and particular energy efficiency measures
- half-hourly measures of internal and external air temperature and external dewpoint
- half-hourly measures of total electricity consumption and heating and cooling appliance electricity consumption
- heating and cooling appliance efficiency
- estimates of cost saving to the householder and cost to the builder
- estimates of greenhouse gas emissions
- measures of human behaviour that might offset or support energy consumption

The scope of work required to achieve this objective included:

- identifying houses with a high probability of a star rating in the required range
- recruiting 414 householder volunteers, which required screening approximately 800 applications
- obtaining access to 414 house plans from local councils or architects, and where available, energy rating reports
- interviewing all householders on site and then following up using a website questionnaire
- installing and maintaining temperature sensors in 414 houses and energy monitoring equipment in 209 houses

- inspecting each house for quality of the efficiency measures and to characterise heating and cooling appliances
- carrying out a NatHERS star rating assessment on each house
- obtaining electricity and gas bills from the energy retailer for each household
- managing data acquisition, data security, data integrity, analysis and reporting

A full description of the methodology is in Appendix A.

1.3 Implementing the methodology

1.3.1 VOLUNTEER HOUSE SELECTION

The study recruited 414 households across three distinct climate zones as determined by the BCA. The climate zones were Zone 2, Zone 5 and Zone 6, as shown in Figure 1-1, which correspond to the major population centres. Zone 2 encompasses Brisbane and much of Queensland's coastline south of the Tropic of Capricorn. Zone 5 covers Sydney, Adelaide and Perth, while Zone 6 covers most of the populated areas of Victoria, including Melbourne. Consequently, house selection focused around major growth areas in the south-east Queensland area and growth areas of Adelaide, Melbourne and Geelong. New South Wales was excluded from the study, due to its use of BASIX to assess houses for building approval, rather than NatHERS. Perth has been excluded due to its distance from the east coast (which would lead to travel cost increases) and the predominance of double brick houses, which could lead to a bias in the results being applied to other houses in the same climate zone.

Houses selected were required to have been subjected to the energy efficiency provisions of the BCA that were first introduced in 2003. Consequently, this put a 10-year age constraint on the houses included in this study. The various states and territories brought in their requirements for the energy efficiency provisions at different times, so the level of performance required varied between regions at a given point in time.

Volunteer recruitment aimed to obtain an even distribution of houses across star ratings ranging from 3 to 5 stars. It was not possible to predetermine star ratings for the houses during the recruitment phase, so date of construction was used as a proxy for star rating. All recruited houses were then re-rated to determine their actual star rating, and this was used as the basis for the star rating analysis. Appendix A (A.3.4) provides a comprehensive analysis of the statistical distribution of star ratings within each subgroup tested.

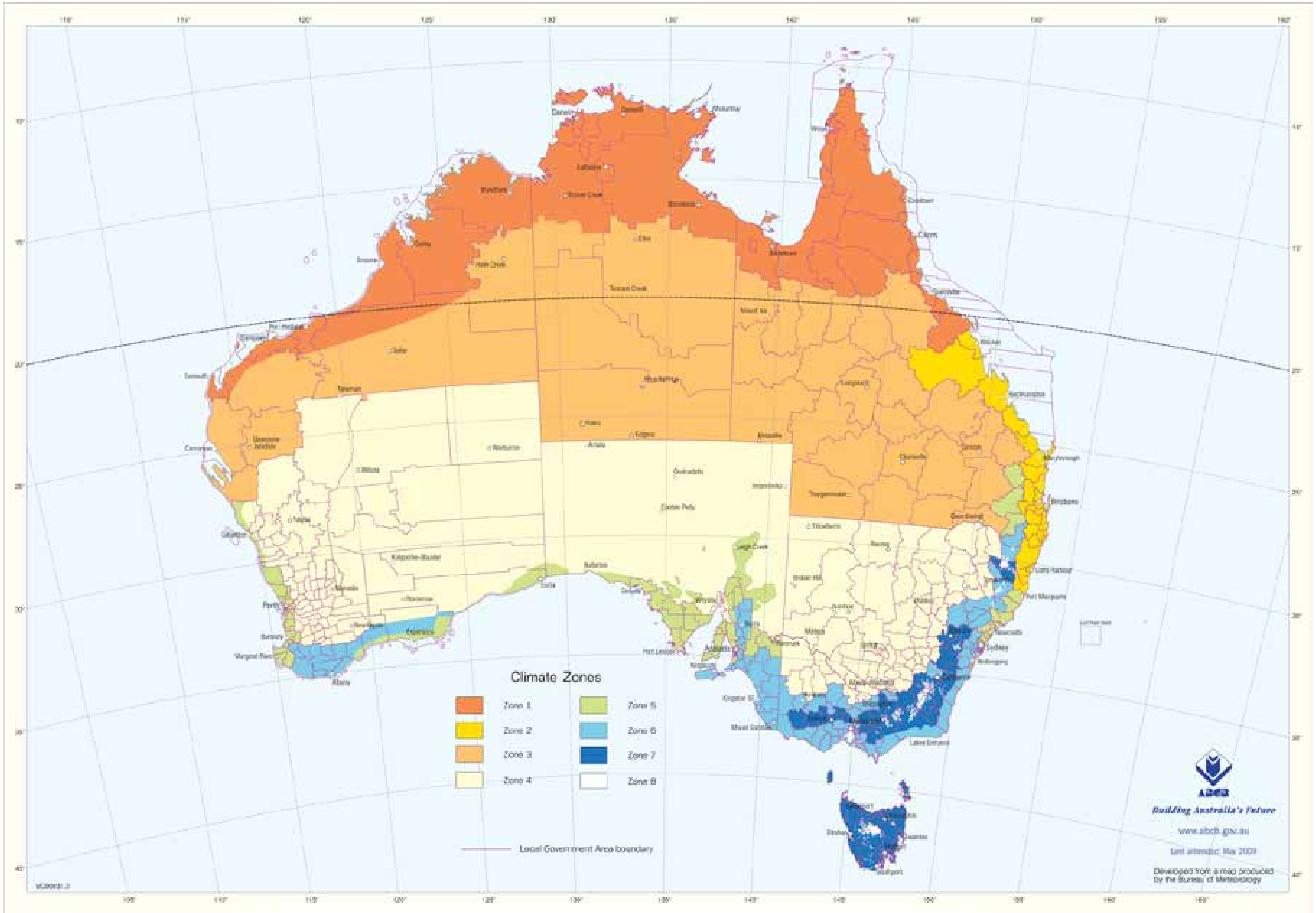


Figure 1-1 **Climate zones of Australia as determined by the Building Code of Australia**

1.3.2 HOUSE SURVEYS

Each volunteer household underwent two surveys: a household survey completed by the occupant, and a house audit survey completed by an Association of Building Sustainability Assessors (ABSA)-accredited assessor who visited the property. The household survey focused on the occupant's perceptions of the energy efficiency aspects of their house and their actions and attitudes towards energy efficiency. The house audit focused on the physical characteristics of the house, including the quality of insulation install, the type of heating/cooling appliances, hot water units and lighting systems being used, and the presence or absence of weather sealing.

Correct 3levels of insulation and proper installation were checked through two main methods. First, a physical inspection (where possible) was undertaken to determine the type of insulation used, including an estimate of its R rating. Where physical inspection was not possible, thermal imaging determined insulation effectiveness and coverage. In most houses, physical inspection of ceiling insulation was possible, but this was not possible for wall insulation. Thermal imaging of all houses confirmed whether insulation was installed correctly.

The BCA assumes a certain level of air tightness in buildings. This is achieved through weather sealing strips, door and window seals, plugging gaps in walls and self-closing seals on exhaust fans. The actual air-tightness level of a building can be determined through a blower door test, which pressurises the building and measures air exchange rates. Blower door tests, along with physical inspection of sealing methods, were undertaken in 20 houses in Melbourne to determine the general level of compliance with the BCA assumptions.

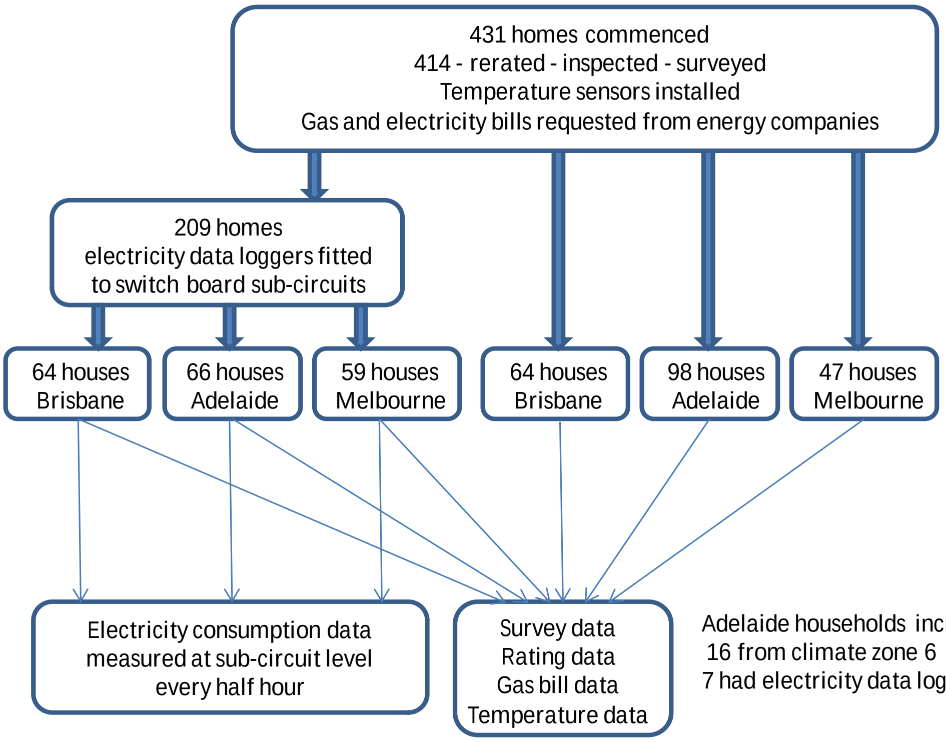
1.3.3 ACCURATE RE-RATING

All houses in the study were re-rated by ABSA-accredited assessors using the latest version of the NatHERS benchmark rating tool, AccuRate (v1.1.4.1). The NatHERS rating values were determined using a rigorous and standardised re-rating process, audited by ABSA, and with one assessor per climate zone. Full details are provided in Appendix B . Original house plans and BCA Energy Efficiency compliance paperwork was obtained from the home owner or local council where available. Figure 1-2 gives an overview of the distribution of data from the cohort of 209 households that originally had electricity data loggers, and the 414 volunteers whose houses had temperature sensors, rating assessments and surveys.

Table 1-1 lists the breakdown of the recruited volunteers by their climate zone, their city and their AccuRate star rating. The table also shows the number of active houses still being monitored by CSIRO, and the number of houses that have dropped out of the study in each climate zone.

Table 1-1 Study sample size

	Houses included in the study								Totals
Climate zone	**Climate Zone 2**		**Climate Zone 5**		**Climate Zone 6**				
City	**Brisbane**		**Adelaide**		**Adelaide**		**Melbourne**		
Still active	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Active**
	130	**17**	**135**	**6**	**31**	**1**	**107**	**4**	**403**
<3.5 stars	56	3	7	0	2	0	6	0	**74**
3.5–3.9 stars	16	3	16	0	5	0	13	0	**53**
4.0–4.4 stars	19	0	24	0	5	0	18	0	**66**
4.5–4.9 stars	17	1	41	4	7	0	36	3	**109**
5.0–5.4 stars	14	0	30	1	9	0	13	0	**67**
5.5–5.9 stars	3	1	12	0	2	0	11	0	**29**
6.0–6.4 stars	3	0	2	0	1	0	8	0	**14**
>6.4 Stars	0	0	1	0	0	0	1	0	**2**
No star rating done	2	9	2	1	0	1	1	1	**17**
Total rated	**128**	**8**	**133**	**5**	**31**	**0**	**106**	**3**	**414**



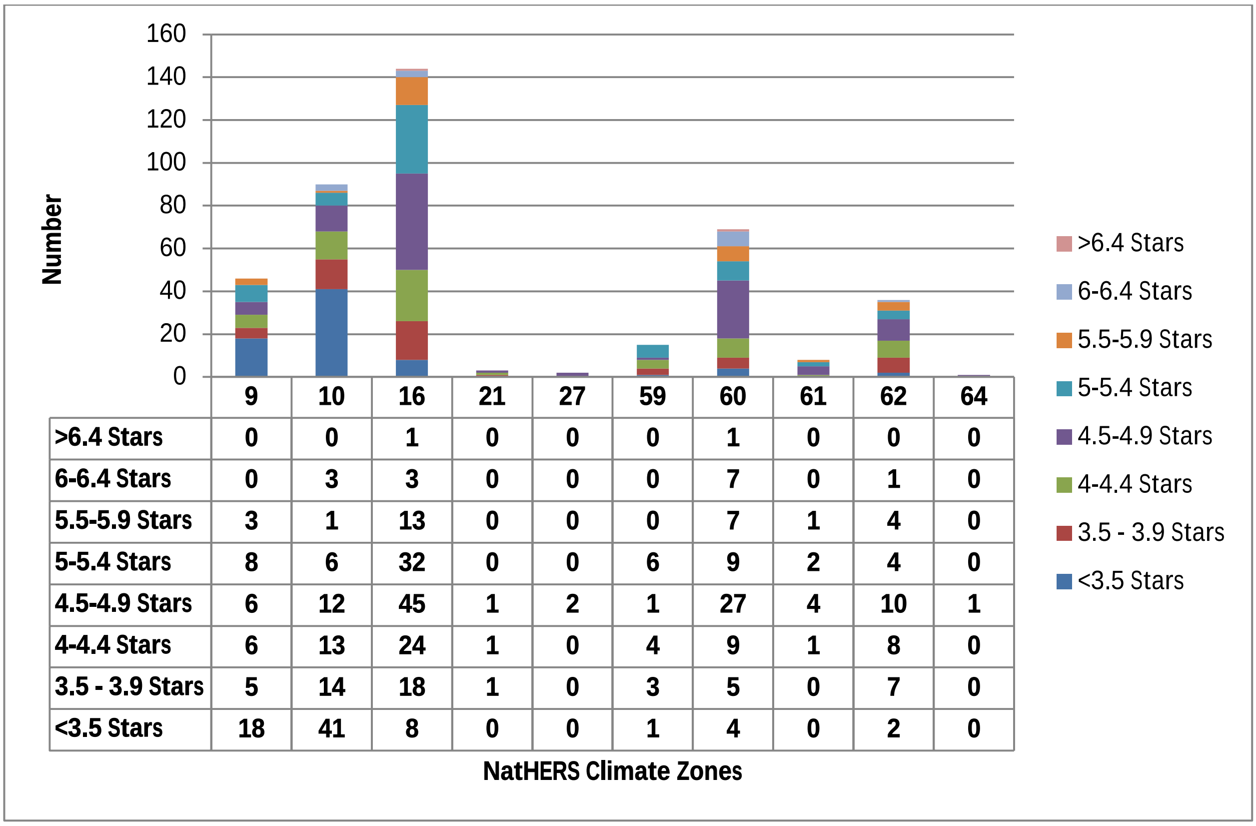
Adelaide households included
16 from climate zone 6
7 had electricity data loggers

431 households commenced
414 could be rated (council, builder, architect or original owner permission denied for the remainder)
Numbers assigned to cities are for rated houses that stayed in study until completion

Figure 1-2 Houses and data distributions

1.3.4 NATHERS CLIMATE ZONES

Although climate zones as determined by the BCA were the primary climate categorisation, NatHERS makes use of a much more refined climate zone categorisation with 69 climate zones. Within this study, ten different NatHERS climate zones were represented and used during the AccuRate re-rating process. Figure 1-3 shows the distribution of houses by their star rating and their NatHERS climate zone. Climate zones 9 and 10 are located in Brisbane, climate zones 16 and 59 are in Adelaide, and climate zones 21, 27, and 60–64 are in Melbourne.



	9	10	16	21	27	59	60	61	62	64
>6.4 Stars	0	0	1	0	0	0	1	0	0	0
6-6.4 Stars	0	3	3	0	0	0	7	0	1	0
5.5-5.9 Stars	3	1	13	0	0	0	7	1	4	0
5-5.4 Stars	8	6	32	0	0	6	9	2	4	0
4.5-4.9 Stars	6	12	45	1	2	1	27	4	10	1
4-4.4 Stars	6	13	24	1	0	4	9	1	8	0
3.5 - 3.9 Stars	5	14	18	1	0	3	5	0	7	0
<3.5 Stars	18	41	8	0	0	1	4	0	2	0

Figure 1-3 **Volunteer houses by NatHERS climate zone and star rating**

1.3.5 DATA COLLECTION

Data collection activities included:

- internal temperature monitoring of all houses
- monitoring of electricity consumption in half the houses in each climate zone
- whole-of-house energy billing data (electricity and gas) from all houses (where available)
- Bureau of Meteorology temperature and dew point data for local weather stations

Where houses had their electricity monitored, the heating and cooling electricity consumption and associated temperatures were measured at half-hourly intervals. This was carried out for the nine-month study period from June 2012 to February 2013 (summer, autumn and winter). Daily gas consumption was assessed from gas billing data.

1.3.6 ELECTRICITY AND TEMPERATURE MEASUREMENTS

Temperature was measured and collected in each house using Thermochron button cell data loggers (Figure 1-4). These were installed in a reasonably well-ventilated area of the main living area, on a wall high enough to be out of reach of young children and pets, and away from any direct source of cooling or heating. Measurements were taken at 30-minute intervals (using two sensors with alternating hourly recordings) and sensors were changed over every 80 days. Figure 1-5 shows a typical data output from one of the Thermochron sensors.

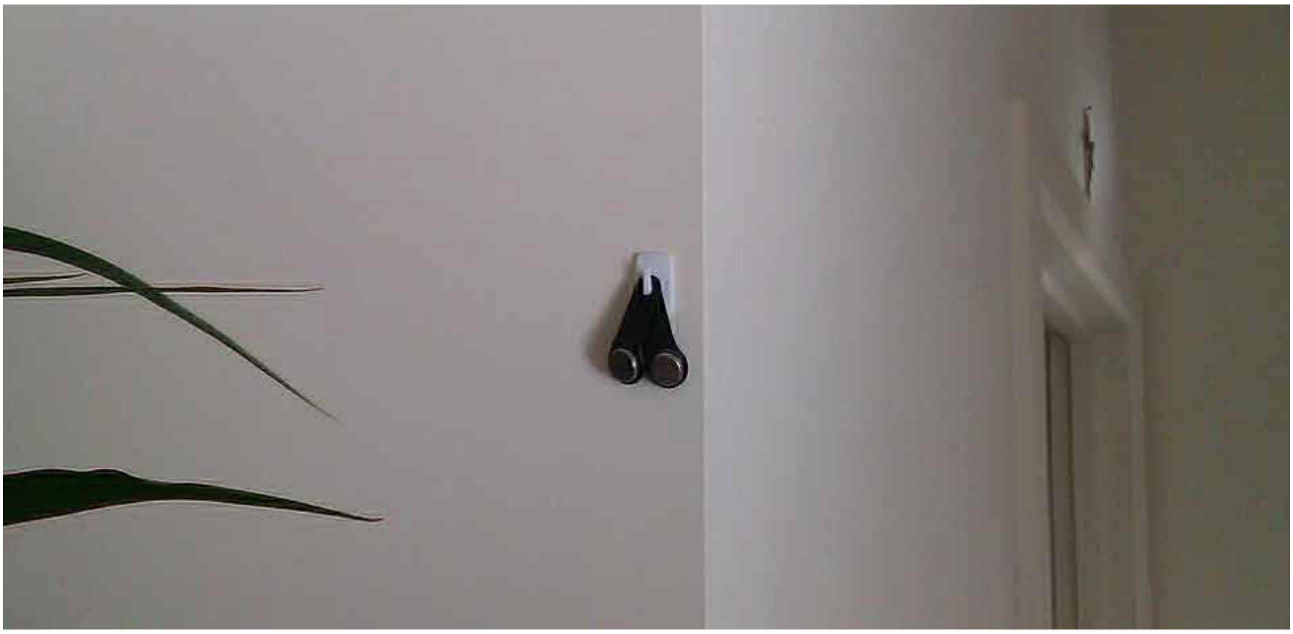


Figure 1-4 Typical Thermochron temperature sensor installed in main living area

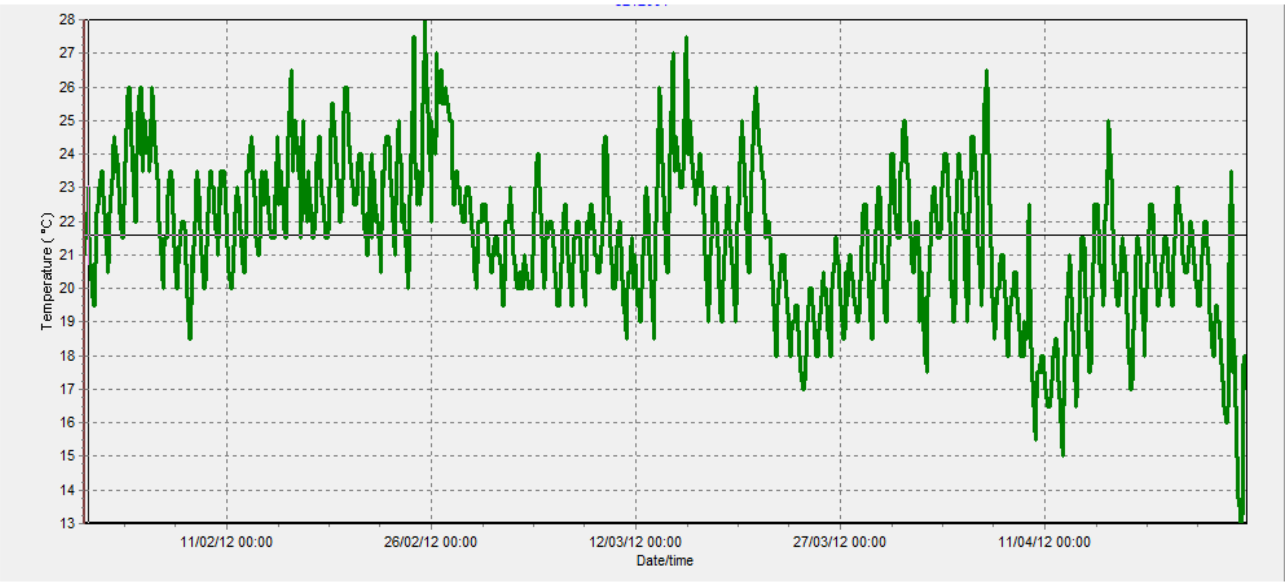


Figure 1-5 **Typical internal temperature data profile from Thermochron sensors**

Total energy consumption, together with heating and cooling energy consumption, was measured and collected in half the houses using an eight channel EcoPulse data logger. The data logger measured the current and voltage for up to eight sub-circuits and power factor at the main circuit in the house mains switch board. Total energy was calculated by summing all non-solar sub circuits. Figure 1-6 shows a typical EcoPulse installation, which also includes the use of a timer to reset the unit each day, and a Wi-Fi router and 3G modem to allow remote access for data downloads and ongoing maintenance checks.

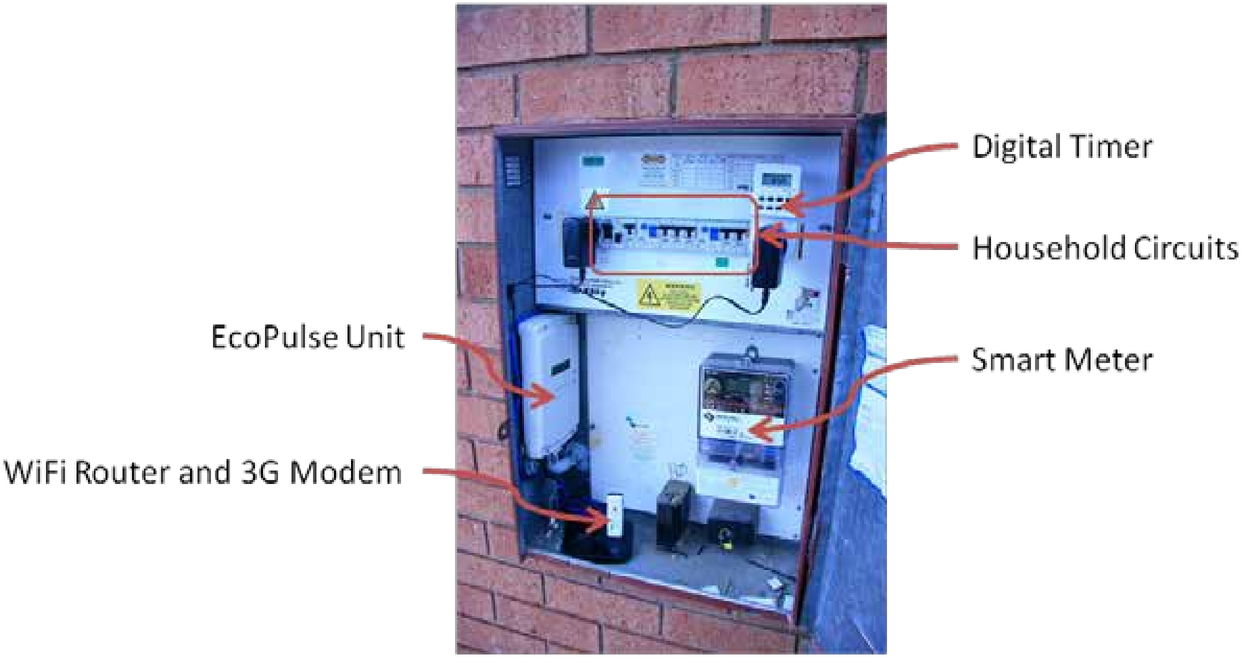
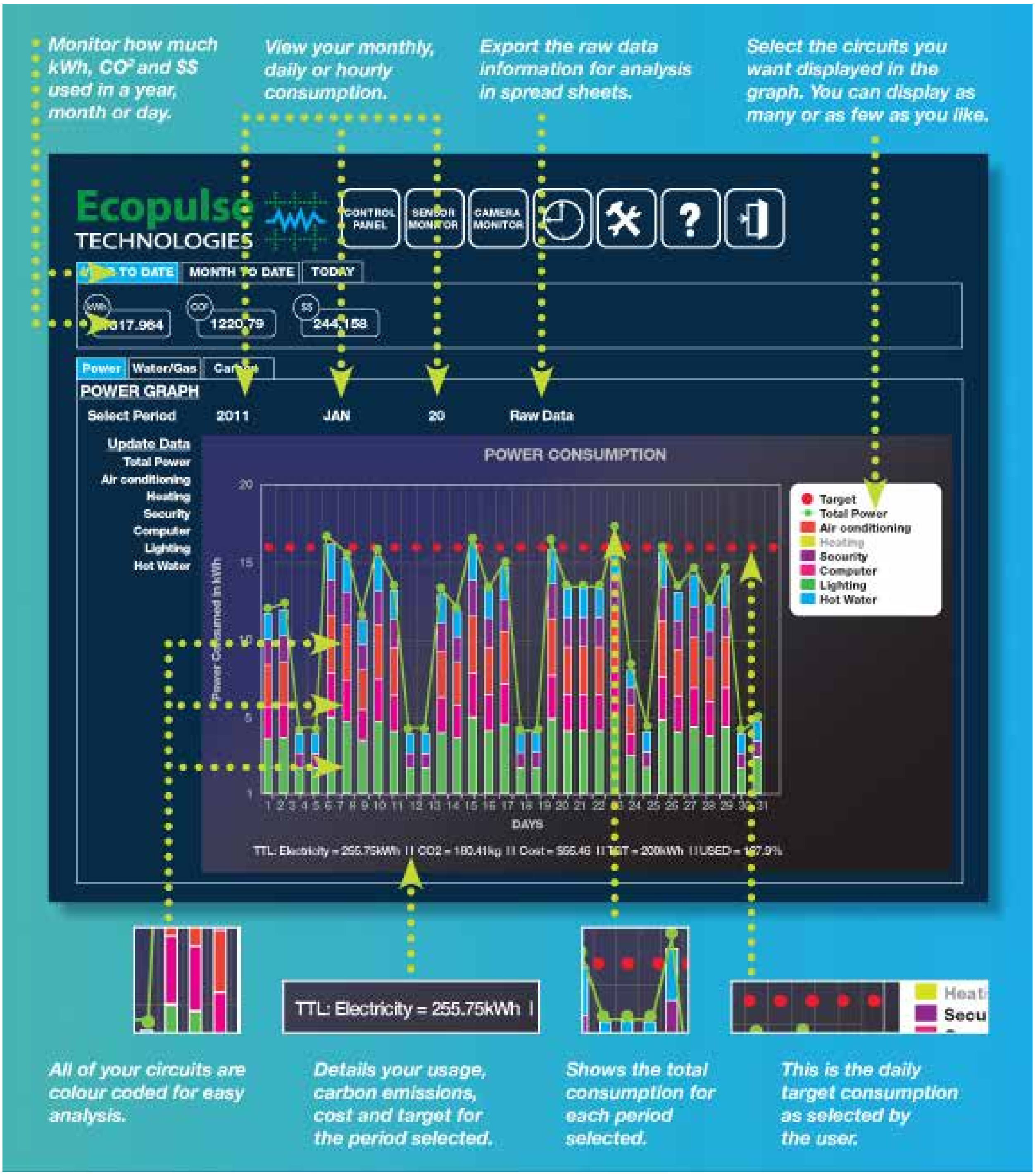


Figure 1-6 **EcoPulse installation with timer, Wi-Fi router and 3G modem**

1.3.7 DATA COMMUNICATION

Data was gathered at the EcoPulse unit and then transferred using a secure internet connection to a CSIRO database. Volunteers were promised access to a secure internet web page at the end of the assessment. This allows each household to monitor their home energy consumption (Figure 1-7). The same web page was used for rapid surveying of energy use patterns, which allowed us to determine characteristic signals in heating ventilation and cooling (HVAC) appliance power circuits.



Monitor how much kWh, CO² and $$ used in a year, month or day.

View your monthly, daily or hourly consumption.

Export the raw data information for analysis in spread sheets.

Select the circuits you want displayed in the graph. You can display as many or as few as you like.

All of your circuits are colour coded for easy analysis.

Details your usage, carbon emissions, cost and target for the period selected.

Shows the total consumption for each period selected.

This is the daily target consumption as selected by the user.

Figure 1-7 **EcoPulse web interface**

1.3.8 DATA STORAGE AND VALIDATION

Data storage for the electrical measurements was at three levels:

- local data storage at the data logger, updated every half-hour
- central data storage at a secure CSIRO server, updated twice a day
- a complete data download from the household units, updated three times during the nine-month monitoring period

Data summary logs were inspected twice daily. This allowed for a fast response to equipment failures at any household.

1.3.9 ANALYSIS OF ENERGY CONSUMPTION AND HOUSE THERMAL EFFICIENCY

Multiple regression analysis was used to estimate factors for the energy consumption dependence on NatHERS star rating, temperature and other variables. This allowed us to estimate the actual and potential savings resulting from application of the 5-star standard.

The calculation of house heating and cooling energy consumption reductions was considered in two parts: (i) energy consumption dependence on star rating, and (ii) energy that could potentially be saved due to temperature dependence on star rating. The second component was necessary because the analysis found a significant increase in the temperature difference in houses with higher star ratings. This is described in detail in 10.1 and in the Methodology in A.3.

1.3.10 ANALYSIS OF COSTS DATA

Building costs

To estimate the costs incurred in achieving the various star-rating standards, the analysis only focused on those elements of the building that are directly related to the star rating, being:

- window area
- window orientation
- glazing material
- floor, wall and roof materials
- wall area
- insulation

Additional sustainability measures that may be required by other aspects of the BCA or by various state, territory or local governments were not included. This included solar hot water systems, low-energy lighting, rainwater tanks and ceiling fans.

The quantities for the various materials were derived from the AccuRate assessments of each house in the study. AccuRate requires material details for external and internal walls, floor, ceiling, roof and insulation, as well as location and type of windows. The quantities of materials were calculated for every house in the study and then costed using Rawlinsons Construction Cost Guide (Rawlinsons, 2011). Costs for all houses are based on 2011 prices.

The average conditioned area of the sample of higher-rated houses was less than the average conditioned area of the sample of lower-rated houses. This could lead to a skewed cost comparison, because the total cost for a smaller house will often be less than a comparable larger house. To account for this, lower-rated houses that had a conditioned space greater than 230m^2 were excluded. This resulted in the average conditioned area of all houses being within ±5% within each city.

Finally, several assumptions were made to allow cost comparisons.

- Expanded polystyrene in a floor was considered to be a waffle pod.
- The cost of waffle pod concrete slab and standard in-ground concrete slab was considered to be the same, so no cost difference was calculated.
- All windows (both single and double-glazed) were considered to be awning windows.
- All external walls were considered to be brick veneer with timber stud and painted plasterboard.
- All wall and ceiling insulation was considered to be glasswool batts of the specified R value.

Operational and greenhouse costs

To determine the benefits of the higher star rating using the results obtained for the houses in each climate zone, our analysis included estimates of:

- savings to date in gas and electricity consumption
- greenhouse gas savings to date (measured as CO_2-e)

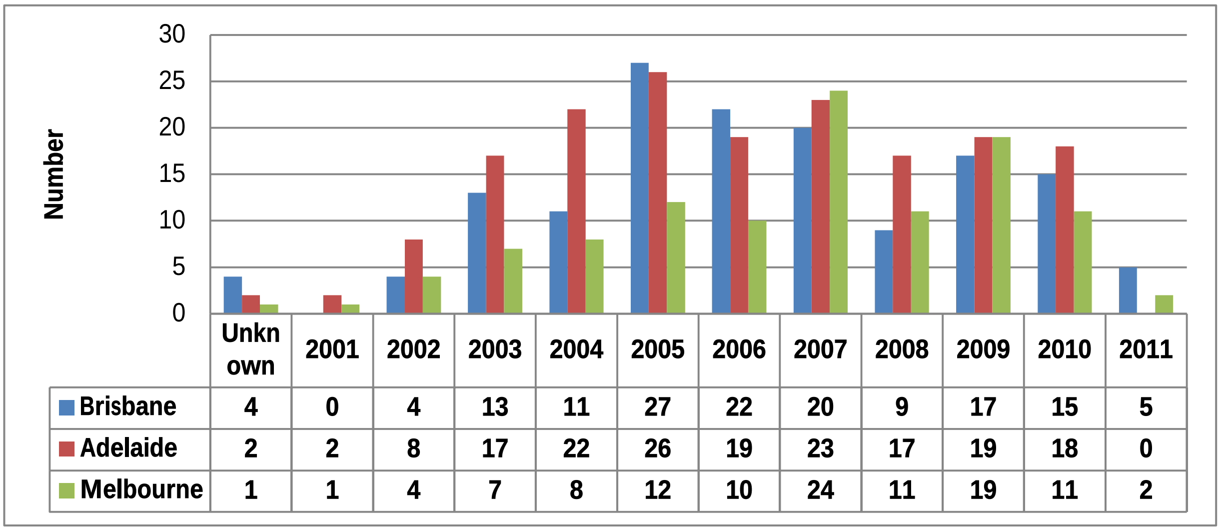
Standard energy tariff rates in each city were used to calculate the energy costs for households.

The greenhouse gas emissions impact of household energy used the factors given in the 'National Greenhouse Accounts Factors – July 2012' (Department of Climate Change and Energy Efficiency, 2012) for each city.

2 Overview of data – house

2.1 House types

The vast majority of houses recruited for the study were detached dwellings. There were 20 semi-detached townhouse-style dwellings, but no flats, units or apartments, because the study only covered BCA Class 1 residential buildings. All houses were constructed in the past 10 years, because houses built earlier than this would not have been subject to the energy efficiency provisions of the BCA. Figure 2-1 shows the distribution of building approval year for the volunteer households in this study, while Figure 2-2 shows the percentage of each. A relatively even spread of years has been achieved across all cities. For a small number of houses, the exact year of construction was unknown, because no dates were visible on the plans that were made available.



	Unknown	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
🟦 **Brisbane**	4	0	4	13	11	27	22	20	9	17	15	5
🟥 **Adelaide**	2	2	8	17	22	26	19	23	17	19	18	0
🟩 **Melbourne**	1	1	4	7	8	12	10	24	11	19	11	2

Figure 2-1 **Distribution of house building approval year by city**

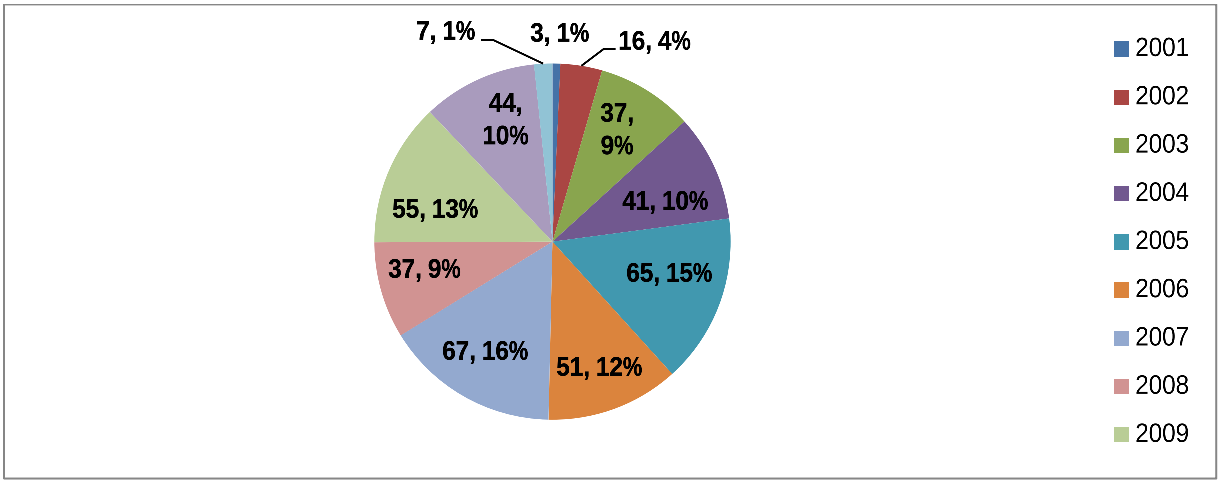
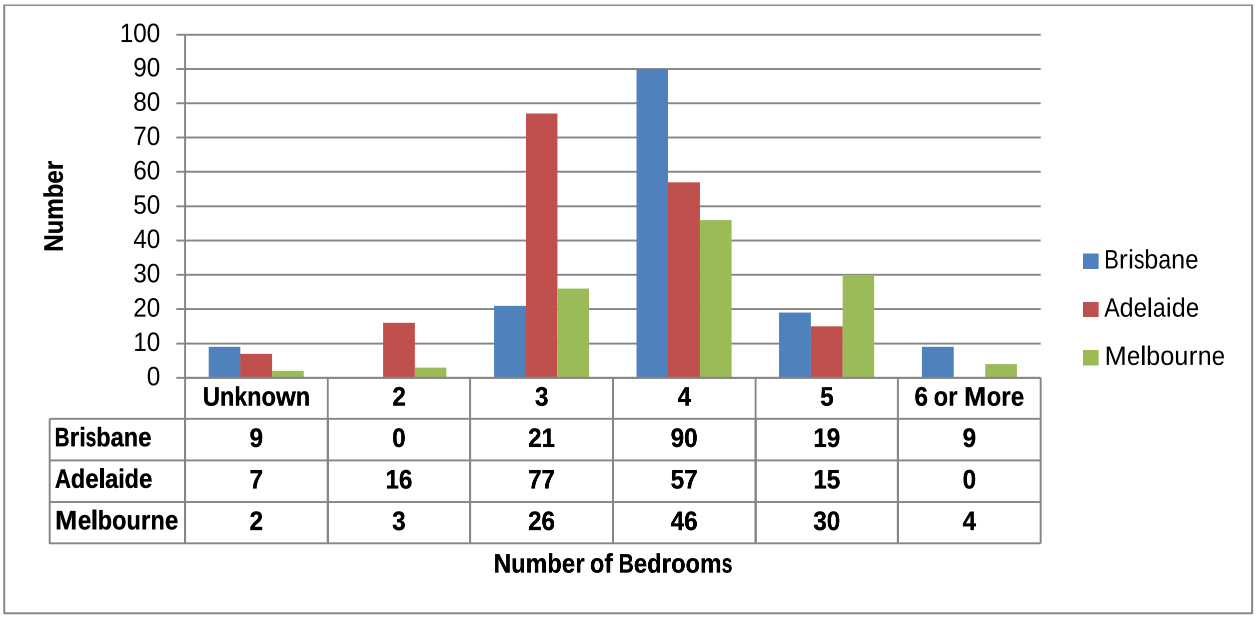


Figure 2-2 **Construction year for all houses (unknowns removed)**

The size of the houses and number of bedrooms reflects the move to larger houses that has been occurring over the past decade. Figure 2-3 and Figure 2-4 show that 63% of houses in the study have four or more bedrooms, although in Brisbane this figure is 85%. By comparison, the latest census data for Australia reveals that only 30.3% of households in the country have four or more bedrooms. The census data includes flats and units, but nevertheless, detached and semi-detached dwellings still represent the vast majority of Australian houses (85.5%).



	Unknown	2	3	4	5	6 or More
Brisbane	9	0	21	90	19	9
Adelaide	7	16	77	57	15	0
Melbourne	2	3	26	46	30	4

Figure 2-3 **Number of bedrooms per house by city**

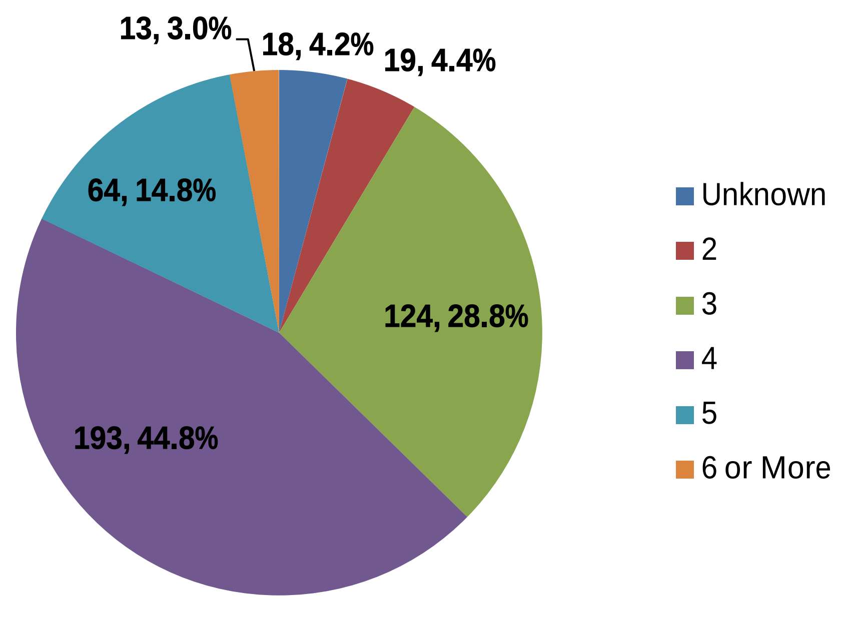


Figure 2-4 **Number of bedrooms for all houses**

Figure 2-5 displays the spread of house floor areas among the sample houses. Overall, the average house size is 201 m^2, with most houses between 100 m^2 and 300 m^2. Several very large houses are included (mostly in Brisbane), the biggest being 552 m^2. By city, Melbourne has the largest houses (224 m^2) and Adelaide the smallest (173 m^2), with Brisbane's average size being 216 m^2.

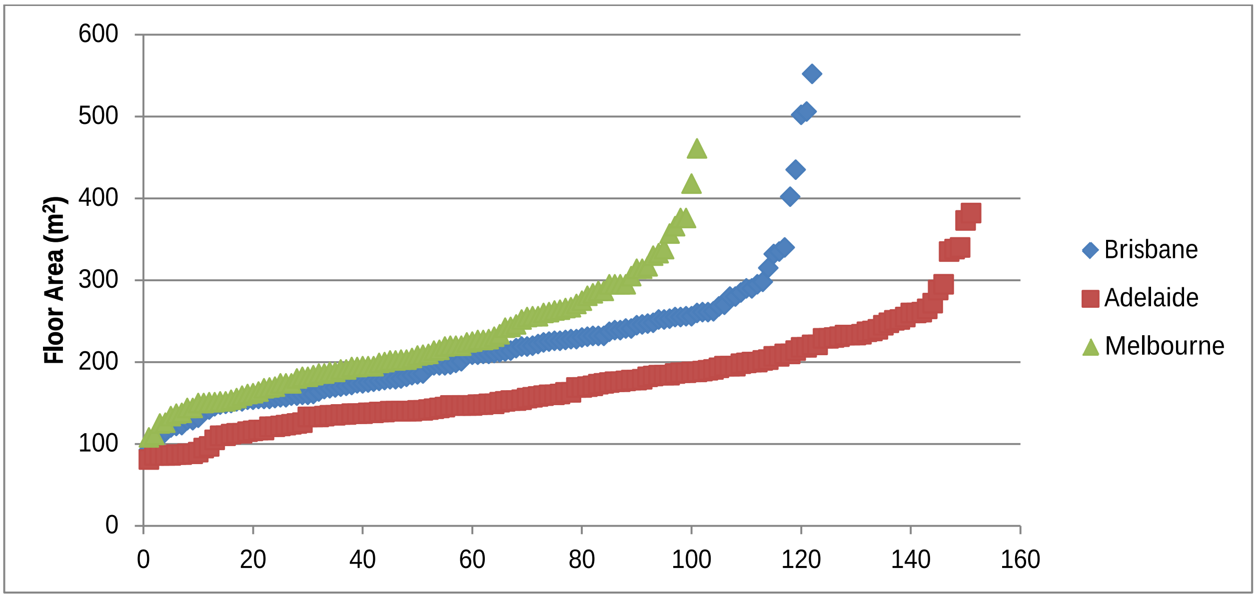
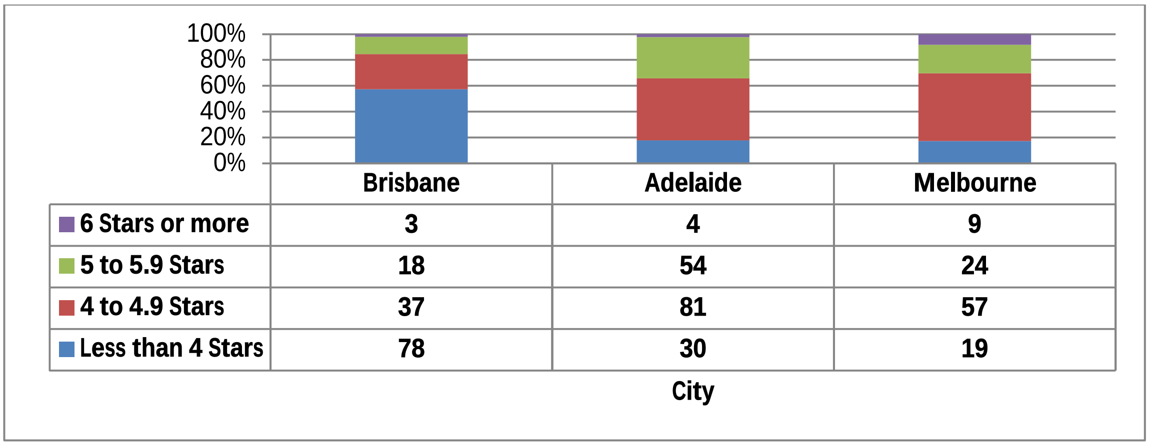


Figure 2-5 **House floor area by city**

2.2 Star rating

As part of the project, all houses were re-rated using AccuRate. The ratings undertaken relied on details obtained from the planning documentation. Where sufficient information was not available, assumptions have been made. These assumptions, and the methodology applied in rating these houses, are detailed in the AccuRate Rating Methodology document prepared by Energy Makeovers (see Appendix B).

Figure 2-6 shows the ratings distribution for the three cities after the re-rating. Very few houses rate at or above 6 stars. Even at the 5 stars and above level, the numbers are low, with only 15% of houses in Brisbane rating at 5+ stars. The best-performing city was Adelaide, with 34% of houses rating at 5 or more stars. Conversely, Brisbane has a large percentage of houses (57%) rated below 4 stars, while in Adelaide and Melbourne, around 17% of houses were rated below 4 stars.



	Brisbane	Adelaide	Melbourne
🟪 6 Stars or more	3	4	9
🟩 5 to 5.9 Stars	18	54	24
🟥 4 to 4.9 Stars	37	81	57
🟦 Less than 4 Stars	78	30	19

Figure 2-6 **Re-rated AccuRate star rating**

The difference between the cities reflects the staged introduction of energy efficiency provisions in each city (**Error! Reference source not found.**). In Brisbane, where requirements for 5-star houses were only introduced in 2009 (previously the requirement had been 3.5 stars), we would expect a lower number of higher-rated houses. In Adelaide, requirements for 5-star houses were introduced in 2006 (previously the requirement had been 4 stars), while in Melbourne, the 5-star provisions were introduced in 2004 (previously the requirement had been 3 stars). From 2011, all the areas covered by this study require a 6 star minimum, although Brisbane allows up to 1.5 star credits for outdoor living areas and photovoltaic generation systems.

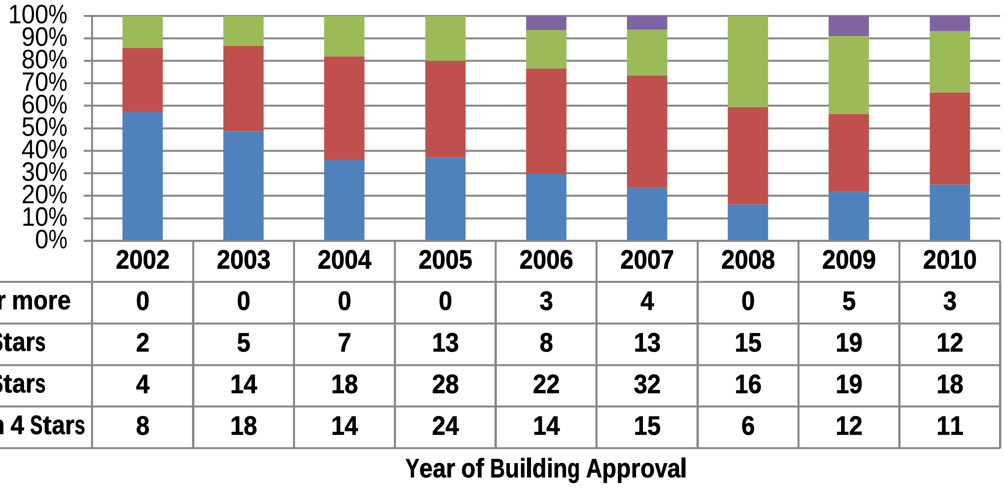
Although the year of introduction of the energy requirements in each state gives some indication of the expected minimum rating for a particular house built in a particular year, it is not a guarantee. Building permits can be issued based on plans that were prepared prior to an increase in the minimum requirements; often, this is left to the discretion of the building permit issuer. It is possible that a building constructed in a particular year was actually issued a building permit based on the energy requirements in place one or two years before construction commenced.

BCA Version	BCA Amdt 12 & 13	BCA 2004	BCA 2005	BCA 2006	BCA 2007	BCA 2008	BCA 2009	BCA 2010	BCA 2011
Stars	3.5 - 4 Stars			5 Stars				6 Stars (DTS)	
Queensland	3.5 Stars - 4 Stars						5 Stars	6 Stars Equiv.	
South Australia	4 Stars			5 Stars				6 Stars	
Victoria	3 Stars	5 Stars							6 Stars
NatHERS Version	1st Generation				1st and 2nd Generation		2nd Generation		

Note: Deemed to Satisfy Provisions (DTS) could also be used for compliance

Figure 2-7 **History of energy ratings regulations in Queensland, South Australia and Victoria**

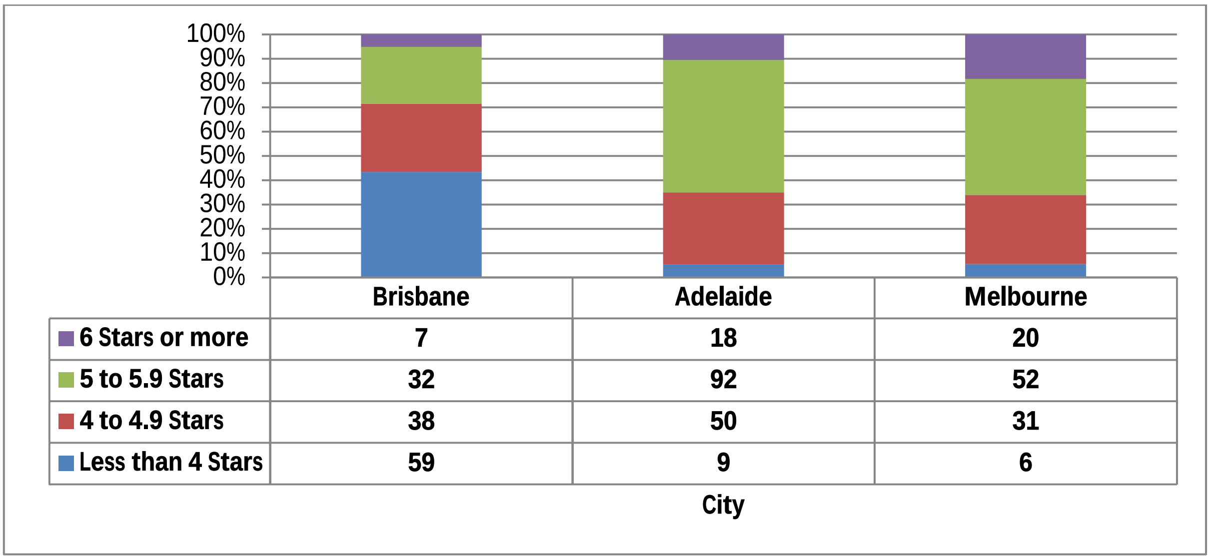
Figure 2-8 shows the rating breakdown based on the year of building approval. Over time, the proportion of higher star-rated houses has increased, although the numbers of higher-rated houses is still lower than what would be expected as a result of regulation changes.



	2002	2003	2004	2005	2006	2007	2008	2009	2010
🟪 6 Stars or more	0	0	0	0	3	4	0	5	3
🟩 5 to 5.9 Stars	2	5	7	13	8	13	15	19	12
🟥 4 to 4.9 Stars	4	14	18	28	22	32	16	19	18
🟦 Less than 4 Stars	8	18	14	24	14	15	6	12	11

Figure 2-8 **Re-rated houses by year of building approval**

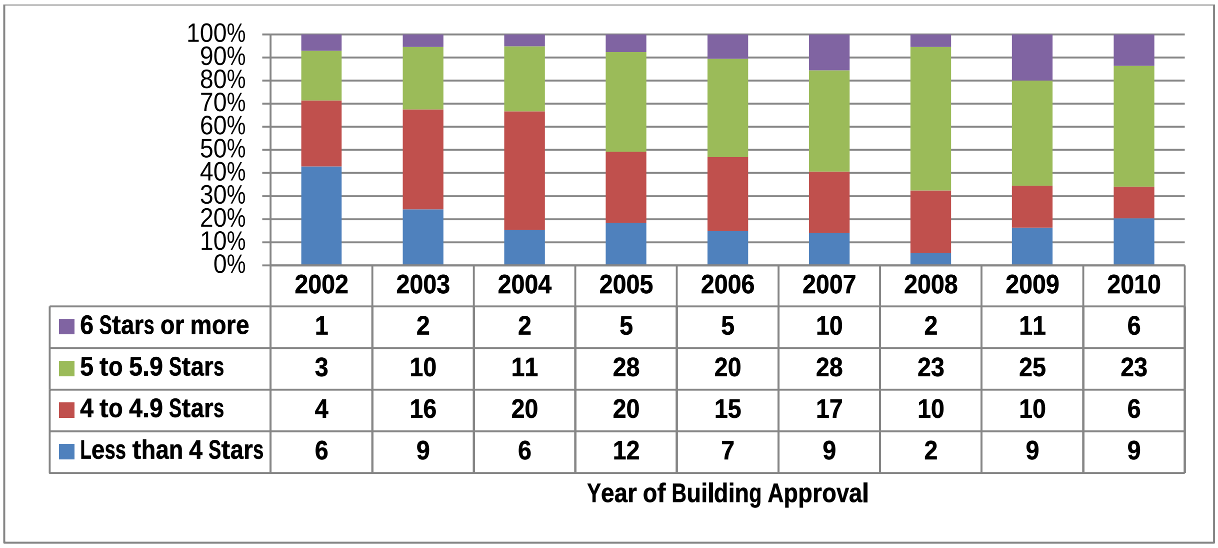
To generate meaningful sample sizes for all later comparisons, the approach taken for clustering houses by star rating was to round up the re-rated star rating by up to half a star. That is, houses have been deemed to be 5 stars or above if their re-rated star rating was greater than 4.5 stars. This was deemed appropriate when taking into account that: i) when built, houses would have been rated with older versions of any of the current NatHERS tools, or been approved under the deemed to satisfy (DTS) provisions of the BCA and not rated at all; and ii) the known variance that occurs among assessors and the conservative rigour applied in the standardised re-rating approach of this study. This led to an increase in the sample size of 5 star or more houses. In Brisbane in particular, only 21 houses rated at 5 stars or more with the original re-rating. Incorporating houses that rated at or above 4.5 stars increased the count to 39 houses (Figure 2-9).



	Brisbane	Adelaide	Melbourne
🟪 6 Stars or more	7	18	20
🟩 5 to 5.9 Stars	32	92	52
🟥 4 to 4.9 Stars	38	50	31
🟦 Less than 4 Stars	59	9	6

Figure 2-9 **Re-rated AccuRate star rating with half-star tolerance**

Likewise, when the half-star tolerance was applied to the year approval was granted, we found a closer correlation to what would be expected based on the regulations (Figure 2-10).



	2002	2003	2004	2005	2006	2007	2008	2009	2010
🟪 6 Stars or more	1	2	2	5	5	10	2	11	6
🟩 5 to 5.9 Stars	3	10	11	28	20	28	23	25	23
🟥 4 to 4.9 Stars	4	16	20	20	15	17	10	10	6
🟦 Less than 4 Stars	6	9	6	12	7	9	2	9	9

Figure 2-10 **Re-rated houses by year of building approval and half-star tolerance**

Figure 2-5 indicated that the average floor area for volunteer households was around 201 m^2. However, when examined within the star-rating cohorts, the higher-rating houses are below this average, at 189 m^2, while the lower-rated houses are slightly larger, at 214 m^2. Figure 2-11 shows the distribution of floor areas based on the star rating. When the very large (>400 m^2) houses were removed from the analysis, the floor area of typical houses was much the same between the lower and higher-rated cohorts.

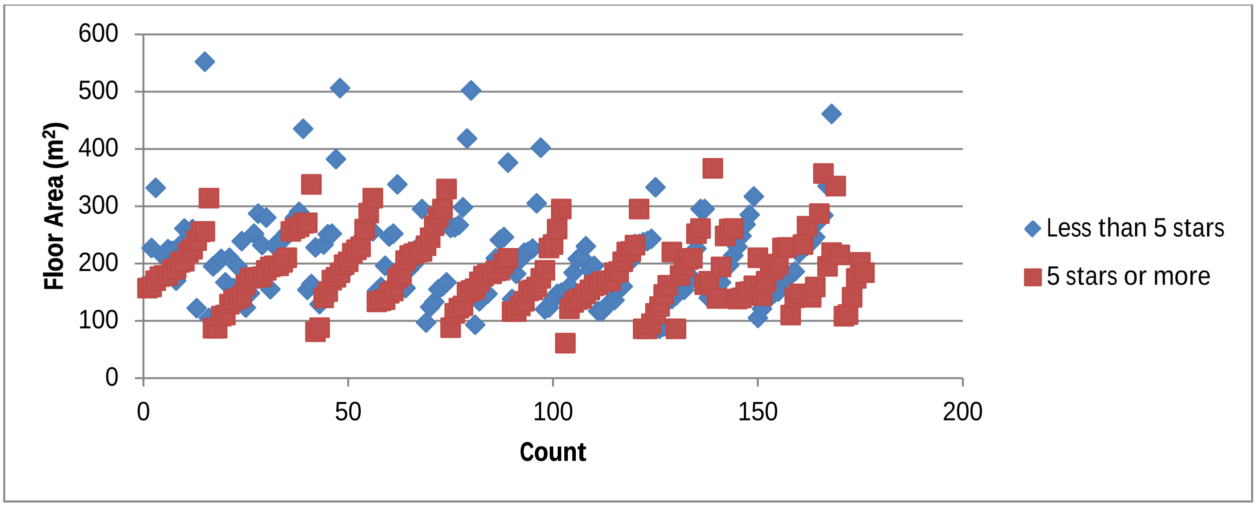
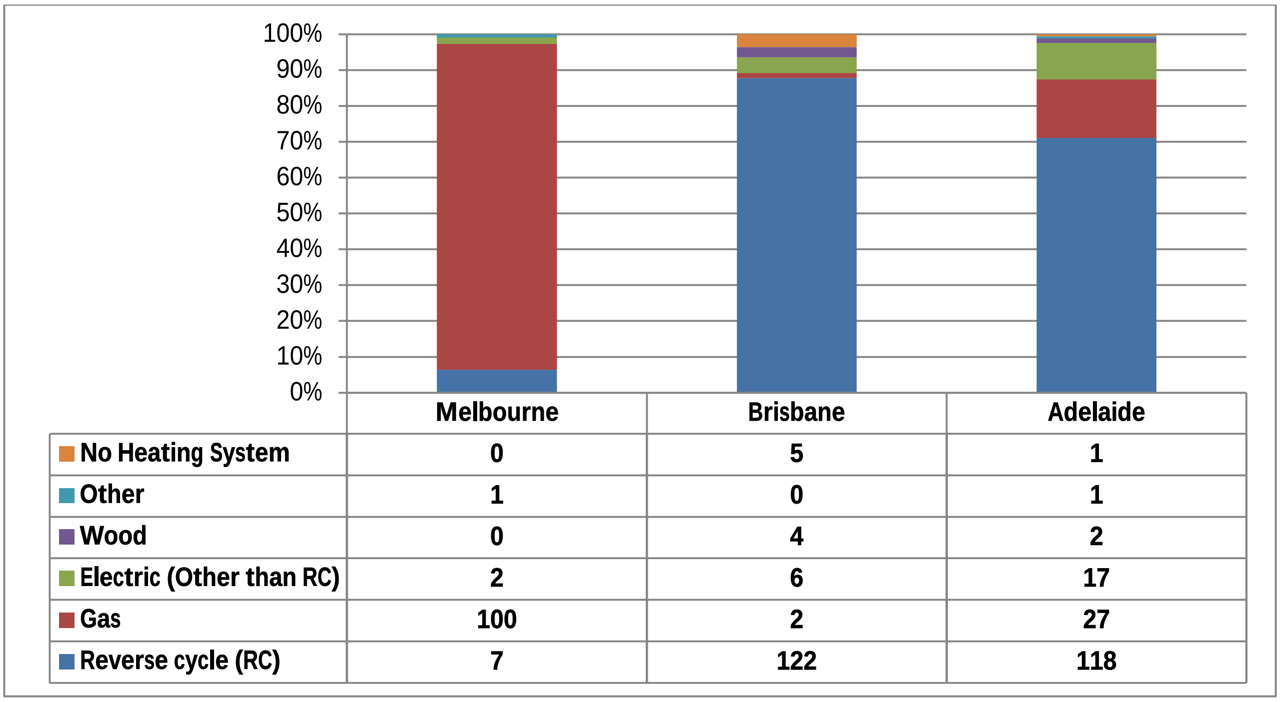


Figure 2-11 **Floor area by star rating**

2.3 Heating and cooling appliances

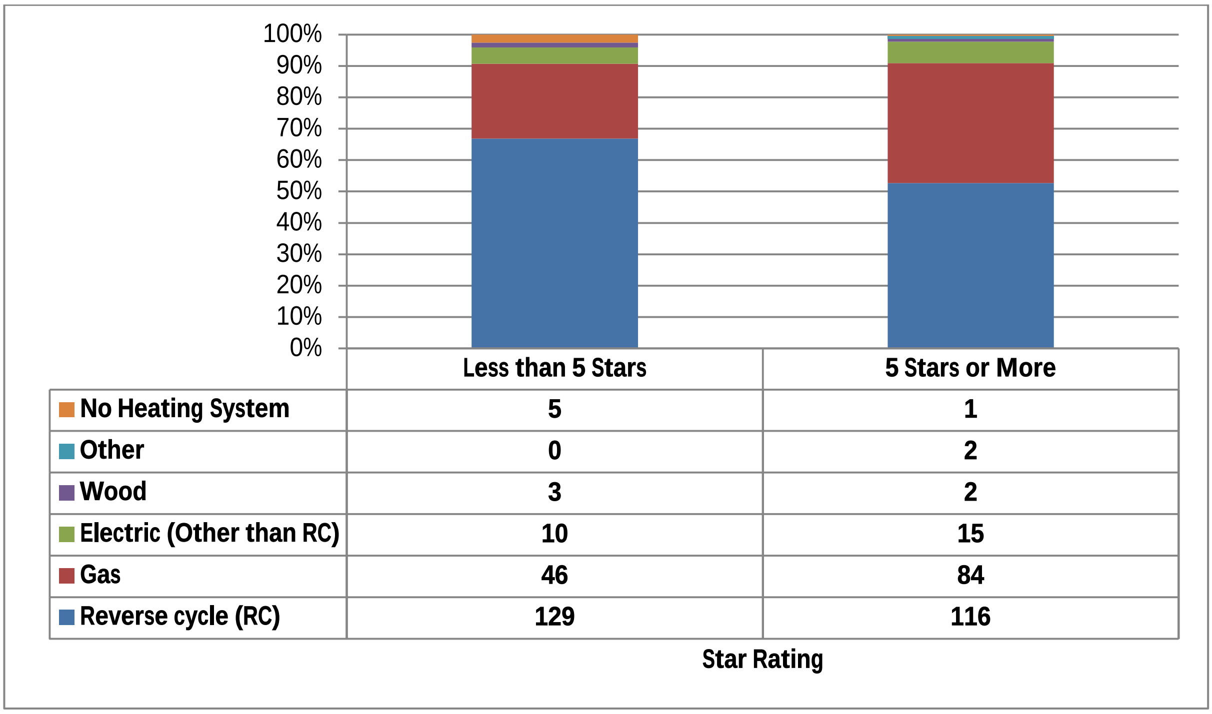
2.3.1 HEATING SYSTEM

Figure 2-12 shows that based on the assessor's audit, 77% of houses in Melbourne have gas heating, compared with 19% and 1% in Adelaide and Brisbane, respectively. In Adelaide and Brisbane, heating is predominantly provided through reverse-cycle systems: 73% in Adelaide and 88% in Brisbane. It is interesting to note that 4% of houses in Brisbane had no fixed heating system. Figure 2-13 shows heating systems in houses by star rating. The higher-rated houses have a higher use of gas heating. However, this is more a result of the higher proportion of higher-rated homes being located in Melbourne, where gas heating is dominant, rather than a shift to gas heating as a result of energy efficiency improvements.



	Melbourne	Brisbane	Adelaide
🟧 No Heating System	0	5	1
🟦 Other	1	0	1
🟪 Wood	0	4	2
🟩 Electric (Other than RC)	2	6	17
🟥 Gas	100	2	27
🟦 Reverse cycle (RC)	7	122	118

Figure 2-12 **Heating systems in houses by city**



	Less than 5 Stars	5 Stars or More
🟧 No Heating System	5	1
🟦 Other	0	2
🟪 Wood	3	2
🟩 Electric (Other than RC)	10	15
🟥 Gas	46	84
🟦 Reverse cycle (RC)	129	116

Figure 2-13 **Heating systems in houses by star rating**

2.3.2 COOLING SYSTEM

In Adelaide and Brisbane, reverse-cycle systems are commonly used for both heating and cooling requirements. Figure 2-14 shows that 92% of houses in Brisbane use reverse-cycle systems for cooling, with the remaining 8% having no fixed cooling system. In Adelaide, 80% of houses use reverse-cycle systems and 17% use evaporative cooling. Only 4% of Adelaide houses had no fixed cooling system, lower than the percentage in Brisbane. Melbourne houses are equally split between evaporative and reverse-cycle systems, with around 82% of houses using either technology. The remaining 18% of Melbourne houses have no fixed cooling system. Figure 2-15 shows cooling systems in houses by star rating. Like the heating systems, the breakdown in cooling appliances is more a result of the higher number of higher-rated houses being located in Melbourne, rather than differences in the type of cooling system. Consequently, increases in evaporative coolers and houses with no cooling systems, and a decrease in the number of reverse-cycle units, are to be expected.

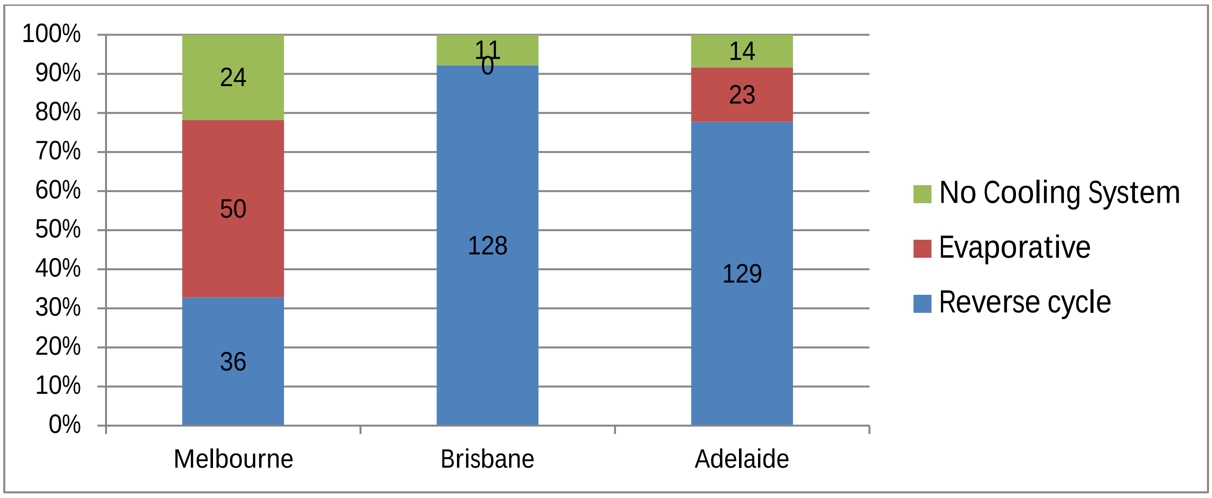


Figure 2-14 **Cooling systems in houses by city**

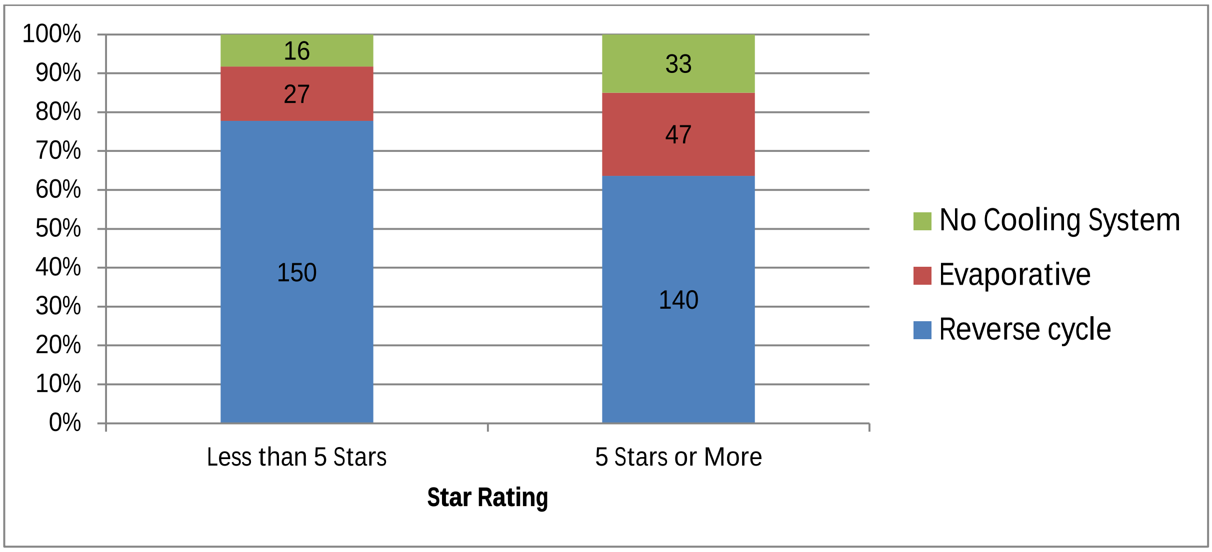


Figure 2-15 **Cooling systems in houses by star rating**

3 Overview of data – household

3.1 Occupant type

The majority of households are families with one or more children (Figure 3-1). Around 15% of households are retirees (either single or couples) and 21% are working couples with no children.

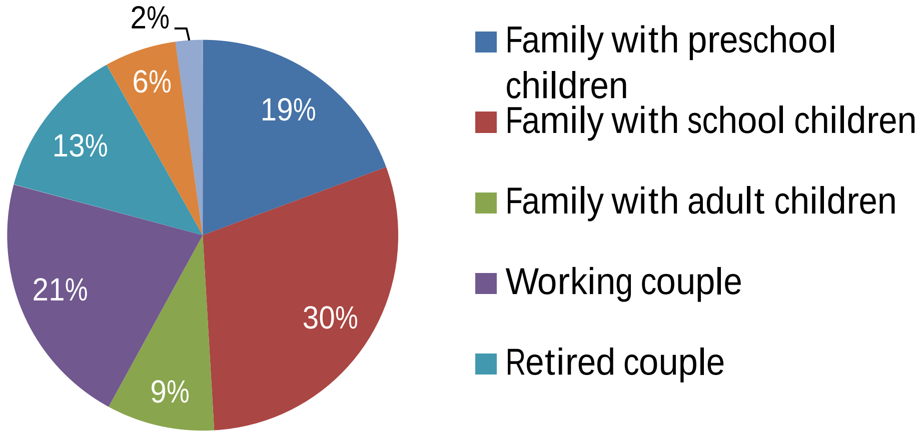
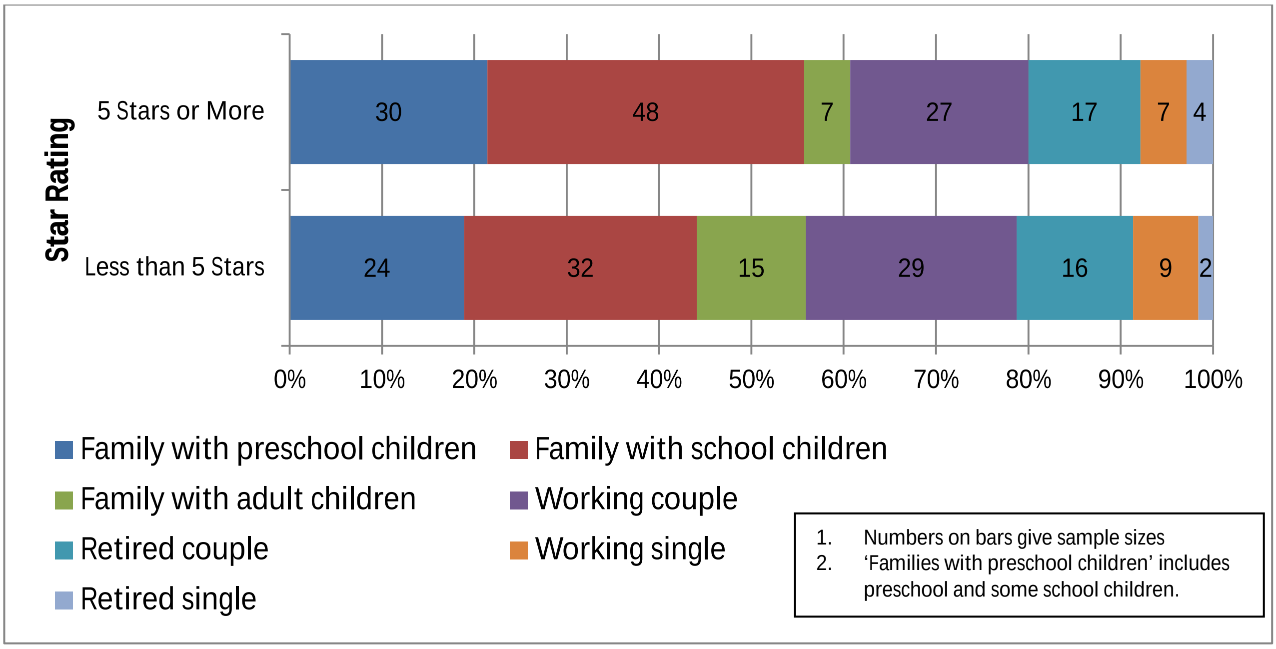


Figure 3-1 **Household profile**

Little difference in household profile existed between the star bands (see Figure 3-2), although slightly more families with younger children (preschool or school age) lived in higher-rated houses than lower-rated houses, with more families with adult children living in the lower-rated houses. This would suggest that as families have grown they have moved into new houses, and stayed in those houses as the family aged.



1. Numbers on bars give sample sizes
2. ‘Families with preschool children’ includes preschool and some school children.

Figure 3-2 **Household profile by star rating**

3.2 Occupancy

Figure 3-3 indicates that just over half the volunteers have somebody at home all day. Twenty per cent of volunteers indicated that nobody was at home during weekdays. The occupancy profiles are similar across the three cities and are also similar for the two star-rating cohorts (Figure 3-4).

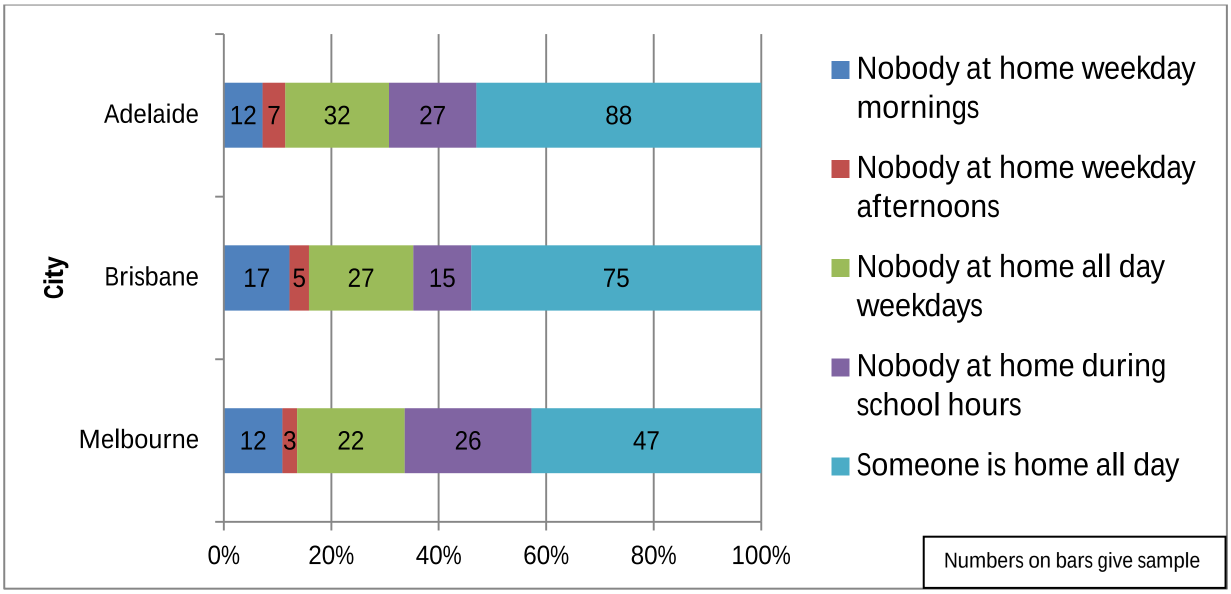


Figure 3-3 Occupancy profile for households by city

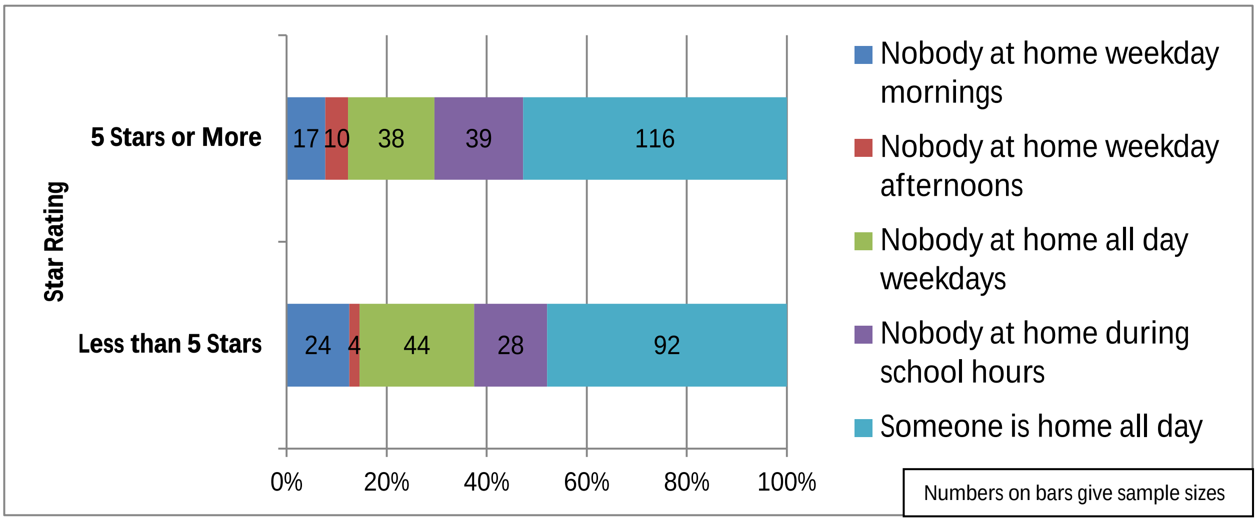


Figure 3-4 Occupancy profile for households by star rating

3.3 Energy efficiency attitudes

Establishing household attitudes and actions towards energy efficiency in the home is important in determining behavioural impacts on overall energy consumption. The way people operate their houses, and the attention to the energy being consumed, help to explain differences that may be evident in seemingly similar dwellings and occupants. For example, the energy needed to heat a building will increase in winter if windows or doors are left open whereas controlled ventilation can reduce a building's cooling energy consumption in summer. Likewise, heating and cooling energy can be significantly higher or lower depending on the thermostat settings an occupant uses.

3.3.1 ENERGY USE

Figure 3-5 indicates that the majority of households have some level of awareness of their energy consumption, with less than 4% indicating that they did not know if their household energy consumption had changed over the last 12 months. Most households (41%) had seen no change over the last year, while 25% believed it had increased and 30% believed it had decreased. Interestingly, more households in the higher-rated houses believed their energy consumption had increased than those households in the lower-rated houses (Figure 3-6), and fewer higher-rated households indicated a decrease in energy consumption than those in the lower-rated houses.

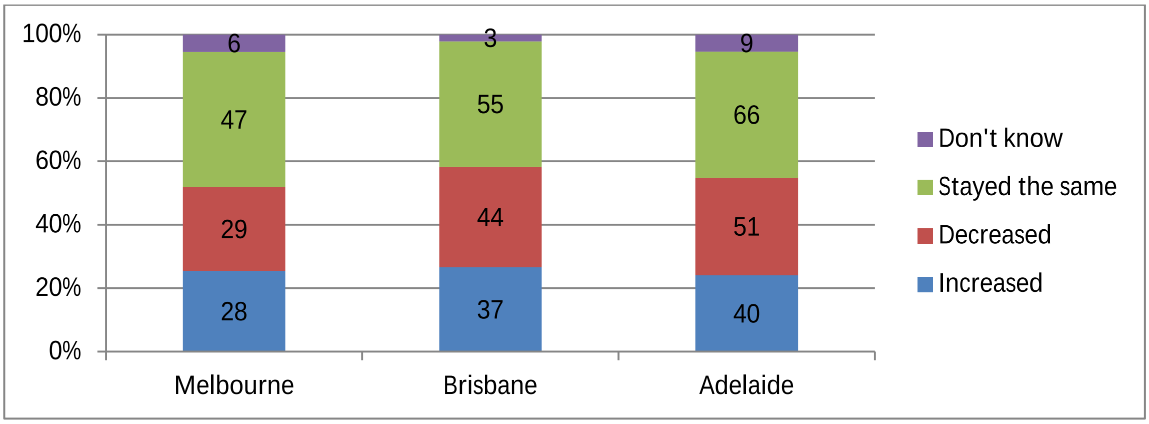


Figure 3-5 **Perceived change in energy use by city**

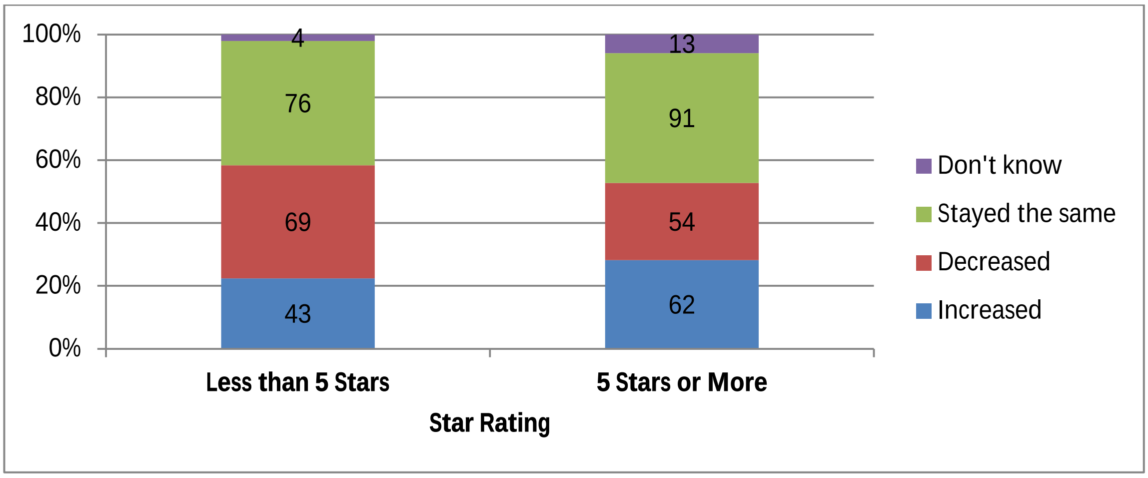


Figure 3-6 **Perceived change in energy use by star rating**

For the households that believed their energy use had increased, most indicated that lifestyle changes were a major factor (Figure 3-7). This could include the arrival of a newborn child, or moving into retirement and thus being at home more often. Increases in the number of appliances (such as larger televisions) and changes in the weather were also cited as major reasons.

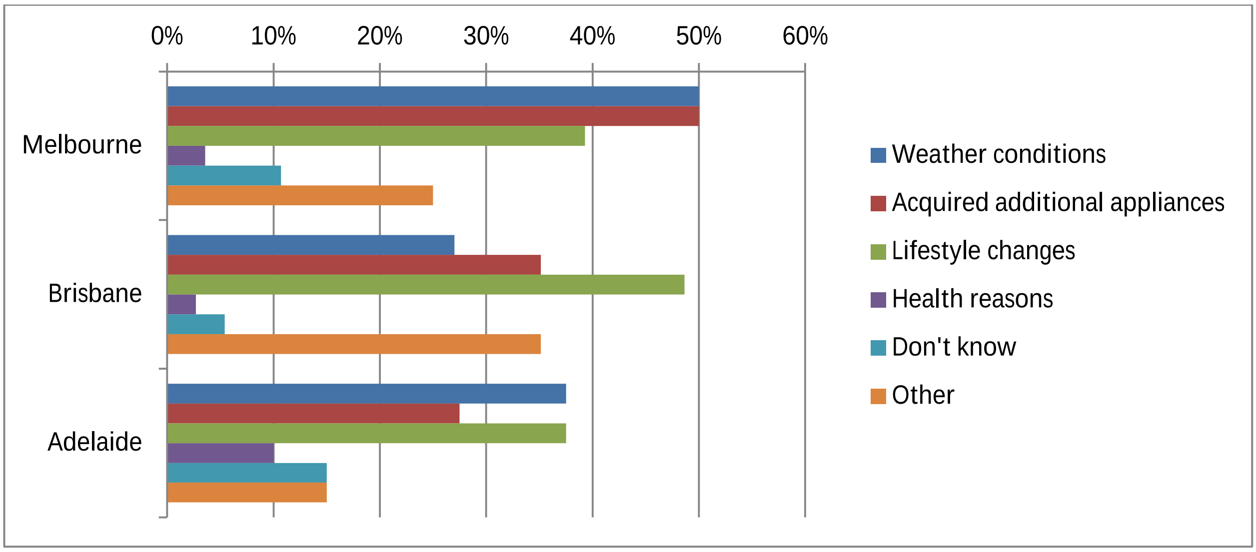


Figure 3-7 **Stated reasons why household energy use increased**

In households that had seen an energy decrease, the major reason cited was an active effort to reduce consumption (Figure 3-8). Sixty-three per cent of volunteers also indicated that cost savings associated with energy reduction was a major factor, with 39% saying they had replaced old, inefficient appliances with more energy-efficient appliances.

The economic benefits associated with reduced energy expenditure are seen by most households as the primary driver for reducing energy consumption (Figure 3-9). Concern for the environment was also a major reason for reducing energy consumption, with 70% citing this as a reason.

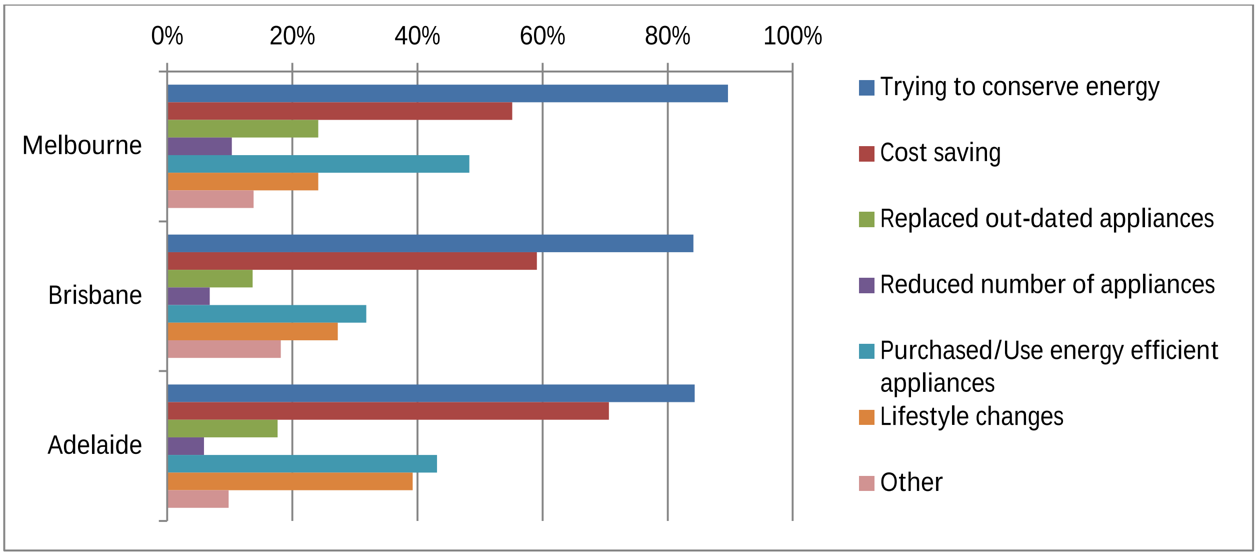


Figure 3-8 **Stated reasons why energy use decreased**

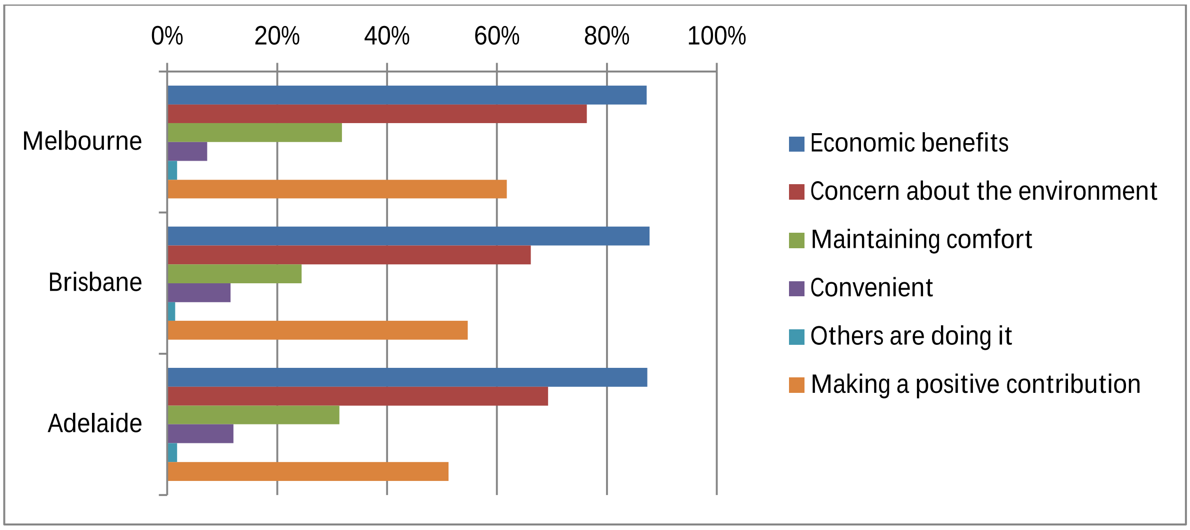


Figure 3-9 **Stated reasons why people reduce their energy consumption**

3.3.2 ENERGY-EFFICIENT HOUSEHOLDS

Many people are aware that their house was built to an energy efficiency standard. However, some confusion remains in the marketplace about what is included within the energy efficiency provisions. Figure 3-10 lists the features identified by occupants that improve energy efficiency. Overall, 96% acknowledged that they had ceiling insulation, while a further 75% believed they had wall insulation. Perceptions on energy-efficient lighting are worth noting, with 73% of households in Melbourne and 66% in Adelaide indicating that they had efficient lighting, despite 81% in both cities actually having inefficient halogen lamps installed. Curious to note also is that 28% of households in Melbourne indicated they have double glazing, yet the assessors reported that only 14% of houses had double glazing. This discrepancy may be due to some houses having a small number of double-glazed windows, while the majority of their windows are single-glazed. Builders often include some double-glazed windows to achieve the required star rating.

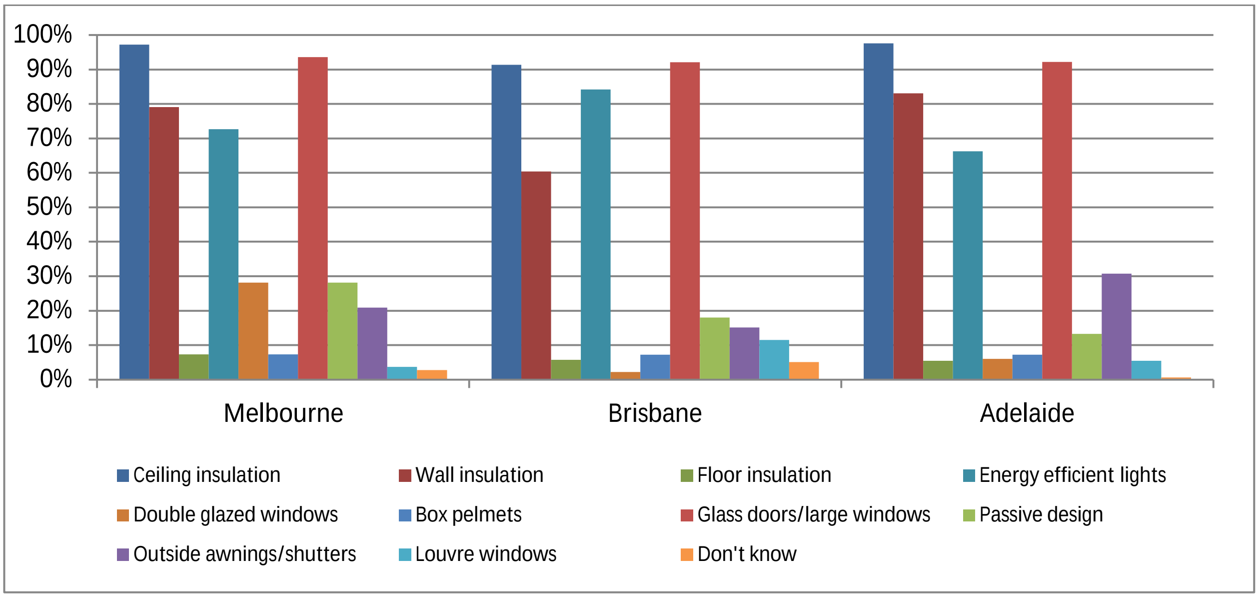


Figure 3-10 **Awareness of energy efficiency features by city**

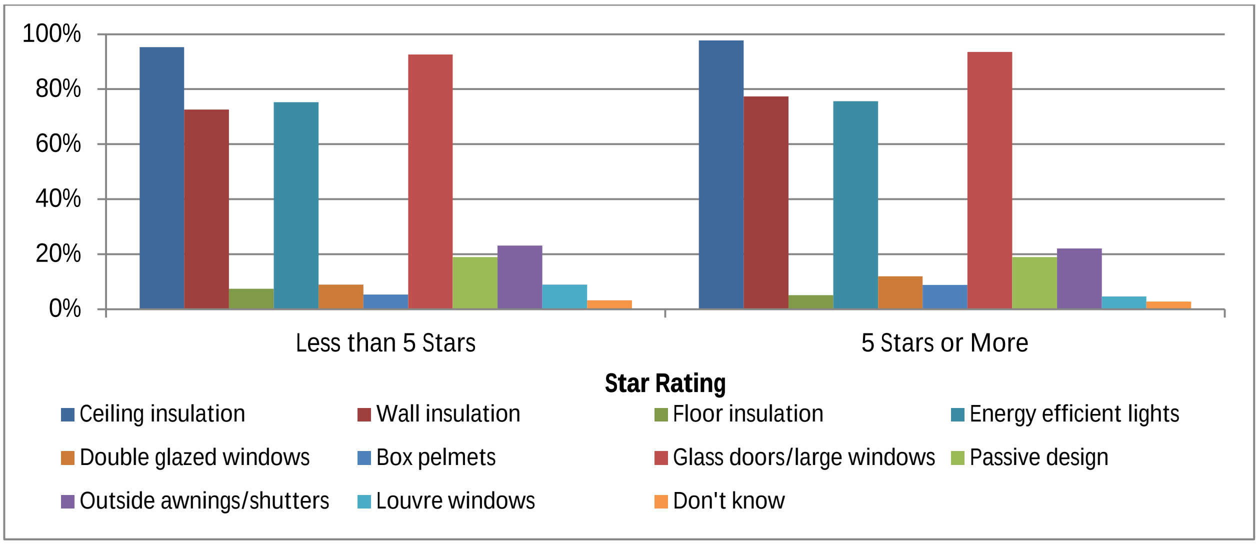


Figure 3-11 Awareness of energy efficiency features by star rating

Despite apparent increases or little change in a household's energy consumption, 91% still indicated that they are taking steps to reduce their energy consumption. As has been seen, changes in lifestyle can often affect energy consumption, despite efforts to reduce consumption. Figure 3-12 shows that most people believe that they are medium energy users (57%), while 30% believe they are low energy users. Figure 3-13 shows that twice as many households in the higher-rated cohort considered themselves high energy users compared with the lower-rated cohort. Figure 3-14 shows that 78% believe they are fairly or very mindful of their energy consumption, while 17% are extremely mindful. Figure 3-15 shows that energy use awareness was similar between the two star-rating cohorts.

Figure 3-16 and Figure 3-17 show the household response to the statement "We are an energy conserving household" by city and star-rating cohort. Both figures show that most households agree with the statement. Those households that strongly agree with the statement are slightly more likely to be in Adelaide. Very few households disagreed with the statement, while none strongly disagreed. A significant proportion remained neutral.

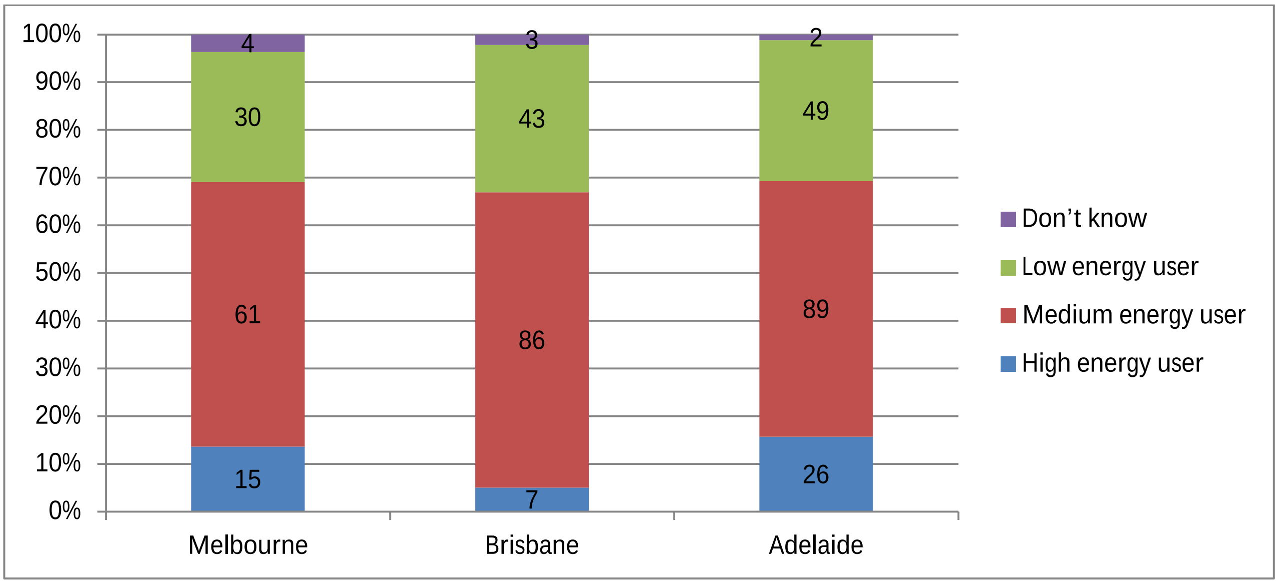
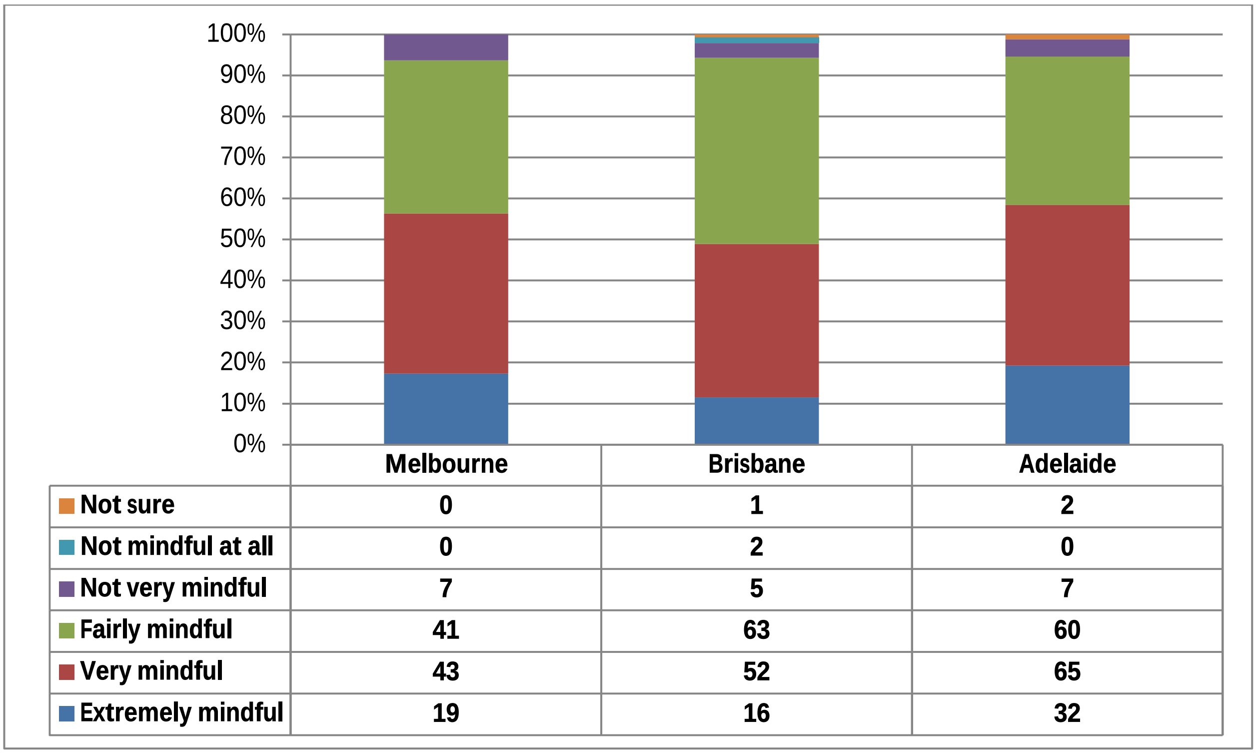


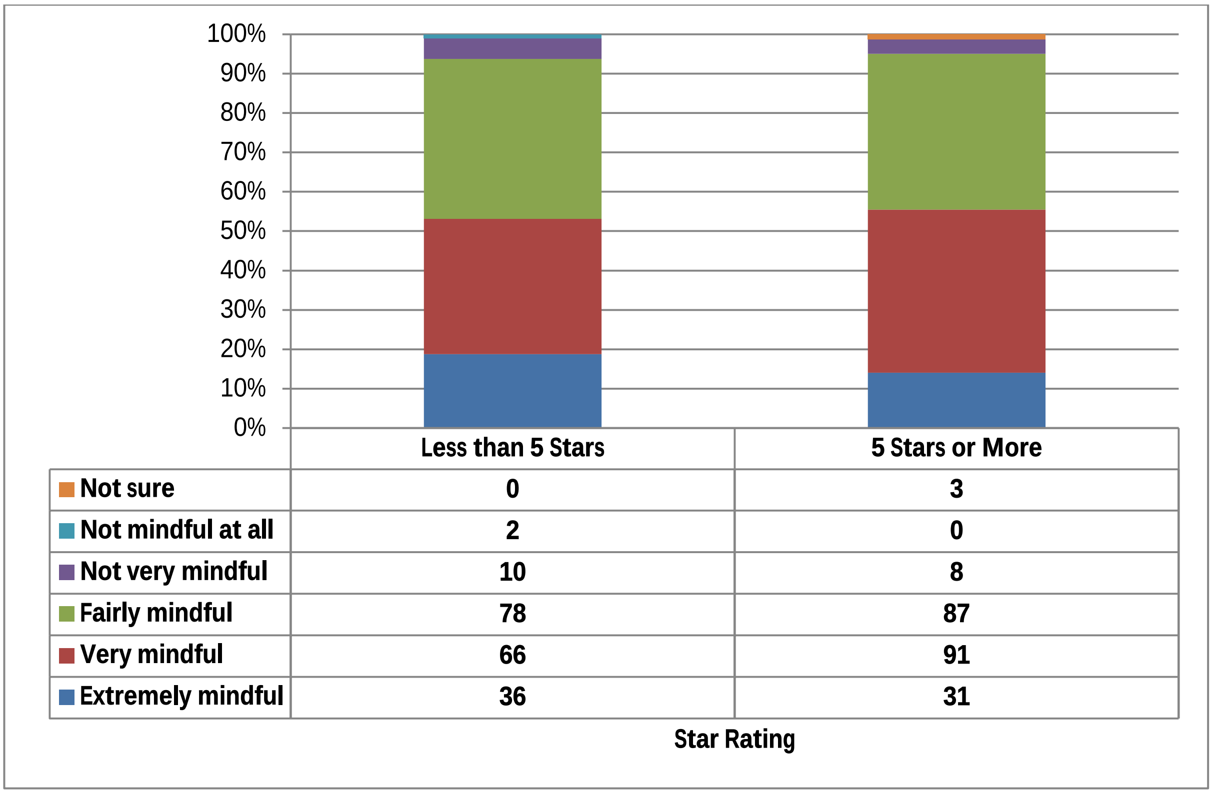
Figure 3-12 Household energy use perception by city

Figure 3-13 Household energy use perception by star rating



	Melbourne	Brisbane	Adelaide
🟧 Not sure	0	1	2
🟦 Not mindful at all	0	2	0
🟪 Not very mindful	7	5	7
🟩 Fairly mindful	41	63	60
🟥 Very mindful	43	52	65
🟦 Extremely mindful	19	16	32

Figure 3-14 Energy use awareness by city



	Less than 5 Stars	5 Stars or More
🟧 Not sure	0	3
🟦 Not mindful at all	2	0
🟪 Not very mindful	10	8
🟩 Fairly mindful	78	87
🟥 Very mindful	66	91
🟦 Extremely mindful	36	31

Figure 3-15 Energy use awareness by star rating

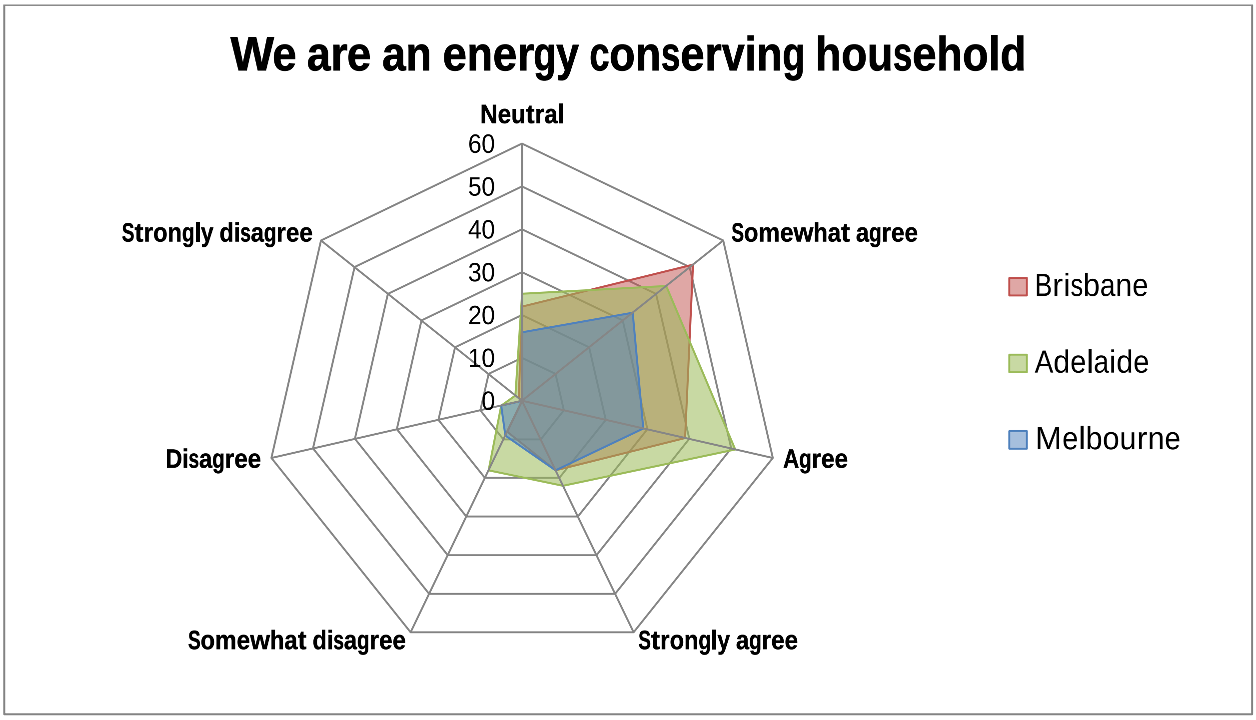


Figure 3-16 Energy conserving household by city (count)

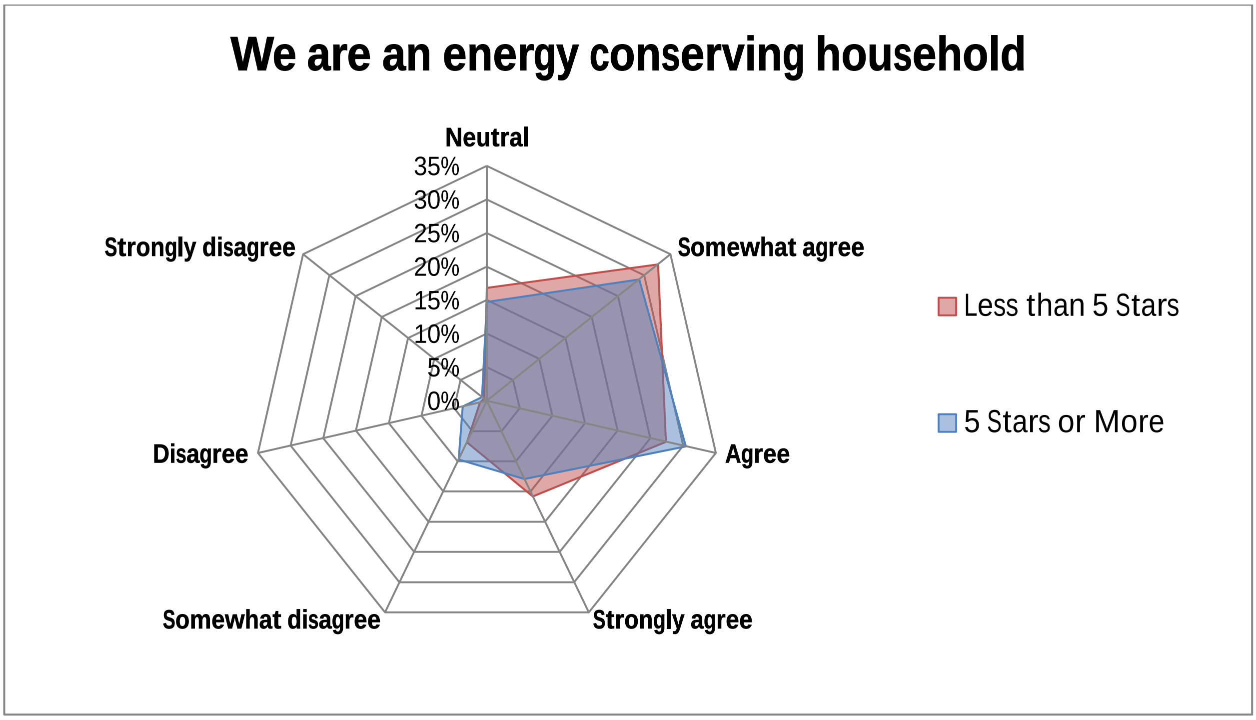


Figure 3-17 Energy conserving household by star rating

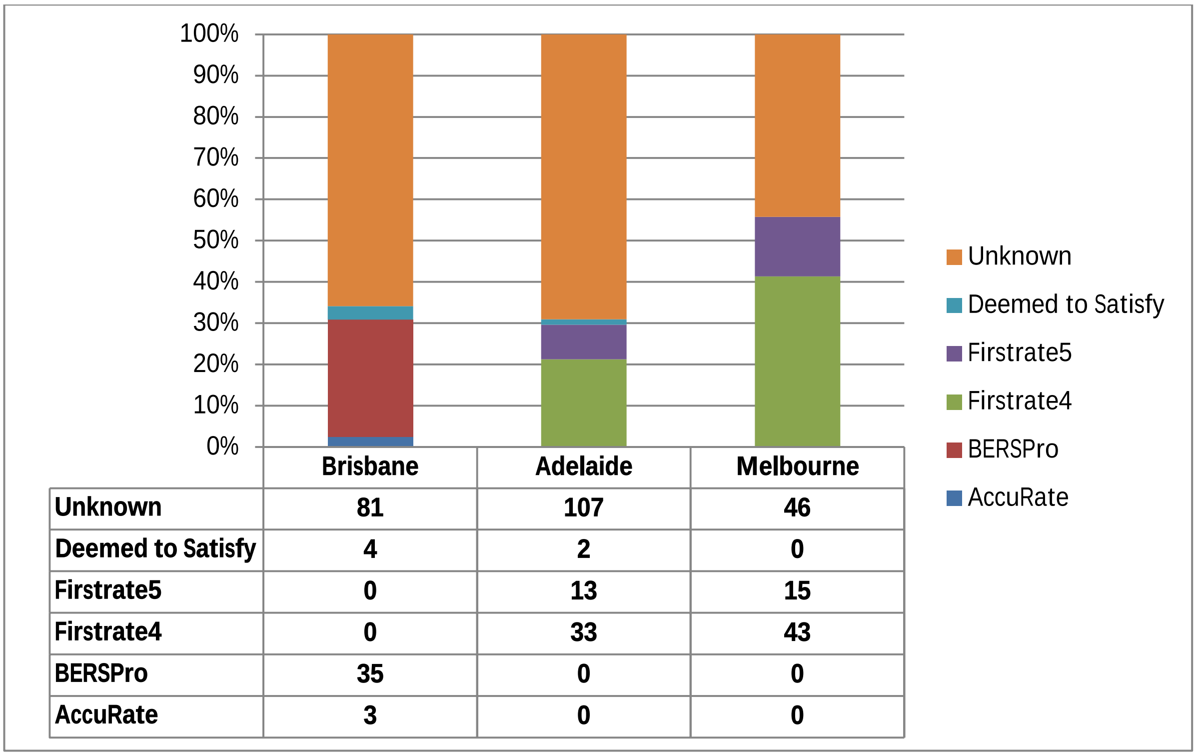
Part 2 Key Outcomes

4 Meeting the star rating

One of the problems encountered while gathering information for this study was the lack of documented evidence about how volunteer houses had met the required energy efficiency standard. All the houses selected would have been subject to some aspect of the regulation and would have been required to demonstrate this to have received a building permit. However, the lack of record keeping for this process has made it difficult to determine the exact methodology used.

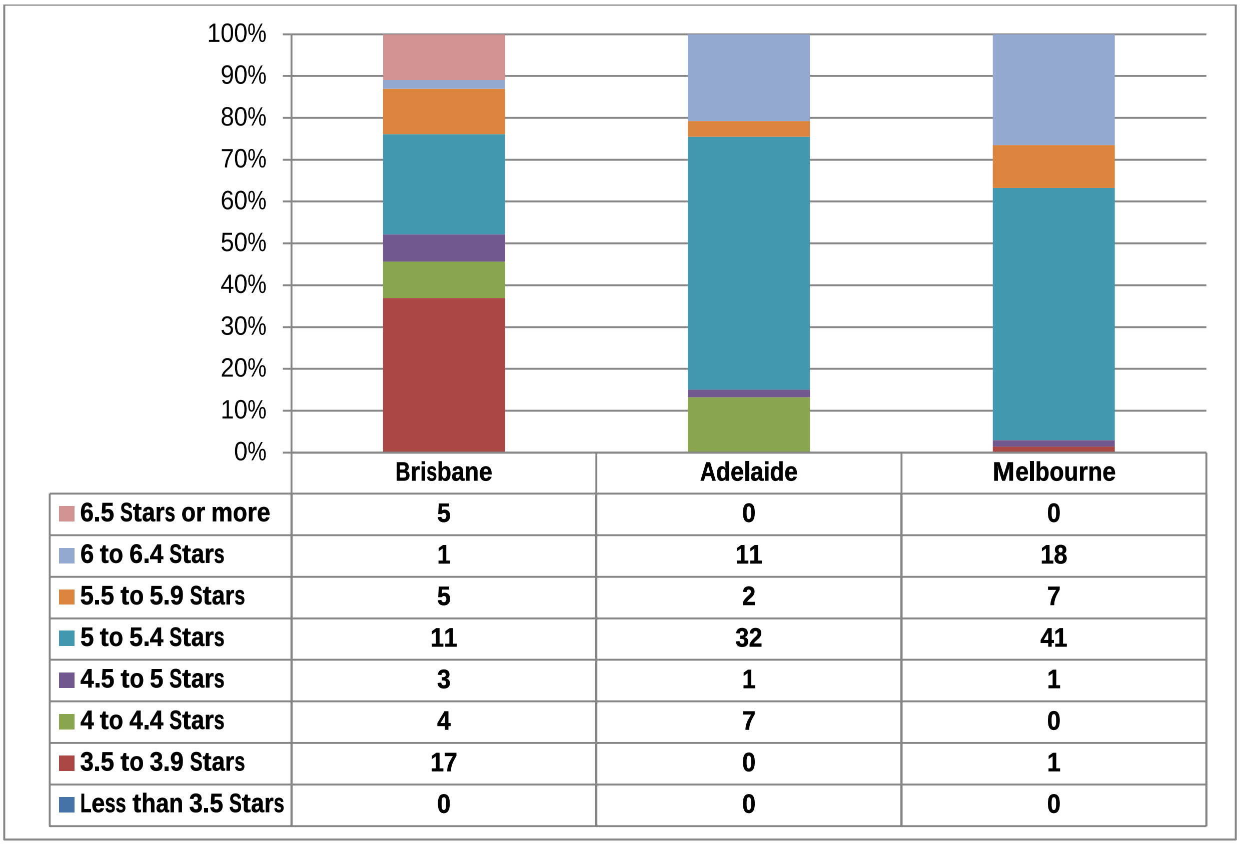
In most jurisdictions, builders could choose to either have the house rated by an assessor using one of the NatHERS certified software tools, or they could comply through DTS provisions. In many cases, the DTS provisions were the popular choice, because they were prescriptive solutions and easy to implement at a relatively low cost to the builder. Figure 4-1 shows the percentage of houses in each city for which the original NatHERS-based star ratings were available, and the method that was used to achieve the rating. Around 30% of houses in Brisbane and Adelaide had ratings available, while the percentage was higher in Melbourne, at 56%.

It cannot be assumed that the houses for which ratings were not available used DTS provisions. The only holders of energy efficiency compliance data were either the local council or the home owner. The quality of local council records varied considerably, and in many cases no house records (or very limited records) were available.



	Brisbane	Adelaide	Melbourne
Unknown	81	107	46
Deemed to Satisfy	4	2	0
Firstrate5	0	13	15
Firstrate4	0	33	43
BERSPro	35	0	0
AccuRate	3	0	0

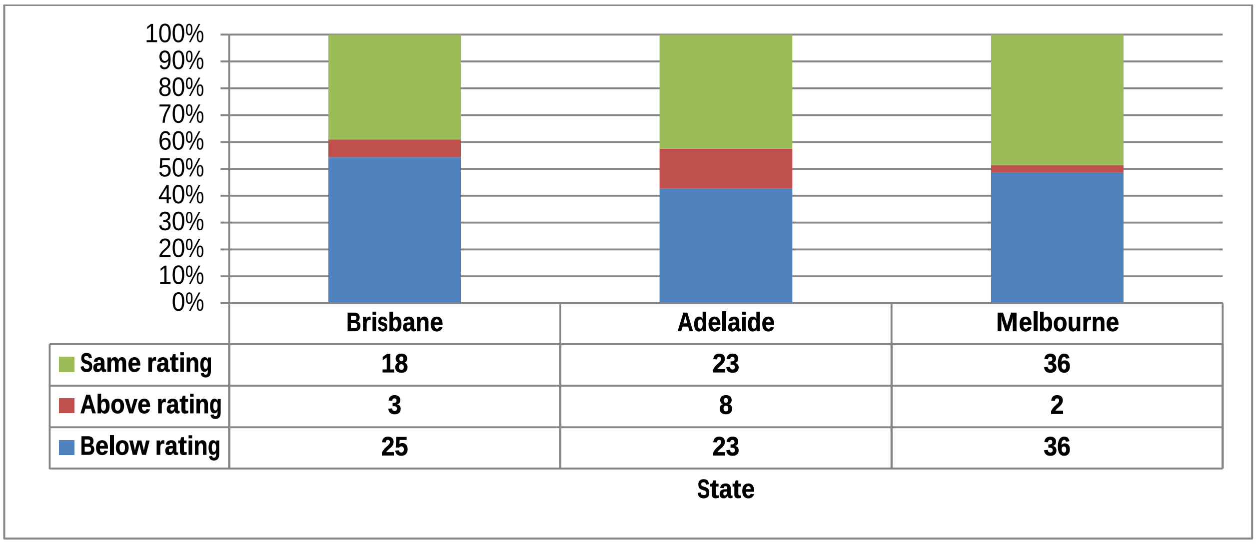
Figure 4-1 Original compliance method



	Brisbane	Adelaide	Melbourne
🟥 6.5 Stars or more	5	0	0
🟦 6 to 6.4 Stars	1	11	18
🟧 5.5 to 5.9 Stars	5	2	7
🟦 5 to 5.4 Stars	11	32	41
🟪 4.5 to 5 Stars	3	1	1
🟩 4 to 4.4 Stars	4	7	0
🟥 3.5 to 3.9 Stars	17	0	1
🟦 Less than 3.5 Stars	0	0	0

Figure 4-2 **Original star rating of houses (where ratings available)**

Figure 4-2 shows the star-rating range within each city for the houses with available original star ratings. Like Figure 2-9, Figure 4-2 also reflects the staged introduction of energy efficiency provisions in each city, but shows a higher proportion of higher-rated houses than was seen in the AccuRate re-rating process. Figure 4-3 compares the original rating and the re-rating, revealing that the re-rated star rating of a significant proportion of houses was below their original rating, even allowing for a half-star tolerance.



	Brisbane	Adelaide	Melbourne
🟩 Same rating	18	23	36
🟥 Above rating	3	8	2
🟦 Below rating	25	23	36

Figure 4-3 **Comparison between AccuRate and original rating by city**

A total of 174 houses from the sample group were available for this comparison. Adelaide was the best performing, yet still had 43% of houses rating below their original rating; in Brisbane and Melbourne, around 50% of the houses were re-rated below their original rating. Overall, 7.5% of houses had an original star rating that was above the re-rated value.

Caution is needed in interpreting these results. For earlier houses, the original NatHERS rating was done with an earlier version of the NatHERS software than the version used for re-rating, which may lead to a lower rating result. The assessment protocols used by the assessors have also changed over time. Differences in the methodologies utilised by assessors are known to occur, which may lead to variation in results.

Figure 4-4, Figure 4-5 and Figure 4-6 show the star rating comparison for each city at half-star increments. In all cities, the original rating is biased to be higher than the re-rated assessment. For example, in Brisbane, 11% of houses had an original rating of 6.5 stars or more, yet the re-rating saw no houses rate over 6.4 stars, and only 2% of houses rate between 6 and 6.4 stars. Likewise, in Adelaide and Melbourne, higher-rated houses were rare in the re-rating process. Only 1.6% and 7.4% of houses rated 6 stars or better in Adelaide and Melbourne, respectively, compared with 20.8% (Adelaide) and 26.5% (Melbourne) rating 6 stars or better in the original rating.

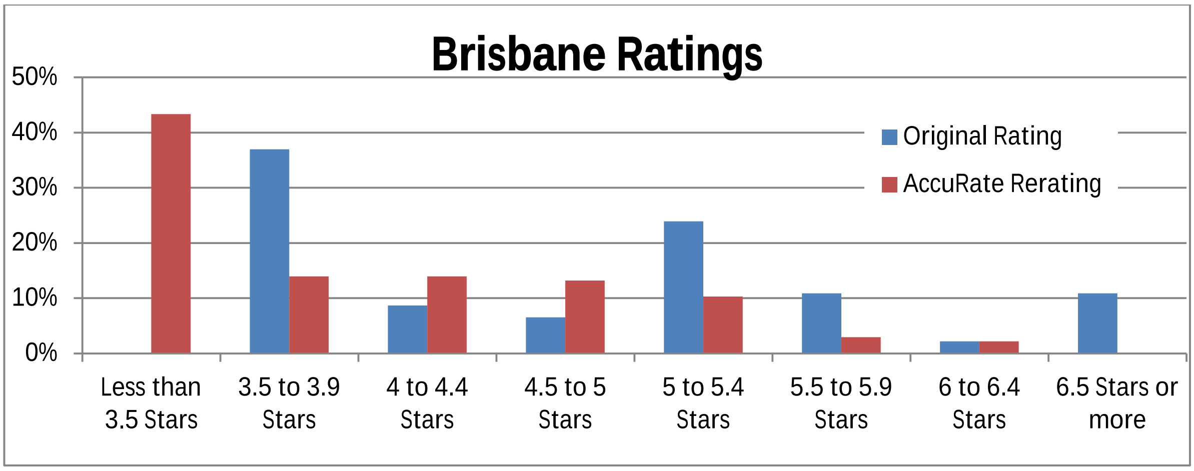


Figure 4-4 **Star rating comparison for Brisbane**

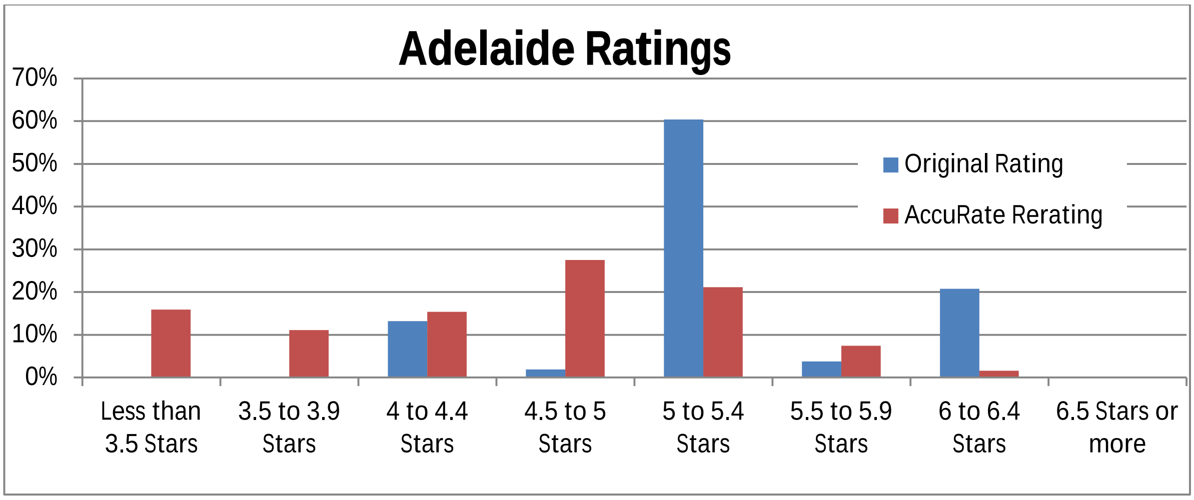


Figure 4-5 **Star rating comparison for Adelaide**

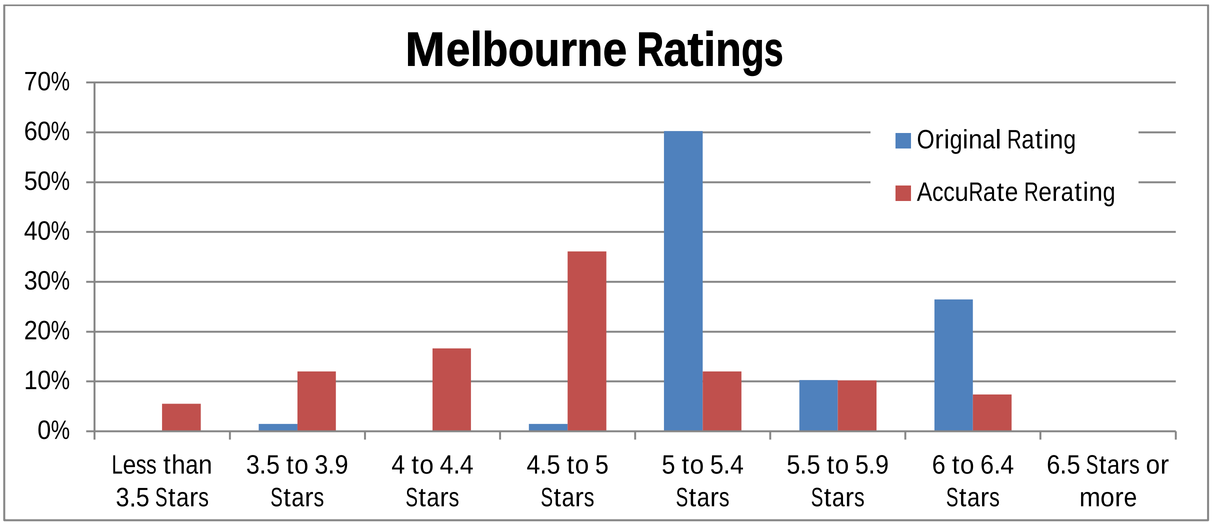
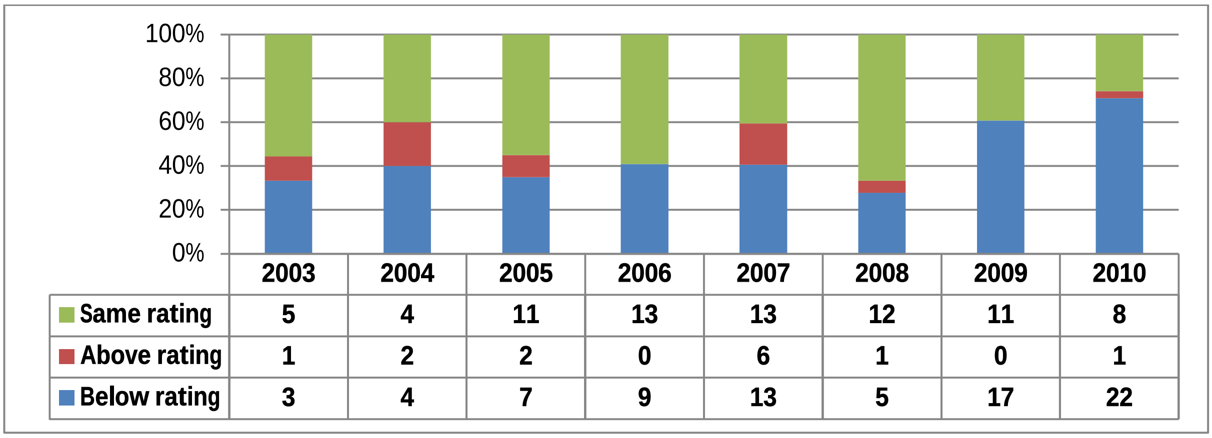


Figure 4-6 **Star rating comparison for Melbourne**

Figure 4-7 shows the same star rating comparison as Figures 4-4 to 4-6, but based on the year of building approval, rather than city. As the star rating requirements have increased, the percentage of houses that rated below their original rating has also increased. Of the 31 houses in the study built in 2010, 71% were below their original rating when re-rated, compared with 33% of houses built in 2003.



	2003	2004	2005	2006	2007	2008	2009	2010
🟩 **Same rating**	**5**	**4**	**11**	**13**	**13**	**12**	**11**	**8**
🟥 **Above rating**	**1**	**2**	**2**	**0**	**6**	**1**	**0**	**1**
🟦 **Below rating**	**3**	**4**	**7**	**9**	**13**	**5**	**17**	**22**

Figure 4-7 **Comparison of the study AccuRate rating and original rating by year of building approval**

Figure 4-8 shows the increase in star rating over the study period for each of the cities. As would be expected, the average star rating has increased over the study period in each city, although the rate of increase varies. Melbourne has seen the biggest improvement, with an average 1.5-star improvement over the nine years. Adelaide and Brisbane have had similar improvements of 0.5 stars; however, Adelaide has had a consistently higher average star rating than the other two cities, especially Brisbane.

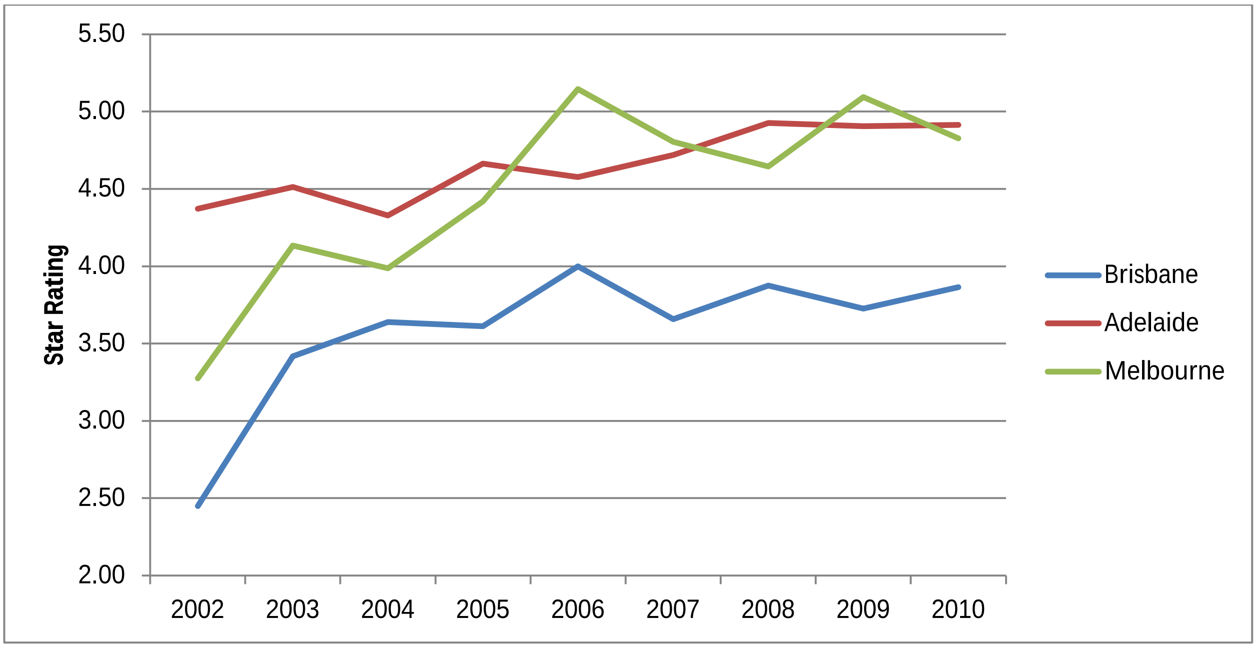
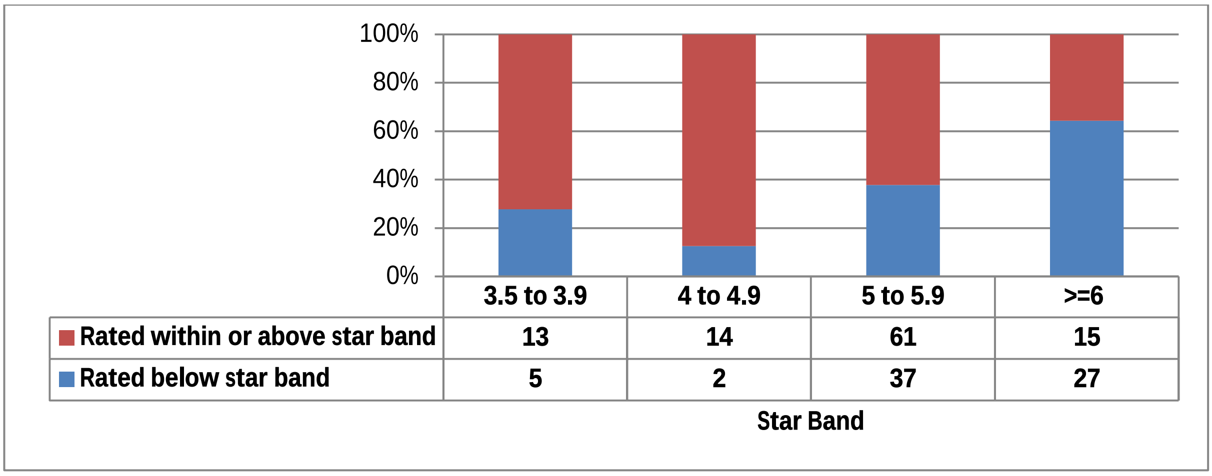


Figure 4-8 **Average star rating by city and year**

Although re-rated houses may have often rated below their original rating, this does not necessarily mean they were rated below that required by the regulations. For example, a house that originally rated at 5.5 stars and re-rated at 5.1 stars would still achieve the required rating of 5.0 stars. It is difficult to determine the precise star rating that a particular house was required to achieve, because this is determined by the date of building approval, which does not always correspond to the date listed on the plan. However, if we assume, for example, that a house that was originally rated between 5.0 and 5.9 stars was required to achieve 5 stars, then comparisons can be made. Using this assumption and allowing for a half-star tolerance, 59% of houses achieved a rating within their star band when re-rated. However, this varied within the star bands, as shown in Figure 4-9. Eighty-eight per cent of houses in the 4.0–4.9 star band achieved this rating when re-rated, while for the higher-rated houses, only 36% of houses originally rated at 6 stars or more were re-rated at the same level. This corresponds with the findings in Figure 4-7, which show that as the rating requirements have increased, the level of compliance has decreased.



	3.5 to 3.9	4 to 4.9	5 to 5.9	>=6
🟥 **Rated within or above star band**	13	14	61	15
🟦 **Rated below star band**	5	2	37	27

Figure 4-9 **Number of houses rated above and below the required star rating**

5 Construction compliance

An important aspect of this study has been establishing how well houses built since the introduction of energy efficiency provisions have met the requirement. Houses are rated at the time of design, and many of the aspects required as part of the energy efficiency provisions are hard to check and verify post-construction. Consequently, many building inspectors will be unable to establish if wall insulation, for example, has actually been installed. Other issues, such as the air tightness of the house, are almost impossible to establish without undertaking specific tests.

Visual inspection of certain aspects can help to establish a degree of confidence in compliance. For this study, trained assessors inspected a range of items in each house and assessed their quality. The following results are based on the findings of the visual inspections.

5.1 Ceiling insulation

Ceiling insulation is probably one of the easiest energy efficiency aspects to inspect. A range of insulation products are available and they need to be properly installed to ensure their optimum performance. Ceiling insulation was inspected for type, thickness of coverage (if applicable) and quality of installation. Figure 5-1 lists the various insulation materials found in use. Glasswool batts were by far the most common ceiling insulation material used, with reflective foil and anticon blankets common in many Brisbane houses.

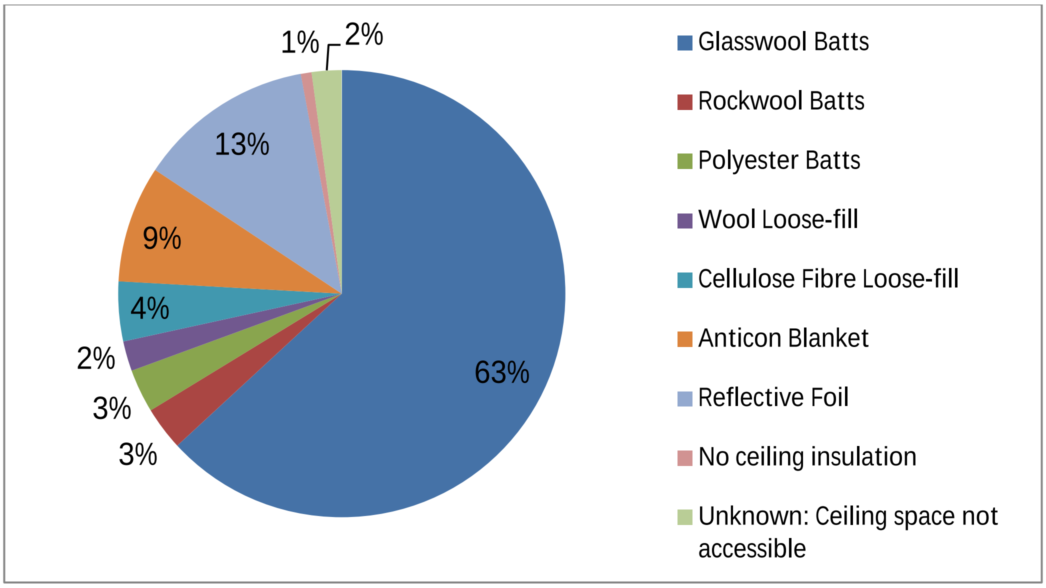


Figure 5-1 **Ceiling insulation types found in the studied houses**

The general condition of ceiling insulation is shown in Figure 5-2. Overall, the condition of the insulation was rated as good or average. Only a small percentage was found to be in poor condition, the worst being in 16% of houses in Melbourne. The higher-rated houses showed a slightly lower level of poor installs than the lower-rated houses (8.6% compared with 11.4%, respectively; see Figure 5-3).

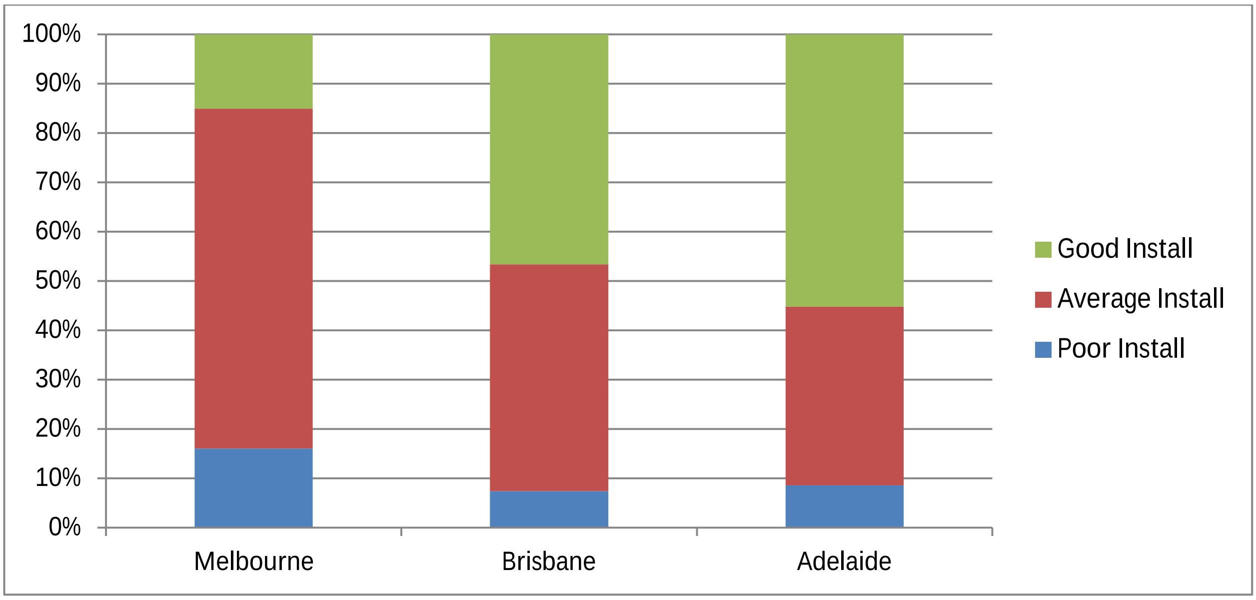


Figure 5-2 **Condition of ceiling insulation by city**

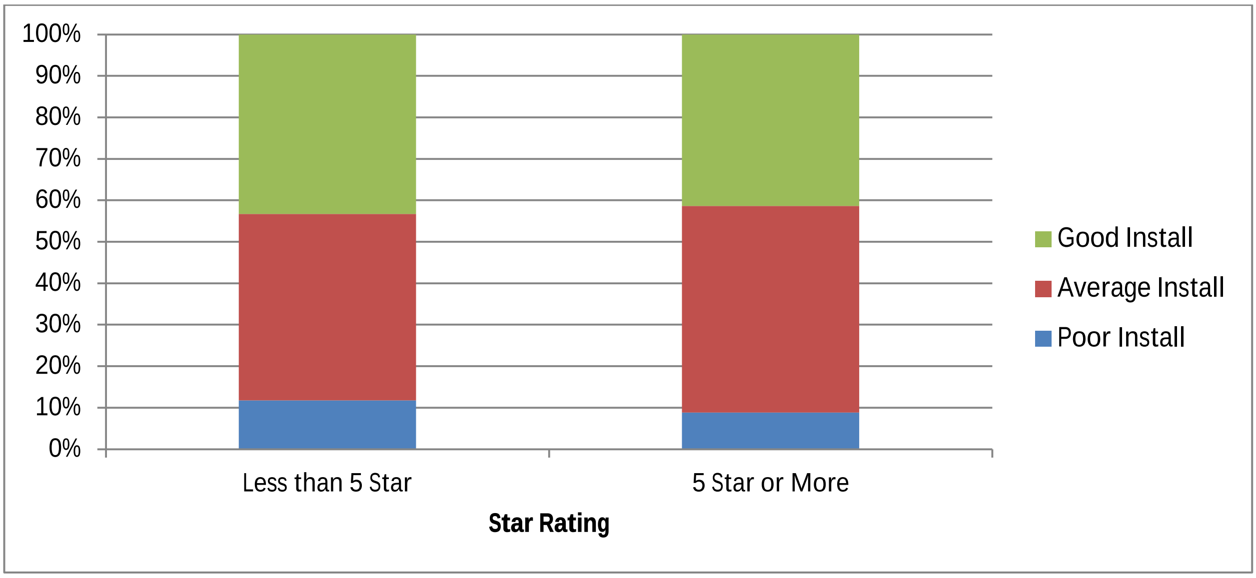


Figure 5-3 **Condition of ceiling insulation by star rating**

Thermal inspection of ceilings and walls helped to determine the quality of the insulation install and identify gaps in coverage. Thermal imaging was particularly useful in areas where access to the roof space was unavailable or difficult.

Figure 5-4 is an example of the thermal inspection showing gaps in the ceiling insulation coverage. The image on the right shows the large gap in insulation (dark area) around a downlight (whitish patch). Downlights present a particular issue, because clearance is required around these fixtures as part of AS/NZS 3000. The standard requires horizontal clearances from thermal insulation in ceilings of 50 mm for an incandescent downlight and 200 mm for a halogen downlight. However, in practice, the requirements of AS/NZS 3000 mean that insulation installers often leave out half a batt (450 mm x 450 mm) around each halogen downlight. Halogen downlights are typically installed at one per 2.5 m^2, meaning that in a 10 m^2 room, 0.81 m^2 of the ceiling is uninsulated. The heat lost through the uninsulated part of the ceiling will double the heat lost through the whole ceiling. This would reduce the effective R value of R3.5 insulation to

R1.2.[2]

Downlight covers are available that may allow insulation to be installed up to the side of the cover. However, these are rarely used.

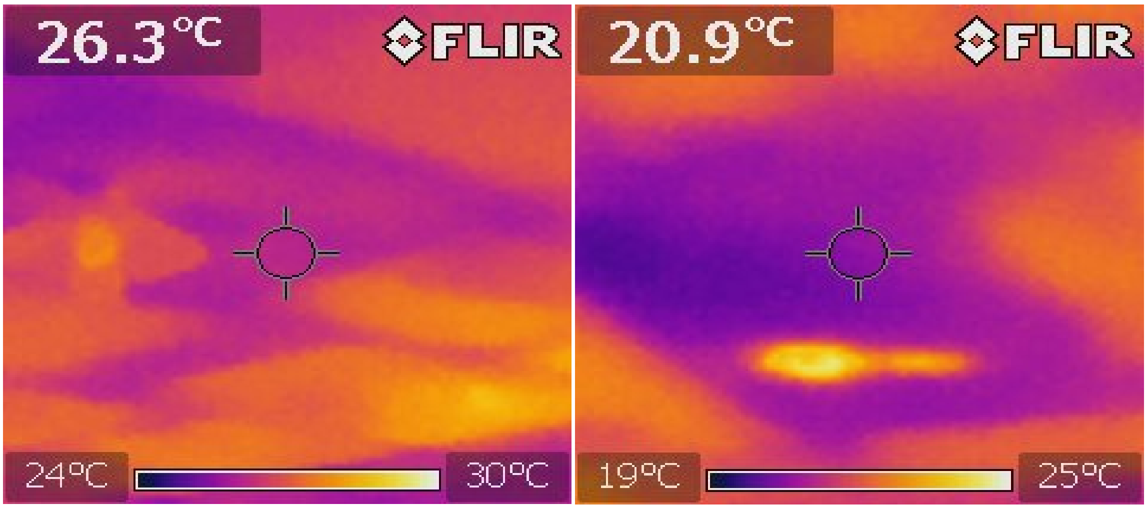


Figure 5-4 **Example thermal images of ceilings showing gaps in the insulation coverage**

5.2 Weather sealing

Good-quality weather sealing is important to reduce leakage of conditioned air from the house; it also reduces the amount of external air entering the house. Regulations require that windows and external doors be weather stripped. Weather stripping is a fairly simple technique, but can be easily damaged by the opening and closing of doors and windows, reducing its effectiveness. Assessors checked for weather sealing on windows and external doors. Most windows were found to have adequate weather stripping, although 6% of the Adelaide houses had none (Figure 5-5). Between the star-rating cohorts, a reduction in the number of houses without weather stripping was identified, down to 2.3% for higher-rated houses from 6.2% for the lower-rated houses (Figure 5-6).

External doors had a lower level of adequate sealing, with only 35% of the Melbourne houses having adequate sealing (Figure 5-7). In Adelaide, 60% of houses had complete weather seals on their external doors. Most houses had some degree of weather sealing, and again only a small percentage had none. As with window sealing, improvements were seen between the star-rating cohorts, with only 7.7% of higher-rating houses having no sealing, down from 10.4% for the lower-rated houses (Figure 5-8). The high use of doors may explain the degree of only partial stripping, because some may have been damaged and removed over time. This requires further investigation.

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[2] NatHERS Technical Note 2 – Guidance for calculating ceiling penetrations.

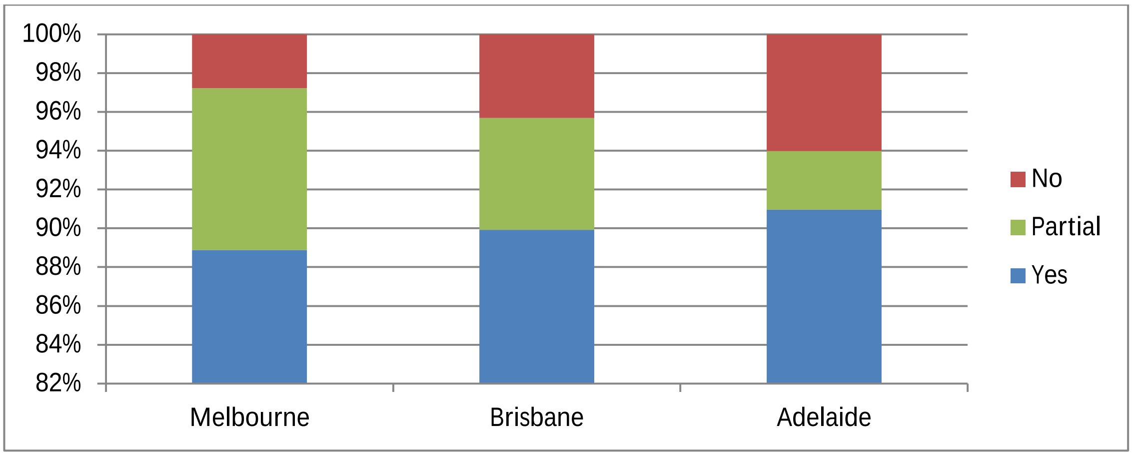


Figure 5-5 Weather stripping on windows by city

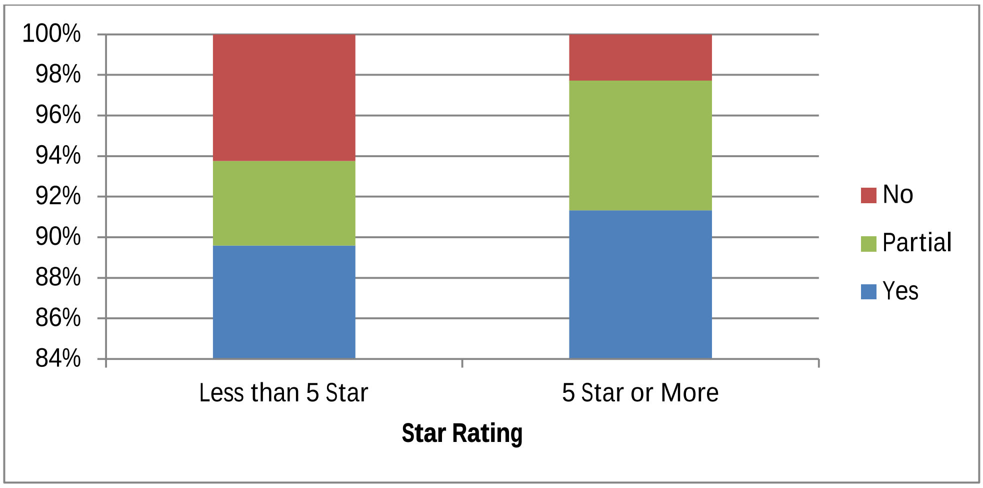


Figure 5-6 Weather stripping on windows by star rating

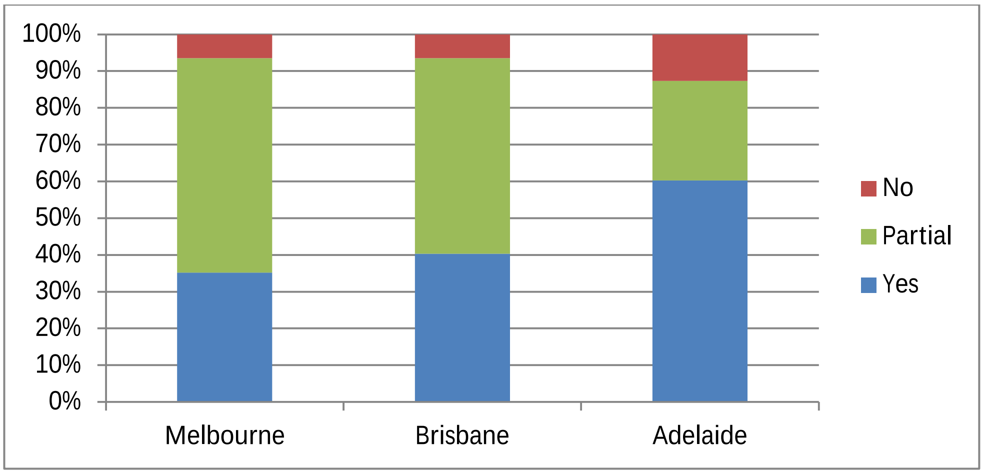


Figure 5-7 Weather stripping on external doors by city

Figure 5-8 **Weather stripping on external doors by star rating**

5.3 Pressure testing

Blower door air pressure testing is an effective way of determining the ‘leakiness’ of a house and helps to determine if the house has been adequately sealed. Each test was conducted according to the ATTMA TS1 standard. The houses were depressurised at different pressures in a 15–60 Pa range and were tested with all external, operable doors and windows closed. Unfortunately, pressure testing is expensive and only limited funds were available for these tests. Consequently, a sample of 20 houses in Melbourne was selected for testing.

The NatHERS software does not specifically define the level of air tightness that is to be achieved, but certain assumed values are used. The rate of 15 air changes per hour (ACH) when the house is pressurised to 50 Pa is considered an average value, with better-sealed houses performing at around 10 ACH @50 Pa. It is interesting to note that the European PassivHaus standard requires houses to achieve a rate of 0.6 ACH @50 Pa: 33 times lower than the average of 19.7 ACH @50 Pa measured for the 20 houses in this study.

Table 5-1 lists the results of the flow rate measured at 50 Pa pressure for each house. Only one house achieved a result below 10 m^3/hr @50 Pa, which is considered to be good sealing, while around half achieved close to 15 m^3/hr @50 Pa, which is considered average sealing. Of concern are the 20% of houses that exceeded 30 m^3/hr @50 Pa. This level of performance is generally found in old, poorly designed houses and would not be expected in houses built within the past 10 years. In addition, as these houses were all located in Melbourne, none were rated below 4 stars.

Table 5-1 **Air pressure results for 20 sample houses tested in Melbourne**

ID	Volume m^3	Flow @ 50 Pa (m^3/hr)	ACH 50 Pa	ACH 2:5 Pa	ACH Natural	ELA (m^2)
1	536	4324	**8.07**	1.34		0.22
2	617	14008	**22.70**	5.00		0.70
3	778	11628	**14.95**	2.32		0.58
4	540	9105	**16.86**	1.79	0.46	0.15
5	793	14099	**17.78**	2.17	0.55	0.26
6	590	14688	**24.90**	5.26	1.23	0.43
7	482	6594	**13.81**	2.22		0.33
8	698	11489	**16.46**	2.08	0.53	0.22
9	847	12166	**14.36**	2.63		0.61
10	383	11696	**30.54**	7.10		0.58
11	503	17043	**33.88**	5.43		0.85
12	526	8278	**15.74**	3.07	0.73	0.22
13	442	14230	**32.20**	7.64		0.71
14	707	11567	**16.36**	2.90		0.58
15	574	12673	**22.08**	3.30		0.63
16	679	20443	**30.11**	6.38		1.02
17	390	6477	**16.60**	2.61	1.40	0.32
18	518	11443	**22.09**	2.94	0.74	0.22
19	530	6763	**12.76**	2.03	1.08	0.34
20	446	5577	**12.51**	2.08	1.07	0.28

ACH = air change per hour; ACH natural = without test pressure; ELA = Equivalent Leakage Area

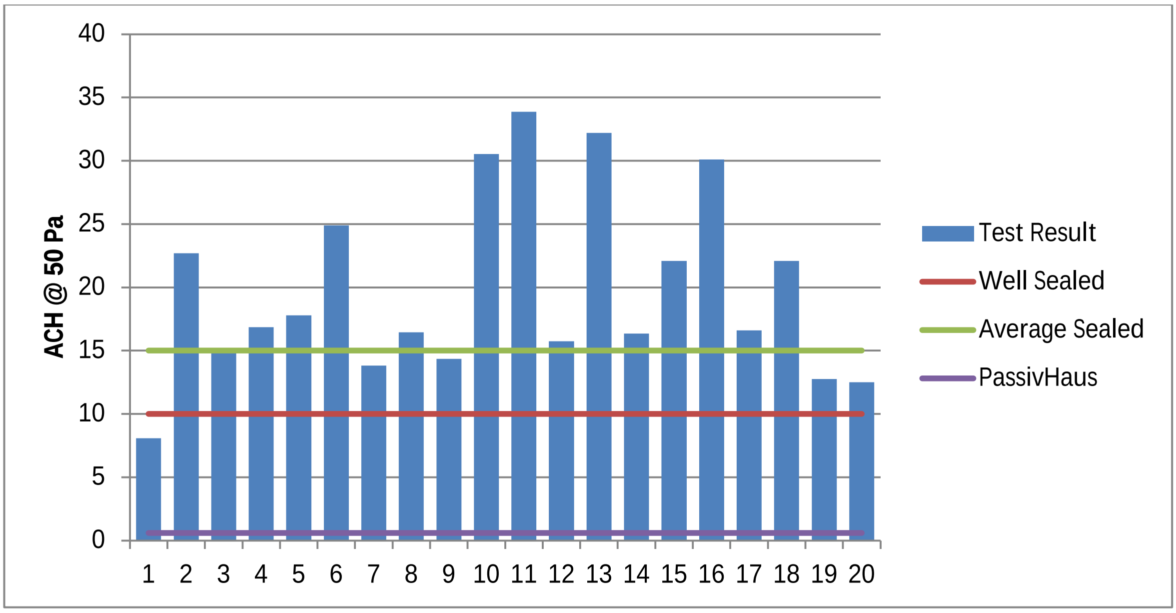


Figure 5-9 **Pressure test results at 50 pascals for 20 sample houses in Melbourne**

Despite the higher-than-expected pressure test results, when the results were organised by year of building approval, they showed that over time the trend has been to improve air tightness in houses (Figure 5-10). This is an encouraging trend, which shows that the best-performing houses were also the most recently constructed.

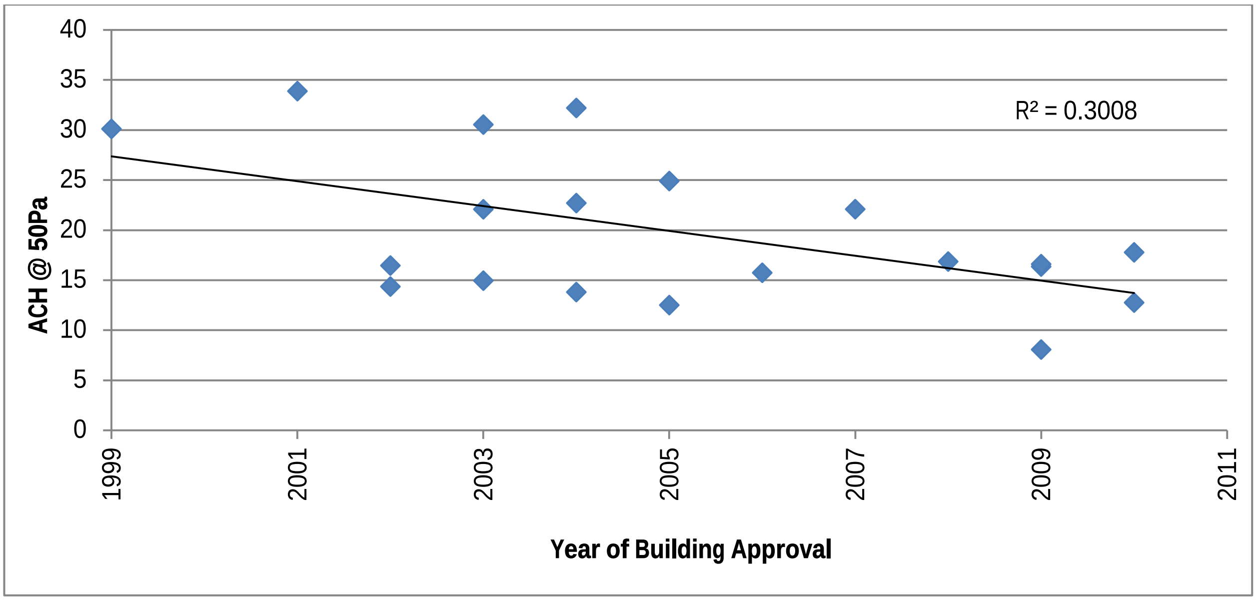


Figure 5-10 **Relationship between year of building approval and pressure test results**

Analysis was also conducted to see if any relationship existed between the star rating of the houses and their pressure results: i.e., were homes with higher star ratings achieving better pressure results. No relationship was identified.

5.4 Internal temperatures

The internal temperatures of all houses in the study were monitored by sensors located in the main living space. The data were used to estimate the internal comfort that households were experiencing in relation to the outside temperature. Temperature data could also be used as an indicator of possible thermostat settings that were being applied. In this respect, it is worth noting that comparisons can be made between the actual internal temperatures that are being set, and the assumed temperature settings that are applied through the NatHERS software. NatHERS uses a fixed comfort range to determine when heating or cooling is required.

Figure 5-11, Figure 5-12 and Figure 5-13 show the average internal temperatures for each city at various times of the day. The most informative is the average internal temperature experienced in the evening (6:00–10:00 pm), a period in which the majority of houses would be occupied and heating/cooling systems in operation if required. The figures also indicate the assumed NatHERS comfort band, which is different for each city. In Brisbane, for example, houses were up to 1.6 °C warmer than NatHERS assumes in February, whereas in Adelaide during July, the average internal temperature was a degree cooler than NatHERS assumes.

Several reasons may account for these differences. For example, the heating/cooling system may have been running at capacity and unable to achieve the comfort band; or, households may have chosen to allow their house to be slightly warmer or cooler than NatHERS assumes. We recommend that this phenomenon be investigated further to better determine the actual cause.

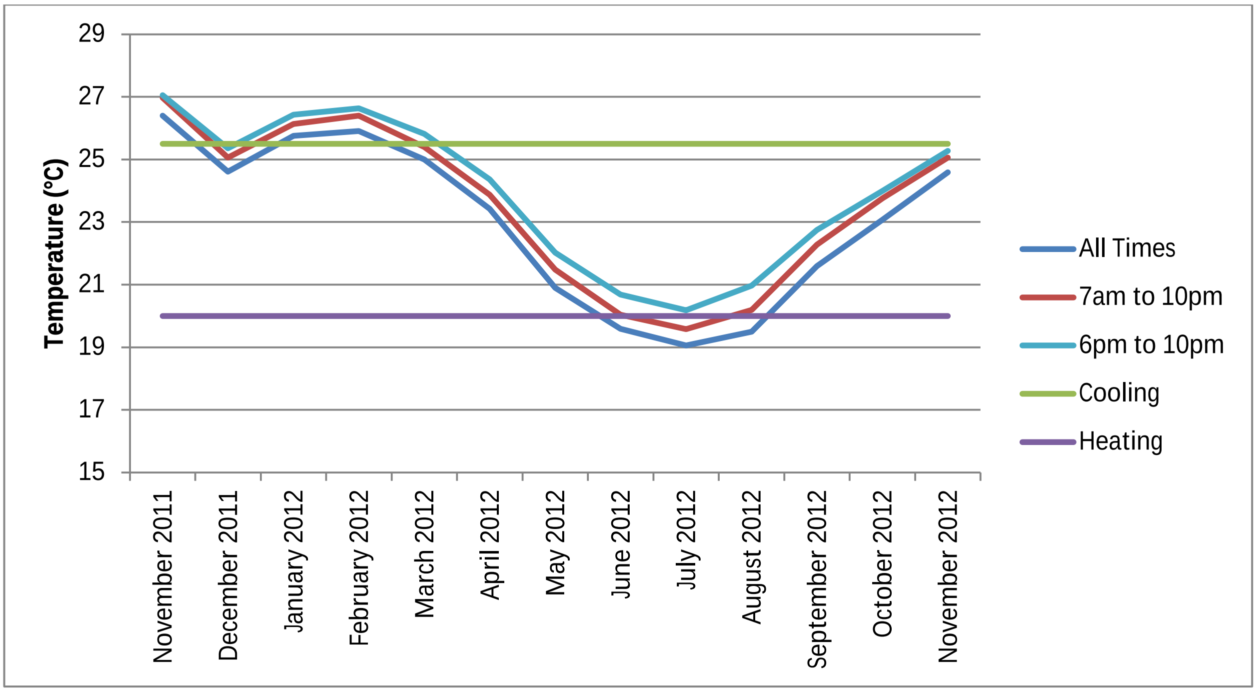


Figure 5-11 **Average internal house temperatures for Brisbane**

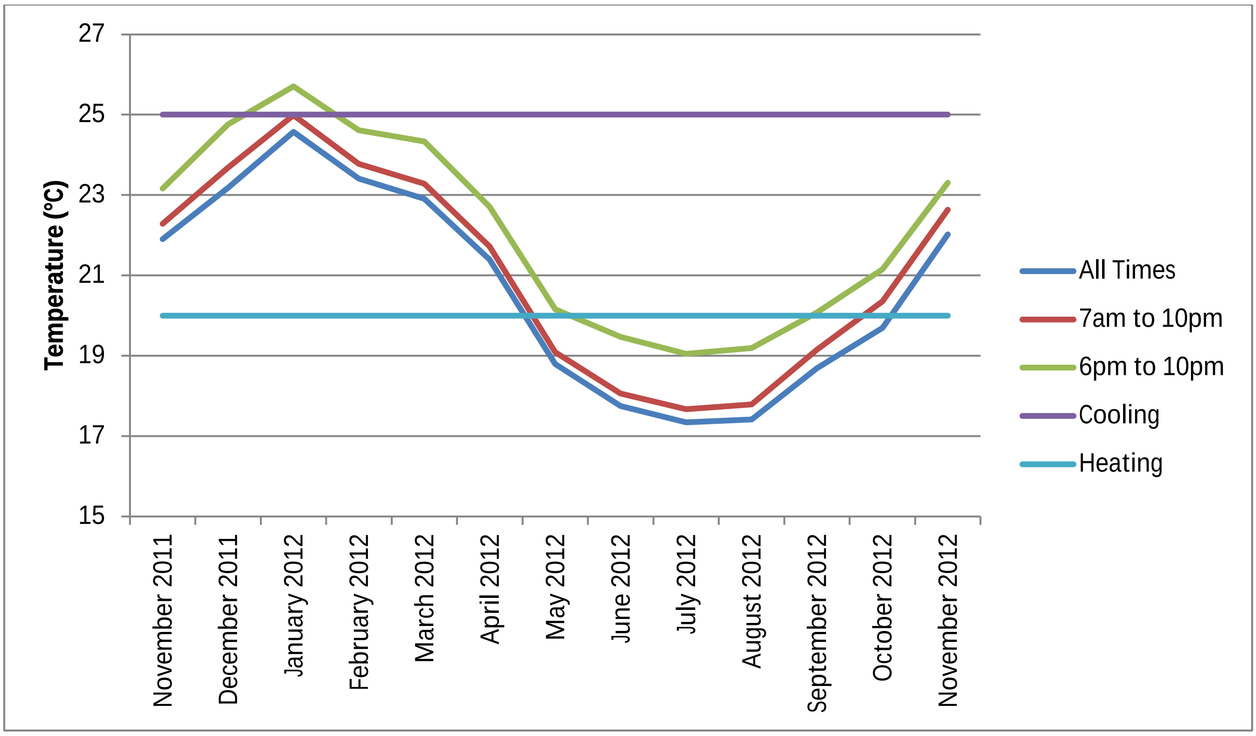


Figure 5-12 **Average internal house temperatures for Adelaide**

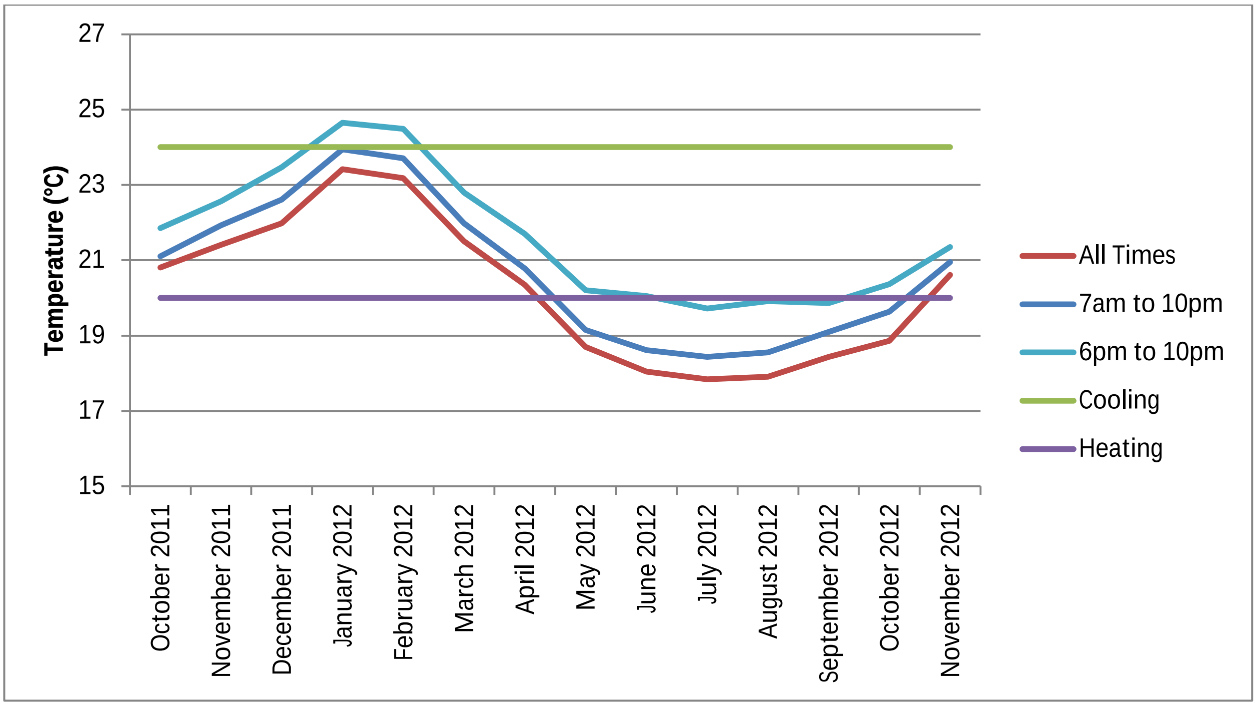


Figure 5-13 **Average internal house temperatures for Melbourne**

6 Construction techniques for achieving compliance

Builders have used a variety of methods to achieve the NatHERS energy efficiency standards. We analysed the AccuRate assessments of all houses in the study to identify these methods, and the changes that have occurred to achieve the higher standards: that is, the shift from 3.5-4 stars to 5 stars or more. The AccuRate assessments listed all the major building materials used in the building envelope, including any insulation materials. The area, location and thermal performance of these materials were also recorded. Consequently, a detailed picture of how residential houses have achieved their required star rating performance has been obtained for each of the three cities in the study.

Essentially, builders used the following methods to achieve the energy efficiency standards:

- insulation to ceilings
- insulation to walls (external and internal)
- insulation to concrete slab floors
- double-glazed windows
- window orientation
- changes to overall glazing area

Our analysis of the changes within each city for each cohort of NatHERS-rated houses has provided an indication of the most popular methods chosen by builders to achieve the required rating.

6.1 Ceiling insulation

The thermal performance level of ceiling insulation varied by city and changed between the star-rating cohorts (Table 6-1). Brisbane houses predominantly have R1.5 or R2.5 ceiling insulation, with increasing use of R2.5 in the higher-rated houses and a corresponding decrease in R1.5. Adelaide predominantly has R2.5 or R3.0 ceiling insulation, while in Melbourne, the higher-rated insulation (R3.5 and R4.0) dominates in the higher-rated houses.

Table 6-1 Ceiling insulation levels (%) by city and star rating

Insulation level	5 stars or more			Less than 5 stars		
	Brisbane	**Adelaide**	**Melbourne**	**Brisbane**	**Adelaide**	**Melbourne**
R1.0	0.0	0.0	0.0	1.8	1.6	1.6
R1.5	31.1	2.7	5.1	46.8	3.4	7.4
R2.0	2.2	3.3	1.1	6.3	9.4	4.2
R2.5	58.3	28.1	20.9	42.7	38.6	54.3
R3.0	3.5	45.8	10.4	2.4	42.6	6.9
R3.5	4.9	13.3	42.5	0.0	2.5	15.2
R4.0	0.0	6.9	20.0	0.0	2.0	10.4

6.2 External wall insulation

The use of external wall insulation is common in the heating-dominated cities (Adelaide and Melbourne), but is rarely employed in Brisbane: even within the higher-rated cohort, where 80% of all external walls have no insulation (Table 6-2). In Adelaide, 82% of the external walls in higher-rated houses have insulation, while the rate is 75% in Melbourne. This is up from around 60% of external walls in lower-rated in both Adelaide and Melbourne. R1.5 or R2.0 is the most common insulation level installed.

Table 6-2 External wall insulation levels (%) by city and star rating

Insulation level	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
None	80.2	16.5	19.2	83.5	32.4	33.5
R1.0	4.9	0.0	1.7	4.8	7.0	7.7
R1.5	9.7	53.4	40.0	8.1	40.6	39.0
R2.0	5.2	29.1	35.0	2.7	20.0	18.5
R2.5	0.0	1.1	4.2	0.9	0.0	1.4

6.3 Internal wall insulation

Internal wall insulation is still uncommon in houses in all of the cities within the study, including houses in the 5-star cohorts. In Brisbane, internal wall insulation is virtually never used, while Adelaide has the greatest use of internal wall insulation, with 19% of walls in lower-rated houses containing insulation, increasing to 24% for higher-rated houses (Table 6-3).

Table 6-3 Internal wall insulation levels (%) by city and star rating

Insulation level	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
None	96.7	76.2	91.4	97.7	80.7	92.9
R1.0	0.2	0.2	0.1	0.2	1.9	0.0
R1.5	2.3	13.7	4.7	0.8	13.2	5.9
R2.0	0.2	9.7	3.5	1.1	4.2	0.4
R2.5	0.6	0.2	0.3	0.2	0.1	0.7

6.4 Floor insulation

The vast majority of houses within the study have a concrete slab for their ground floor. A small number have raised floors (14 in Brisbane, 8 in Adelaide and 6 in Melbourne). Of these, 18 have no insulation, four have some form of insulation, and six are unknown.

Of the houses that use concrete slabs, many use a waffle slab, which has insulative properties via the use of polystyrene pods. The AccuRate software used for the star-rating modelling cannot formally model the thermal impact of waffle pods, but a common work-around adopted by assessors is to include a layer of expanded polystyrene on the underside of the slab. This polystyrene layer usually provides an R value of 1.0 to the slab. Table 6-4 lists the percentage use of waffle pods and the corresponding insulative impact. The use of waffle pods over traditional, in-ground concrete slabs has been increasing over the years, and this is reflected in the newer 5-star houses. The main reason for the increasing uptake is that waffle pod systems are usually easier, faster and cheaper to install than traditional concrete slabs. The increased insulation benefits have not been a driver of the uptake, but can provide up to a half-star increase in the rating in some cities.

Table 6-4 Slab insulation via the use of waffle pods (%) by city and star rating

Insulation level	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
None	76.2	98.6	54.8	88.0	100.0	78.7
R1.0	23.8	1.4	45.2	12.0	0.0	20.0
R1.5	0.0	0.0	0.0	0.0	0.0	1.3

6.5 Double-glazed windows

In the heating-dominated cities, particularly Melbourne, double glazing helps to reduce heat loss over the winter heating periods. However, double glazing is still a relatively expensive option, and consequently, uptake has been limited. Nevertheless, Table 6-5 shows an increase in the use of double glazing in Melbourne for the higher rated compared to the lower rated cohorts. A total of 13.3% of all windows in the higher-rated houses were double-glazed, up from 7.7% in the lower-rated houses.

Table 6-5 Window types (%) used by city and star rating

Window type	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
Single-glazed	100.0	95.1	86.7	98.8	99.4	92.3
Double-glazed	0.0	4.9	13.3	1.2	0.6	7.7

6.6 Glazing area

Windows typically account for the greatest amount of heat gain or loss in the building fabric. For example, heat gain through an unshaded window can be 100 times greater than through the same area of insulated wall (Reardon, Milne, McGee, & Downton, 2008). Consequently, reducing glazing area is often used as an effective technique to improve the star rating of houses. Table 6-6 shows the reduction in glazing that has occurred with the increase in star rating. The window/wall ratio indicates the percentage of external facade that is glazed. There has been a small reduction in this ratio of around 1.1% in all cities. However, the average area of glazing has also significantly reduced, with around a 20% reduction in all cities. The reason why this has not translated to a bigger reduction in the window/wall ratio is that the houses themselves have become smaller in area, and are more rectangular. Consequently, the average external wall area has also reduced.

Table 6-6 Glazing areas by city and star rating

	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
Window/wall ratio (%)	20.6	18.5	18.5	21.8	19.7	19.5
Average glazing area per house (m^2)	38.48	33.10	36.44	52.33	42.15	48.11

6.7 Window orientation

Maximising north-facing glazing and minimising west-facing glazing helps control heat gain through windows. North-facing windows allow winter sun to enter to warm the house, while hot summer sun can be excluded with effective shading. This is one of the main principles of passive design, and helps houses reduce their reliance on auxiliary heating and cooling systems. Traditionally, the orientation of houses has been dictated by the orientation of the block of land and the location of the street. Only limited attention has been paid to the orientation of the windows, especially the large living area windows. Correctly orientated windows will help improve a house's star rating.

Small changes in window orientation can be observed between the star-rating cohorts (Table 6-7). In Brisbane and Adelaide, the percentage of north-facing glazing has increased, while west-facing glazing has decreased. In Melbourne, the percentage of north-facing glazing actually decreased, with the higher-rated houses showing an increase in west-facing glazing.

North-facing glazing was considered to be any window that was within 30° either side of north, while south-facing glazing was within 30° either side of south. East and west-facing glazing were the remaining azimuths between north and south.

Table 6-7 Window orientation (%)

Window orientation	5 stars or more			Less than 5 stars		
	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne
North	28.4	23.9	24.6	22.3	21.0	25.4
East	29.3	29.4	27.8	32.6	33.6	27.4
South	21.7	18.9	19.2	20.1	17.0	22.2
West	20.6	27.8	28.4	25.1	28.3	25.0

6.8 House area

A surprising finding has been that the average conditioned area of houses has reduced for the higher-rated houses. This has occurred in all three cities, although only a small reduction was seen in Adelaide (Table 6-8). The conditioned area of the house was taken from the AccuRate modelling and typically excludes areas such as bathrooms, laundries and garages. The decrease in house size may be due to factors such as a reduction in average block size or the cost of construction.

Table 6-8 Average conditioned floor areas (m^2) by city and star rating

City	5 stars or more	Less than 5 stars	Difference	% change
Brisbane	149.3	173.6	24.3	14.0
Adelaide	141.7	145.1	3.4	2.3
Melbourne	155.7	177.3	21.6	12.2

Figure 6-1 details this further, and clearly shows the trend towards smaller floor areas as the star rating increases. In all cities, the lowest-rated houses also have, on average, the largest floor areas.

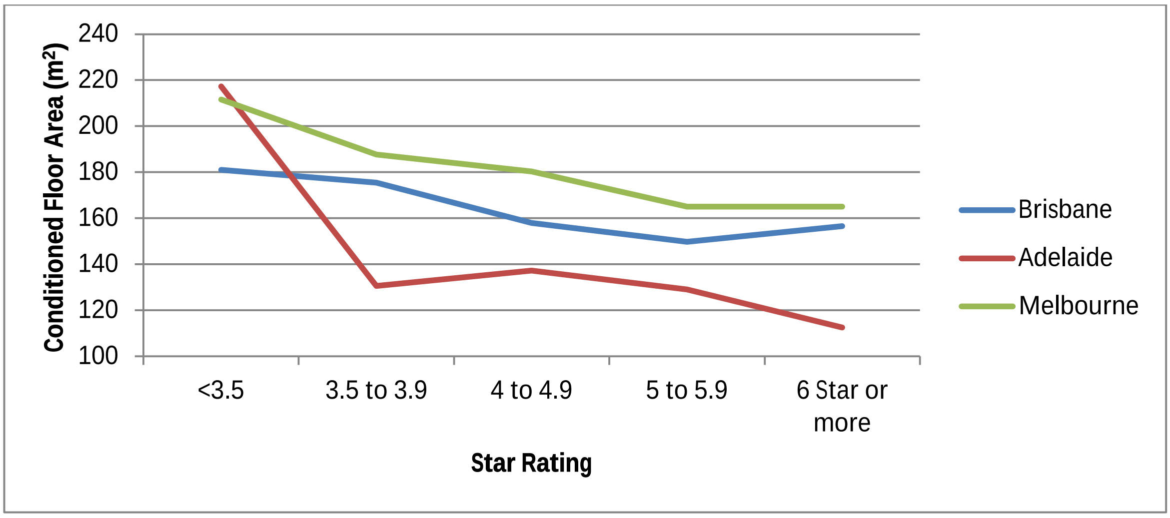


Figure 6-1 Average conditioned floor area by city and star rating

6.9 External wall area

With houses becoming smaller, the area of external walls would also be expected to reduce, and this is reflected in the houses in the study. Table 6-9 shows that the change in external wall areas has been quite significant, especially in Brisbane and Melbourne. It is important to note that the percentage change in wall area is greater than the percentage change in floor area.

Table 6-10 lists the change in wall area after floor areas are corrected; still, around a 14% reduction in external wall area is evident in all cities.

The reason for the change may be due to simpler floor layouts and more rectangular buildings. Reducing the number of corners in a design will reduce the external wall perimeter and consequently reduce wall area. Smaller blocks may also be a factor in driving the change to smaller, more rectangular buildings.

Table 6-9 Average external wall areas (m^2) by city and star rating

City	5 stars or more	Less than 5 stars	Difference	% change
Brisbane	134.3	173.7	39.4	22.7
Adelaide	133.1	159.4	26.3	16.5
Melbourne	146.6	183.6	37.0	20.2

Table 6-10 Average external wall areas (m^2) corrected for floor area

City	5 stars or more	Less than 5 stars	Difference	% change
Brisbane	134.3	161.1	26.8	16.6
Adelaide	133.1	152.6	19.5	12.8
Melbourne	146.6	167.9	21.3	12.7

7 Construction costs in meeting compliance

As energy efficiency standards increase, the common belief has been that building costs will also increase. As discussed in Section 6, the main techniques that have been observed to affect the star rating of houses have been increased insulation levels, a shift to waffle pod slabs, an increase in the use of double glazing, and a shift in window orientation. In addition, a possible shift towards more rectangular buildings has reduced window area without significantly reducing window/wall area ratio. While many of these techniques do incur costs, some actually reduce costs. In particular, the reduction in glazing area translates to a direct cost saving as expensive glazing is replaced by less expensive walling. The reduction in wall area also reduces cost.

An observed reduction in conditioned area for the higher-rated houses may have lead to a skewed cost comparison, because the total cost for a smaller house will often be less than a comparable larger house. To account for this, we excluded lower-rated houses with a conditioned space of greater than 230 m^2. This resulted in the average conditioned area of all houses being within approximately ±5% in each city.

The cost analysis involved extracting a list of materials and components, and their corresponding quantities, from the AccuRate file for each house. Essentially, this resulted in a bill of quantities for those elements of the house that affect star rating. For each star-rating cohort in each city, the quantities of the various elements were summed and then divided by the number of houses in the cohort to derive an average quantity of each element for a ‘typical’ house. The resulting quantities for each element were then costed using cost data obtained from Rawlinsons Cost Guide 2011 (Rawlinsons, 2011). Appendix F lists the unit costs that were applied.

As an example of this methodology, we can examine the use of double-glazed windows in Melbourne, where 40 houses were below 5 stars and 91 houses were above 5 stars. Examination of the AccuRate data revealed that the lower-rated cohort contained 1686 m^2 of single glazing and 35 m^2 of double glazing, while the higher-rated cohort had 2873 m^2 of single glazing and 443 m^2 of double glazing. When divided by the number of houses in each star-rating cohort, the lower-rated houses have an average total window area of 43 m^2, of which double glazing represents only 0.87m^2 (2%), and the higher-rated houses have an average total window area of 36 m^2, of which double glazing represents 4.86 m^2 (13%). Consequently, it can be concluded that in the higher-rated houses, on average, total window area has decreased while the proportion of those windows that are double-glazed has increased. Costs can then be applied to these average quantities. Using a cost of \$461/m^2 for a double-glazed awning window in Melbourne results in an average cost of \$400 for a lower-rated house (461 x 0.87), and \$2242 for a higher-rated house (461 x 4.86).

Finally, the following assumptions were made to allow cost comparisons.

- Expanded polystyrene in floors was considered to be waffle pods.
- The cost of waffle pod concrete slab and standard in-ground concrete slab was considered the same, so no cost difference was calculated.
- All windows (both single and double-glazed) were considered to be awning windows with aluminium frames.
- All external walls were considered to be brick veneer with timber stud and painted plasterboard.
- All wall and ceiling insulation was considered to be glasswool batts of the specified R value.

Table 7-1 lists the average cost per house for each of the star rating cohorts within each city. The surprising result is that the costs related to achieving the regulations for the higher-rated houses are lower than the costs incurred for the lower-rated houses. Closer examination of the data reveals that the main reason for the cost saving is reduced external wall area and glazing area, which is occurring in all cities. The reduced glazing translates to a significant cost saving as windows are replaced by walls. A standard brick veneer wall is more than 40% cheaper than a standard single-glazed awning window, and more than 60% cheaper than a double-glazed awning window.

Table 7-1 Average house cost (AU$) for achieving the NatHERS star rating standard by city

	Less than 5 stars			5 stars or more		
City	**Brisbane**	**Adelaide**	**Melbourne**	**Brisbane**	**Adelaide**	**Melbourne**
External wall insulation	249.40	905.49	924.87	245.48	993.44	1,119.57
Internal wall Insulation	39.56	244.40	140.98	54.78	350.05	137.71
Ceiling/roof insulation	1,718.41	1,727.35	1,717.73	1,669.38	1,747.74	1,941.58
Single glazed windows	14,245.27	12,897.33	13,784.03	11,735.70	10,233.07	10,324.50
Double glazed windows	349.72	121.31	400.15	0.00	774.28	2,241.68
External walls	27,510.48	30,679.32	30,249.51	22,932.88	26,765.32	26,407.48
Total cost	44,112.85	46,575.20	47,217.27	36,638.22	40,863.91	42,172.52
Difference				–7,474.63	–5,711.29	–5,044.75

The apparent simplification of design layout has lead to the observed reduction in external wall area, which is the main reason for the cost savings. As discussed in Section 6.9, even after correcting for floor area, external wall area has decreased by around 14%. This translates to a cost savings of around 15% for the external walls. Other factors have also contributed, including the reduction in glazing area. The cost savings more than compensate for the increased cost of improved insulation. In most cases, the incremental cost of increasing insulation performance is small. For example, the cost difference between R2.5 and R4.0 ceiling insulation is only \$3.40/m^2.

Overall, the measures required to achieve the higher ratings are costing at least \$5,000 less than the equivalent lower-rated house. In Brisbane, the 5-star houses are costing \$7,400 less to achieve their higher star requirement than the corresponding lower-rated houses. This result demonstrates the benefits of a performance-based regulation as opposed to a prescriptive-based regulation. The reasons for the observed changes in design may be due to factors unrelated to the star rating requirements, such as smaller lot sizes and customer preferences. However, the inclusion of these design changes has an impact on both star rating and cost.

8 Whole-of-house total energy usage and greenhouse gas emissions

8.1 Sample representativeness and energy usage variations

The sample selection methodology described in 1.3.1 was chosen with the desire to measure representative energy consumption for houses before and after changes to the BCA energy efficiency regulations. The extent to which this has been achieved is crucial in understanding the confidence that can be placed in the following energy efficiency data and analyses. Key questions that need to be asked include:

- *Are the occupants in the lower and higher star-rating house cohorts sufficiently similar to allow us to expect that energy usage patterns would be the same*? Preliminary results in Section 3 suggest a slight difference in occupancy for lower-rated houses than for higher-rated houses. However, the results from assessments during peak usage periods of the day are consistent with the results reported for seasonal periods. This suggests that occupancy differences are not unduly influencing the seasonal results. However, further research is needed on the effects of star-dependent occupancy to determine if they affect the star-rating dependence of energy consumption.
- *Are the houses in the lower and higher star-rating cohorts using the same heating and cooling appliances*? Reverse-cycle air conditioners were the dominant appliance in Brisbane and Adelaide. In Melbourne, a larger fraction of the higher-rated houses had no cooling. Both Melbourne cohorts used gas for winter heating, with only a small amount of reverse-cycle air conditioning. A small number (~4%) of the lower-rated houses used electric-resistance heating, which was not evident in the higher-rated houses.
- *Are the houses in the lower and higher star-rating cohorts the same size*? Section 6.8 found that the house sizes are generally fairly similar, with the exception of a number of very large (>300 m^2) houses, which are all in the lower star-rating cohort. Inclusion of these larger houses may skew the lower star-rating cohort towards higher energy consumption.
- *Is the energy usage behaviour of the occupants in the two cohorts representative of normal behaviour in the broader population*? Section 3 found that around 15% of households are retiree households (either single or couples) and 21% are working couples with no children. However, this study is limited in scope, and as previously described, is not representative of all households in Australia.

These measureable differences may provide some pointers towards possible differences. However, even in an otherwise perfect sample (with no outwardly measureable distinguishing features), the selected houses may still contain a biased group of individual occupants with electricity-using preferences that are not representative of the broader population.

The spread of household energy use by frequency (Figure 8-1) shows that energy consumption exceeds the median by factors of 3% for Brisbane, 15% for Adelaide and 11% for Melbourne. This suggests that energy use, behaviour, house size and household income may be significant factors, and that simple averaging is inappropriate for comparing star ratings.

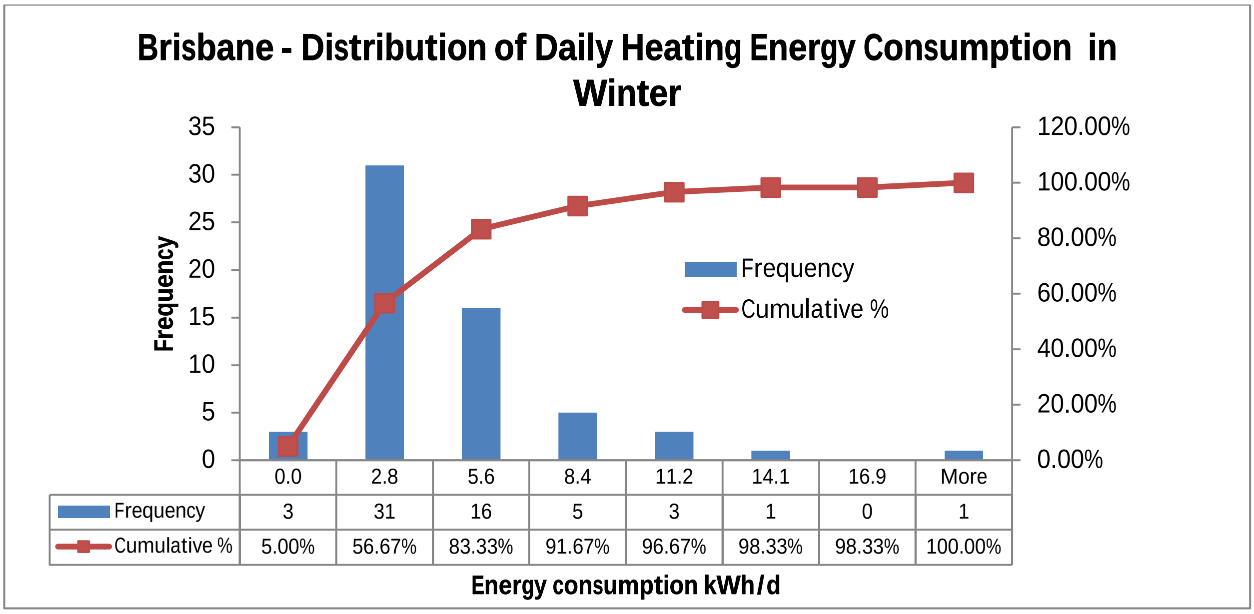


Figure 8-1 Distribution of daily heating energy for houses in Brisbane in winter

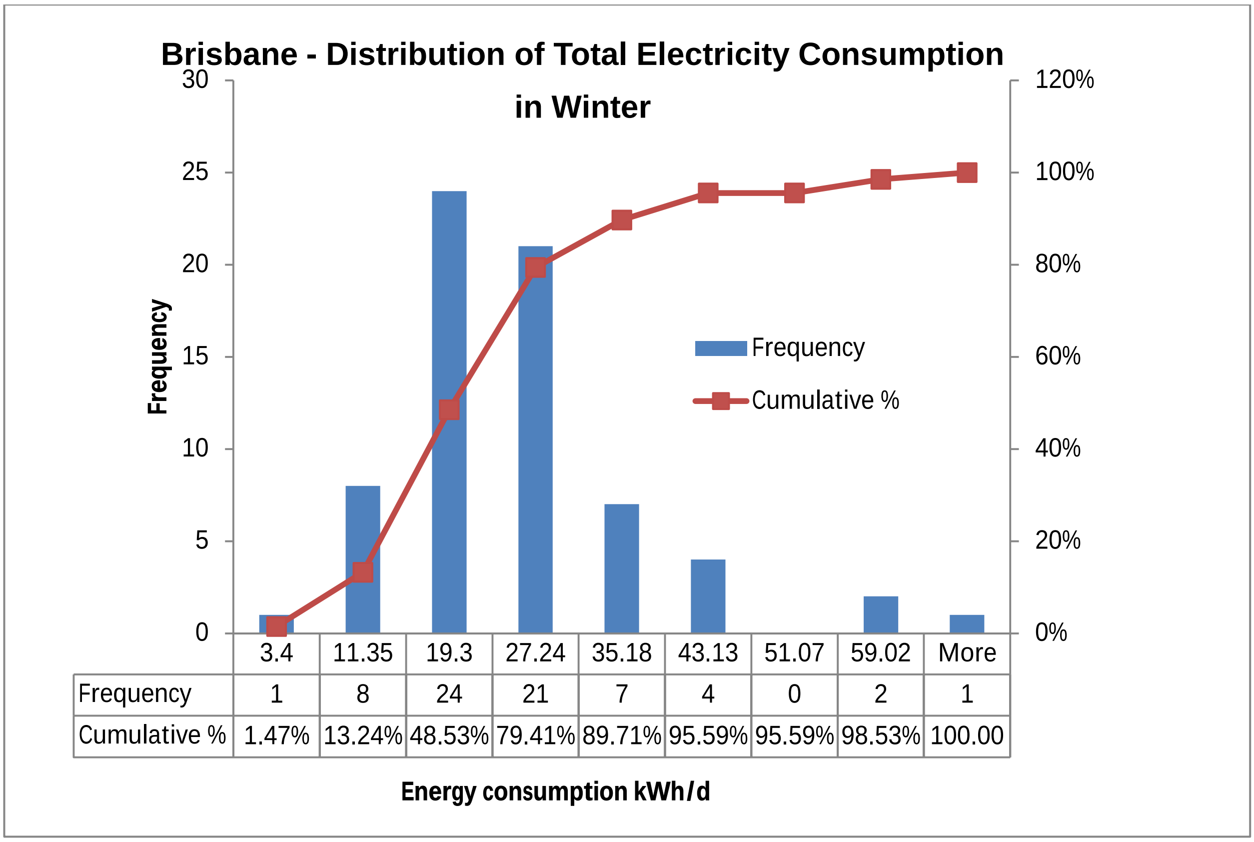


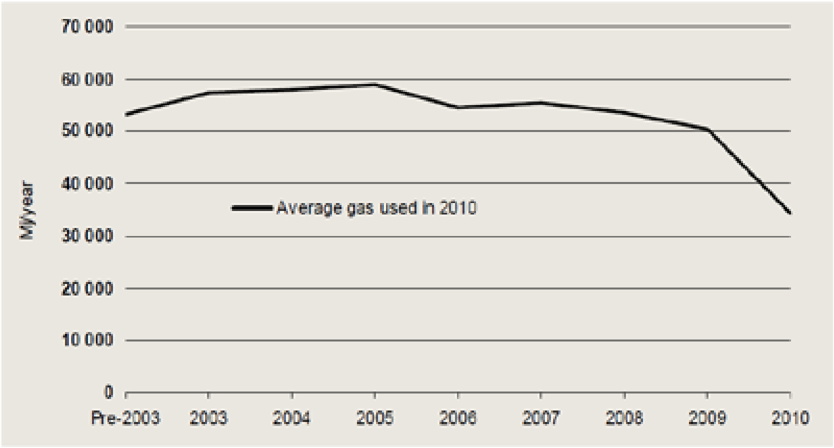
Figure 8-2 Distribution of daily total energy for houses in Brisbane in winter

To further check if the sample looks broadly representative, the average whole-of-house electricity consumption in the sample houses in each city was compared against the expected electricity consumption for houses in that city (Table 8-1). The expected annual electricity consumption was obtained using the Energy Made Easy website calculator (http://www.energymadeeasy.gov.au/bill-benchmark), using a comparable occupancy profile to the sample.

Table 8-1 **Comparison of electricity consumption in sample houses against average city houses (www.energymadeeasy.gov.au)**

	Brisbane	Adelaide	Melbourne
Measured (kWh)	7225±2641	6365±2748	6008±3131
Expected (kWh)	6791	6425	6048

A major bias in the results reported in this section is that the CSIRO data set is extrapolated to one year, from a sample that was taken over nine months. In the near future, we will have a year's worth of data to make these estimates more accurate. However, 8.1 suggests that (i) annual electricity use in the Adelaide and Melbourne samples is broadly in line with the expected values, and that (ii) annual electricity usage in the Brisbane sample is above the expected values. However, as expected, there is large variability in energy usage between houses, and the ratios of standard deviations to mean values given in Table 8-1 are very close to such ratios measured in much larger studies (statistics for a New South Wales study of house total energy consumption: A. Higgins, CSIRO, personal communication). Average household gas energy consumption in single dwellings in Melbourne is around 55,000 MJ/yr, whereas the sample of Melbourne houses consumed about 37,600 MJ/yr each. This reduction possibly reflects the earlier introduction of house efficiency regulations, and is consistent with an SPAusnet study of gas usage (Figure 1-1) (Centre for International Economics, 2012).



Data source: The CIE.

Figure 8-3 **Melbourne average household gas use by year of connection**

These issues go some way towards explaining the very large spread of values that may be encountered in a statistical analysis of energy consumption by householders. It is therefore important not to expect that comparisons of simple averages from restricted populations can yield definitive results. For statistically significant conclusions, it is necessary to use parameters that are, as far as possible, independent of human behaviour. We have found that it is also necessary, particularly with heating and cooling energy consumption, to consider the skewed statistical distribution. The values given in this section are provided in response to the requirement for qualitative and indicative information. For statistically significant results, we advise the reader to use sections 10 and 12, and understand that this only represents a subset of the population of houses and householders.

8.2 Energy consumption

Electricity and natural gas are the two main fuel sources used to provide energy in the volunteer households. For half the houses in the study, electricity consumption was monitored at a circuit level. For the remainder of the houses, billing data was used (where available). For natural gas consumption, only billing data was used. Monitored data was collected from June 2012 through to the end of February 2013. To allow for a full-year comparison, data for the autumn period (March to May) was considered to be the same as the spring period.

Electricity was used by all houses with air conditioners for summer cooling and in Brisbane and Adelaide for winter heating, while natural gas was predominantly used for winter heating in Melbourne. A small number of houses in Adelaide also used natural gas, but for the purpose of this analysis, natural gas consumption was restricted to Melbourne only, and consumption averages were derived from the billing data received from volunteer houses in this city. Electricity consumption averages were derived from the monitored houses in each of the three cities.

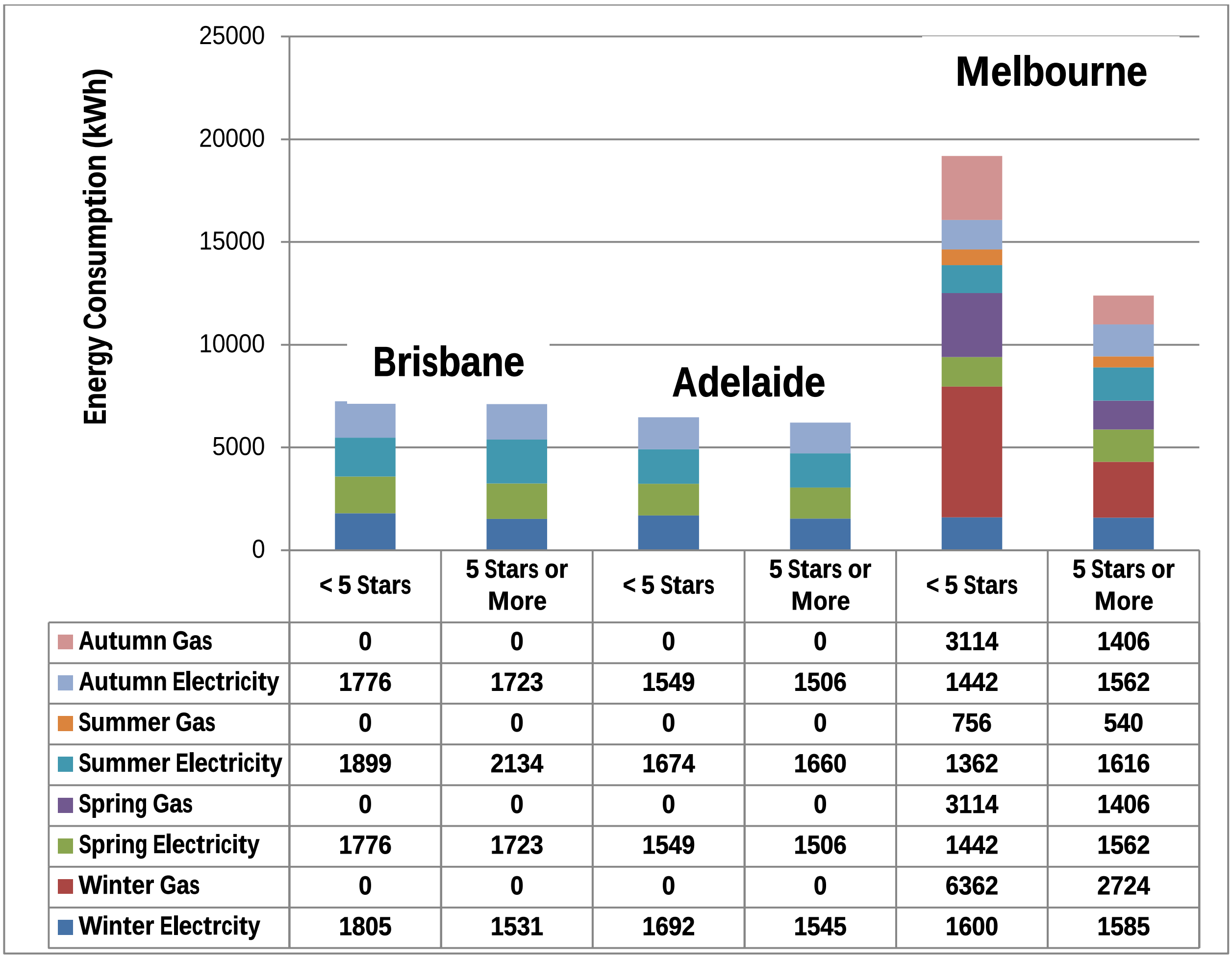
Whole-of-house energy consumption varied over the year, due to the effect of seasonal changes on space conditioning, hot water and lighting. This was especially true in heating-dominated climates such as Melbourne, which rely on heating for much of the winter period. It should be noted, however, that space conditioning (the component influenced by the NatHERS star rating) was generally less than a third of the whole-of-house energy consumption. In the case of electricity particularly, other loads will significantly affect whole-of-house energy consumption. Gas, which is only used for space heating, hot water, and to a lesser extent, cooking, could be more significantly influenced by star rating.

Figure 8-4 shows the average seasonal energy consumption for houses in each city. In Brisbane and Adelaide, the total energy consumption of the lower and higher star-rating cohorts was similar. However, in Melbourne, a significant 35% reduction in energy consumption was seen in the higher-rated houses. This was due entirely to a 54% reduction in gas consumption.

Only small differences in electricity consumption were seen between the star-rating cohorts in Brisbane and Adelaide. Annual electricity consumption in the higher-rated houses in Melbourne was significantly higher than in the lower-rated houses. Electricity consumption in the shoulder seasons (autumn and spring) is more than 8% higher in the high star-rating Melbourne cohort, even though space conditioning would not be expected to be in heavy use over these milder seasons.

Initial investigation of gas consumption in Melbourne found differences depending on the type of hot water system installed. These results are discussed further in Appendix E and show that some of these results were counterintuitive. Consequently, houses with gas-boosted solar hot water systems were removed from the gas calculations done in this section, so that a clear comparison could be made for non-house heating-related gas consumption. Therefore, the dramatic reduction in gas consumption in Melbourne can be wholly attributed to the reduced gas required for house heating.

For both Brisbane and Melbourne, the higher star-rating cohort showed around 16% higher electricity consumption over summer than for the lower star-rating cohort.



	< 5 Stars	5 Stars or More	< 5 Stars	5 Stars or More	< 5 Stars	5 Stars or More
■ Autumn Gas	0	0	0	0	3114	1406
■ Autumn Electricity	1776	1723	1549	1506	1442	1562
■ Summer Gas	0	0	0	0	756	540
■ Summer Electricity	1899	2134	1674	1660	1362	1616
■ Spring Gas	0	0	0	0	3114	1406
■ Spring Electricity	1776	1723	1549	1506	1442	1562
■ Winter Gas	0	0	0	0	6362	2724
■ Winter Electrcity	1805	1531	1692	1545	1600	1585

Figure 8-4 Seasonal energy consumption by star rating and city

Standard energy tariff rates have been used to calculate the energy costs for households. Table 8-2 lists the rates for electricity and natural gas that have been used in each city.

Table 8-2 Tariff costs for energy by city

City	Electricity (c/kWh)	Natural gas (c/MJ)
Brisbane	25.378	–
Adelaide	36.806	–
Melbourne	29.711	1.95

Average energy cost over the year was based on the daily average for each season. Table 8-3 shows that overall, reductions in total energy costs were observed in Adelaide and Melbourne for the higher-rated houses, with a 3% reduction in costs in Adelaide and a 13% reduction in Melbourne. Brisbane houses effectively remained the same.

Table 8-3 Annual energy costs by star rating and city

City and house rating	Annual energy costs (electricity and gas) (AU$)
<5 stars – Brisbane	1,842
5 stars or more – Brisbane	1,805
<5 stars – Adelaide	2,379
5 stars or more – Adelaide	2,289
<5 stars – Melbourne	2,673
5 stars or more – Melbourne	2,306

8.3 Greenhouse gas emissions

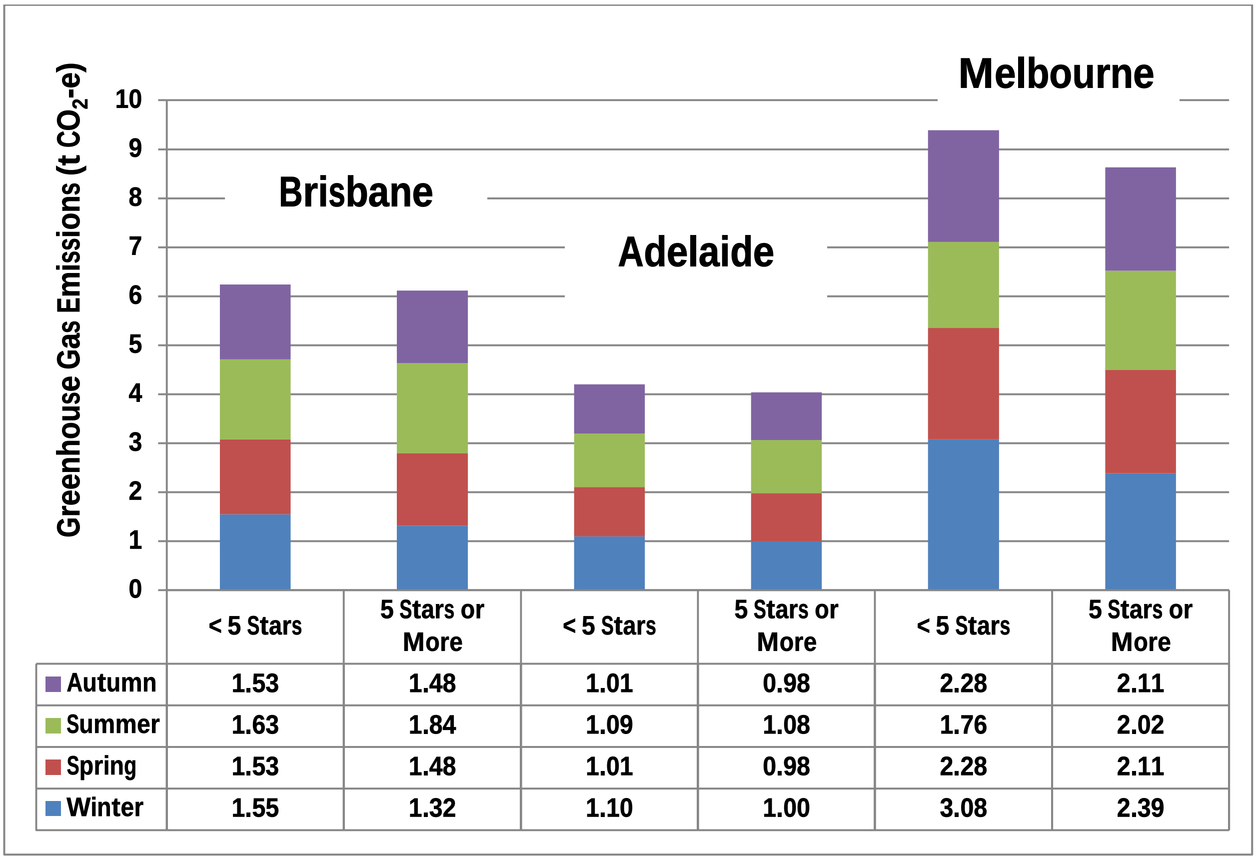
The calculations for the greenhouse gas emissions impact of household energy were based on the factors given in the 'National Greenhouse Accounts Factors – July 2012' (Department of Climate Change and Energy Efficiency, 2012).

Emission totals from electricity consumption are very much linked to the fuel source for the electricity. In Melbourne, the majority of electricity comes from brown-coal generators. Consequently, Melbourne emissions are higher than the other cities. Table 8-4 lists the greenhouse gas coefficients that have been used in this study.

Table 8-4 Greenhouse gas coefficients for energy sources by city

City	Electricity (kg CO_2e/kWh)	Natural gas (kg CO_2e/GJ)
Brisbane	0.86	–
Adelaide	0.65	–
Melbourne	1.19	51.2

As discussed earlier in this section, energy savings were seen in the overall energy use data between the star-rating cohorts in Adelaide and Melbourne. However, this does not necessarily translate to an equal greenhouse gas emission reduction. In Brisbane and Adelaide, emission totals were in line with their energy consumption, because only one energy source was used. However, this is not the case in Melbourne, where a mix of energy sources is in use. Although a significant energy reduction was seen in Melbourne, which was achieved through a significant reduction in gas consumption, it was countered somewhat by an increase in electricity consumption. The much higher emissions coefficient for electricity in Melbourne has consequently resulted in increased emissions from electricity consumption, countering the emission savings from the reduced gas consumption. This has resulted in only an 8% decrease in greenhouse gas emissions in Melbourne for the higher-rated houses, compared with their 46% decrease in energy consumption.



	< 5 Stars	5 Stars or More	< 5 Stars	5 Stars or More	< 5 Stars	5 Stars or More
🟪 Autumn	1.53	1.48	1.01	0.98	2.28	2.11
🟩 Summer	1.63	1.84	1.09	1.08	1.76	2.02
🟥 Spring	1.53	1.48	1.01	0.98	2.28	2.11
🟦 Winter	1.55	1.32	1.10	1.00	3.08	2.39

Figure 8-5 **Seasonal greenhouse gas emissions by star rating and city**

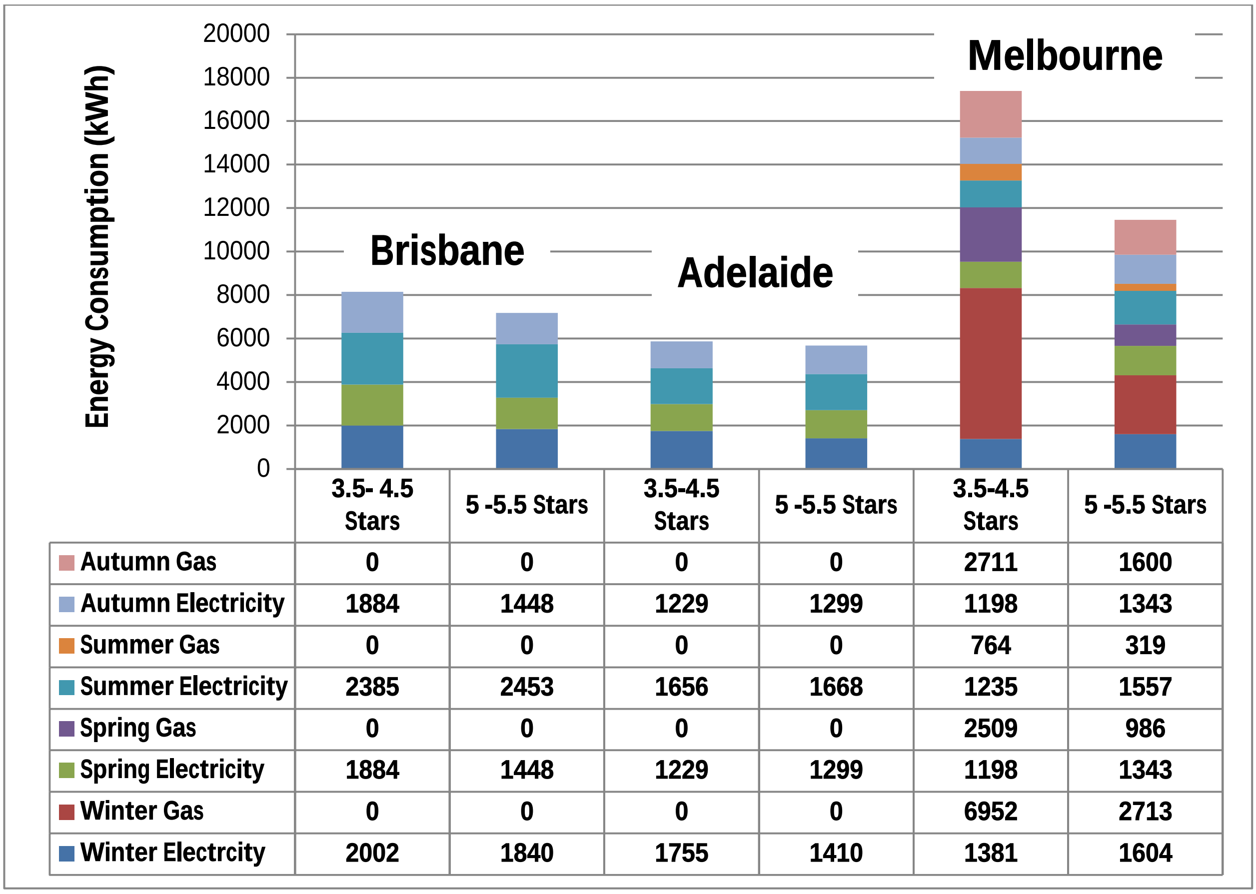
8.4 Reduced star-rating cohort

Following feedback from industry sources, we decided that it would be worthwhile to redo the calculations in this section, focusing on a narrower star-rating band. This was to see if a bias was present, particularly in the higher-rated cohort, which might lead to a skewing of results. The star-rating bands were restricted to include houses that were 3.5 to 4.5 star for one cohort and 5 to 5.5 stars for the other cohort.

Figure 8-6 shows that improvements in energy efficiency were more identifiable in this reduced set, particularly in Brisbane. Over the year, houses in Brisbane in the high star-rating cohort were on average using 12% less energy than the lower star-rating cohort. Most of this improvement was realised through autumn and spring energy savings of 25%. Summer still saw an increase in energy consumption among the higher-rated houses (3%), but it was not as big a difference as seen in the earlier comparisons.

Once again, only small improvements were seen in the Adelaide houses, with a 3% reduction in the total energy consumption for the higher-rated houses. This was entirely due to a reduced winter energy consumption of 20%, which was offset by increases in the other seasons.

Finally, Melbourne houses again showed the biggest improvement, with a reduction in overall energy of 36% for the higher-rated houses, once again all due to a significant reduction in gas consumption of 57%. As before, increases in electricity consumption were seen in all seasons for the higher-rated houses.



	3.5- 4.5 Stars	5 -5.5 Stars	3.5-4.5 Stars	5 -5.5 Stars	3.5-4.5 Stars	5 -5.5 Stars
Autumn Gas	**0**	**0**	**0**	**0**	**2711**	**1600**
Autumn Electricity	**1884**	**1448**	**1229**	**1299**	**1198**	**1343**
Summer Gas	**0**	**0**	**0**	**0**	**764**	**319**
Summer Electricity	**2385**	**2453**	**1656**	**1668**	**1235**	**1557**
Spring Gas	**0**	**0**	**0**	**0**	**2509**	**986**
Spring Electricity	**1884**	**1448**	**1229**	**1299**	**1198**	**1343**
Winter Gas	**0**	**0**	**0**	**0**	**6952**	**2713**
Winter Electrcity	**2002**	**1840**	**1755**	**1410**	**1381**	**1604**

Figure 8-6 Seasonal energy consumption by city for two star-rating cohorts

9 Heating/cooling energy

Section 8 provided analysis of whole-of-house energy consumption across all 414 houses of the study. This section looks specifically at the fixed heating and cooling appliance monitoring data from the 209 fully sub-metered houses.

Figure 9-1 compares the average fixed heating and cooling appliance energy consumption and the average whole-of-house energy consumption across 59 air-conditioned houses in Adelaide.

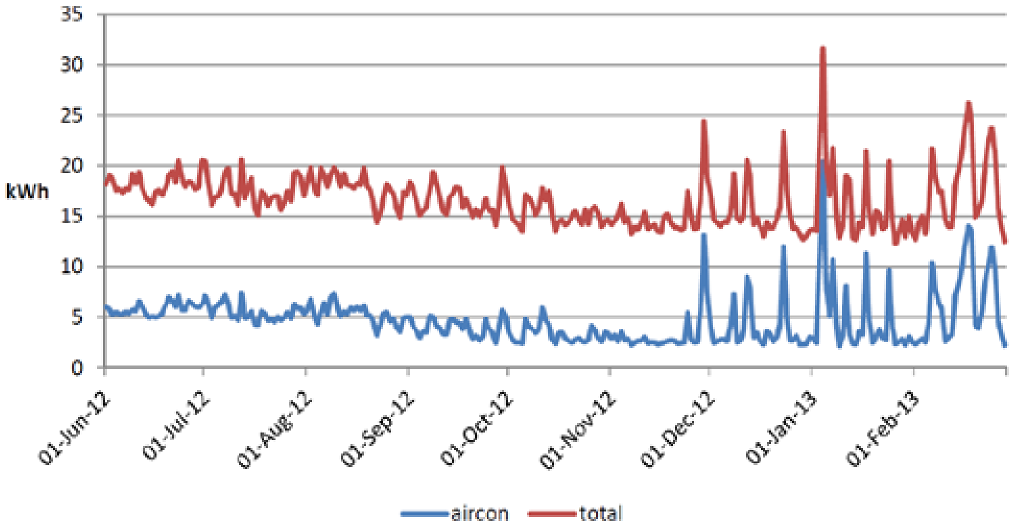


Figure 9-1 **Average whole-of-house and heating and cooling energy consumption – Adelaide**

Figure 9-1 shows that air-conditioning energy consumption is a major, but not totally dominant, energy consumer across most of the year. However, it is highly volatile, and is far and away the dominant cause of peak electricity demand.

It should be noted, however, that the simplicity of the comparison in Figure 9-1 created by the averaging process masks a high degree of variability between houses. Variability is created by differences in factors such as user occupancy (timing and number of people), internal heat loads, user comfort perceptions and health needs. As a result, a full statistical analysis is required to properly interpret the data (see Section 10), and the gross averaged data presented in this section should be treated with some caution.

9.1 Heating vs. cooling demand

Over the year, demand for heating or cooling energy will shift. In the more temperate climates, demand is more focused on the summer cooling periods, whereas in the colder climates, winter heating energy is the more dominant.

The average daily usage for houses in Brisbane is shown in Figure 9-2, which shows that winter energy consumption is quite low compared with summer usage. This reflects the sub-tropical climate of Brisbane, which has a mean maximum temperature of 21.8 °C in July. Consequently, winter heating requirements are minimal. However, the January mean maximum for Brisbane is 30.2 °C, which falls well outside the accepted temperature comfort band, so it would be expected that cooling energy is required.

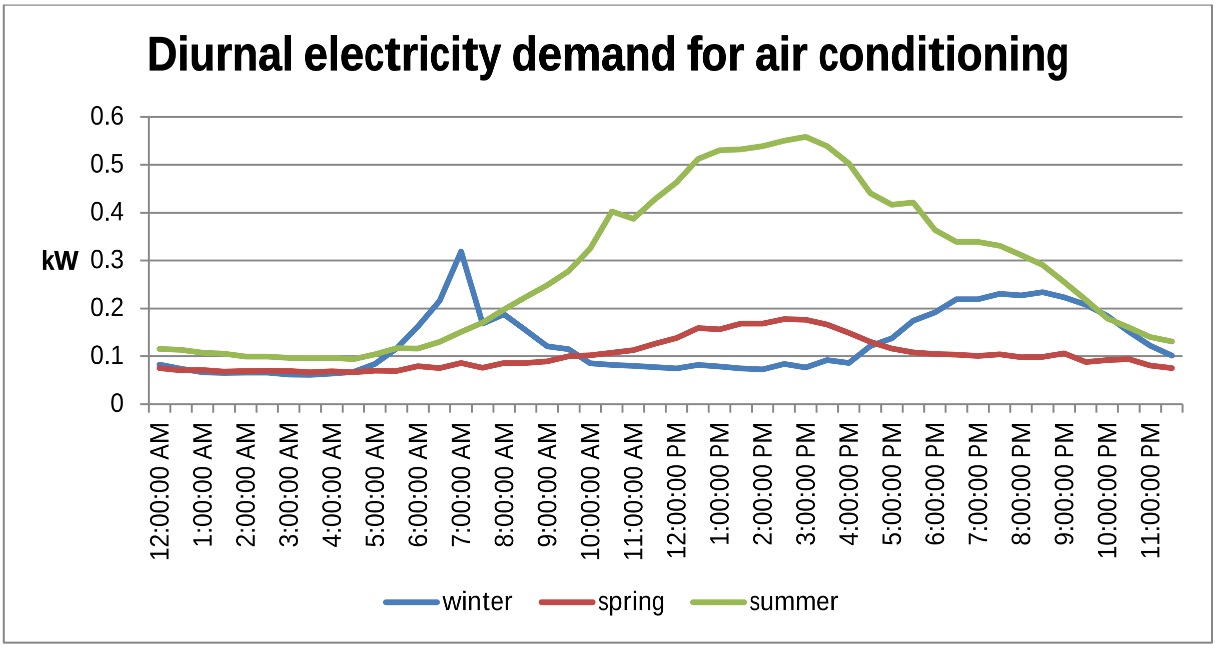


Figure 9-2 Daily heating and cooling electricity use in Brisbane

Adelaide's climate is much more variable than Brisbane's, with relatively cool winters and hot dry summers. Mean maximum temperatures for Adelaide in July and January are 15.3 and 29.3 °C, respectively. Figure 9-3 shows the average daily usage in Adelaide. The periods of most use in winter were from 5:00 am to 9:00 am and 5:00 pm to 10:00 pm local time. We estimated that the corresponding 'in use' peak power load for the evening period between 7:00 pm and 9:00 pm was 1.8 kW Peak power loads, Section 12.2). This suggests that during this period, a significant proportion of air conditioners would have been working at their rated power independently of the NatHERS house rating. Their measurement would therefore contribute noise, but not much signal, to the estimate of the energy impact of the star rating.

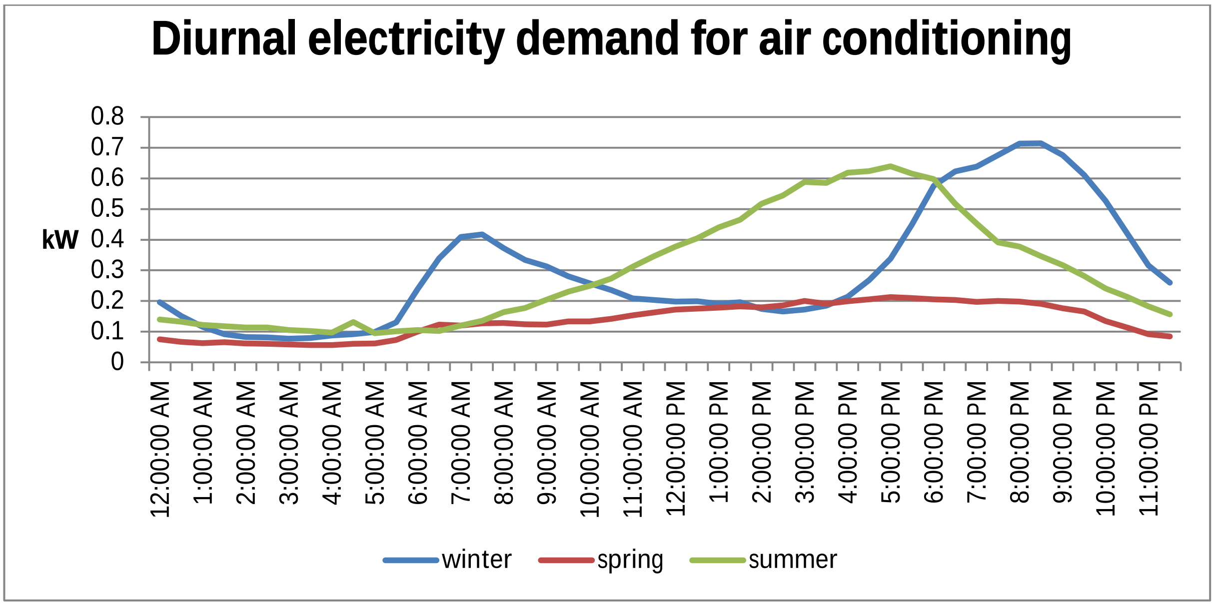


Figure 9-3 Daily heating and cooling electricity use in Adelaide

Melbourne's climate is heating dominated and experiences cold winters, while summers are generally milder, although hot periods are not uncommon. On average, Melbourne has mean maximum temperatures in July and January of 13.1 and 26.3 °C, respectively.

Figure 9-4 shows the average daily heating and cooling electricity use in Melbourne. Although winter demand is higher than summer, the summer demand is still significant. Like Adelaide, winter has a morning and afternoon peak, while summer demand is restricted to the afternoon. The winter profile for Melbourne is based on only a few households that rely on electricity for their winter heating, so some caution is required in interpreting these results. The majority of Melbourne houses use gas for their winter heating.

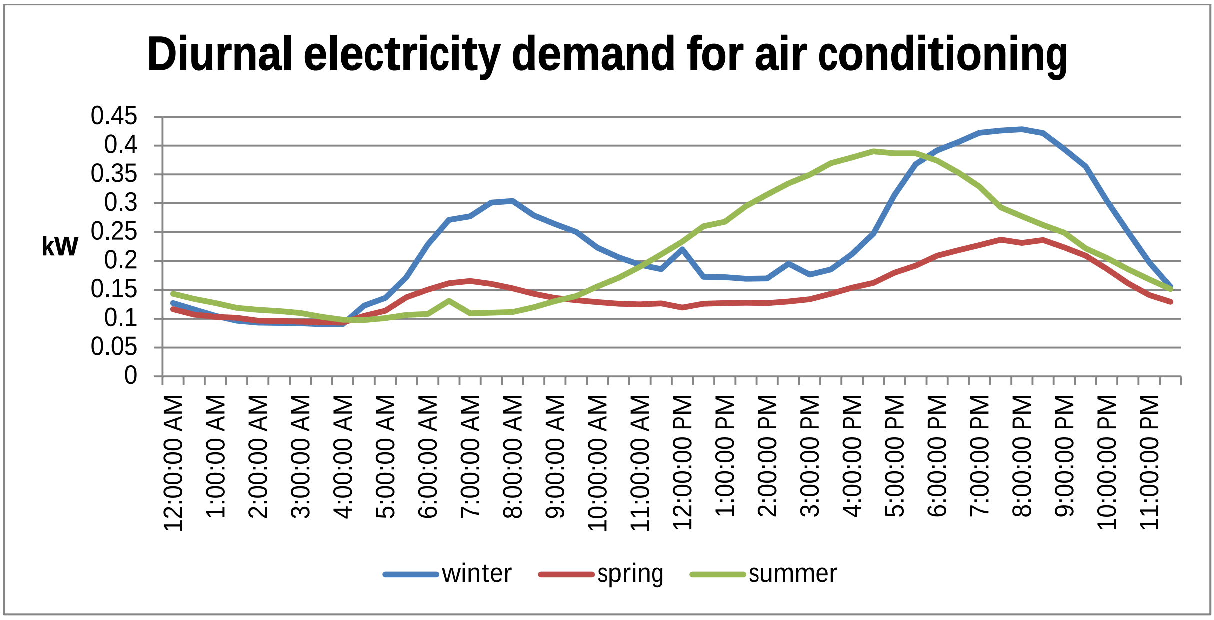


Figure 9-4 Daily heating and cooling electricity use in Melbourne

9.2 Winter performance

Heating-related energy consumption varies over the year due to seasonal changes. This is especially true in the heating-dominated climates, such as Melbourne, which rely on heating for much of the winter period.

Table 9-1 shows the average daily heating energy consumption for houses in each climate zone, along with the associated energy costs and greenhouse emissions. A small reduction in energy consumption is seen between the star-rating cohorts in Brisbane and Adelaide, but a significant reduction is seen in Melbourne. Brisbane and Adelaide rely on reverse-cycle systems for winter heating, while Melbourne uses natural gas.

Overall, winter energy consumption in Melbourne is significantly more than in the other cities, and this translates to increased daily costs and greenhouse emissions. Daily winter costs in Melbourne are around $3.50, while in Brisbane, they are a quarter of that cost. The higher electricity tariff in Adelaide puts daily winter costs at around $2.20. Costs are based on the tariffs listed in Table 8-2.

Daily winter greenhouse gas emissions peak in Melbourne at 13 kg for lower-rated houses, but drop by an impressive 50% for the higher-rated houses.

Table 9-1 **Winter daily heating energy consumption, costs and greenhouse gas emissions**

	Electricity (kWh)	Gas (MJ)	Daily cost ($)	Greenhouse gas (kg CO_2e)
< 5 stars – Brisbane	3.13	0.00	0.79	2.69
5 stars or more –Brisbane	2.77	0.00	0.70	2.38
< 5 stars – Adelaide	6.39	0.00	2.35	4.15
5 stars or more – Adelaide	5.81	0.00	2.14	3.78
< 5 stars – Melbourne	1.39	224.80	4.80	13.16
5 stars or more – Melbourne	0.84	108.42	2.36	6.55

9.3 Summer performance

Daily summer energy consumption is higher than daily winter consumption in Brisbane and is similar in Adelaide, but is significantly lower in Melbourne. Electricity consumption between the star-rating cohorts actually increases in all three cities for the higher-rated houses, with a 28% increase in Brisbane (Table 9-2). This translates to increased energy costs and resulting greenhouse gas emissions.

Table 9-2 **Summer daily cooling energy consumption, costs and greenhouse gas emissions**

	Electricity (kWh)	Daily cost ($)	Greenhouse gas (kg CO_2e)
< 5 stars – Brisbane	5.51	1.40	4.74
5 stars or more –Brisbane	7.08	1.80	6.09
< 5 stars – Adelaide	5.50	2.02	3.58
5 stars or more – Adelaide	6.11	2.25	3.97
< 5 stars – Melbourne	1.65	0.49	1.96
5 stars or more – Melbourne	2.26	0.67	2.69

9.4 Annual performance

Average heating and cooling energy consumption over the year was based on the daily average obtained over the monitoring period. Table 9-3 shows that overall, significant reductions in heating and cooling energy consumption were observed in higher-rated houses in Melbourne (48% reduction), while the energy consumption in higher-rated houses in Adelaide virtually remained unchanged. However, higher rated houses in Brisbane actually had a 12% increase in energy consumption compared with the lower-rated houses.

Although large reductions in overall energy consumption were observed in Melbourne, this did not translate to a corresponding reduction in their greenhouse gas emissions. Overall gas consumption decreased by 52%, but this decrease was counteracted by an 8% increase in electricity consumption. The higher greenhouse coefficients that apply to electricity reduce the savings achieved through the gas reductions. Consequently, emissions have reduced by 32%, which is still a significant saving.

Table 9-3 Annual heating/cooling energy consumption, costs and greenhouse gas emissions

	Electricity (kWh)	Gas (MJ)	Total (kWh)	Daily (kWh)	Cost ($)	Greenhouse gas (kg CO_2e)
< 5 stars – Brisbane	1321	0.00	1321	3.62	335.28	1136
5 stars or more –Brisbane	1480	0.00	1480	4.05	375.78	1273
< 5 stars – Adelaide	1712	0.00	1712	4.69	630.17	1112
5 stars or more – Adelaide	1706	0.00	1706	4.67	628.13	1109
< 5 stars – Melbourne	443	20232	6063	16.61	526.31	1563
5 stars or more – Melbourne	478	9758	3189	8.74	332.50	1069

10 Statistical analysis of the relationship between heating and cooling energy and star rating

10.1 Statistical approach

Sections 8 and 9 compared the average energy consumption of entire cohorts of houses that were broadly categorised as before (<5 star) and after (>5 star) changes in the building energy efficiency regulations, in Adelaide, Melbourne and Brisbane. The results indicated that the higher-rated houses used less energy in winter, but more energy in summer, compared with the lower-rated houses. However, the large variability in energy consumption observed inside each cohort means that these results cannot be claimed to be statistically significant.

Further statistical analysis was required to better interpret the results. This was done by disbanding the segregation between the cohorts based on the star rating being above or below 5. Instead, the analysis looked for direct statistical correlations of the effect of house star rating (i.e. the re-rated star ratings, see 1.3.2) on energy consumption using single and multi-variable linear regression.

The regressions were performed on datasets of comparable houses and scenarios. The groupings were by city, by season and by air-conditioning technology type, as illustrated by the red boxes in Figure 10-1.

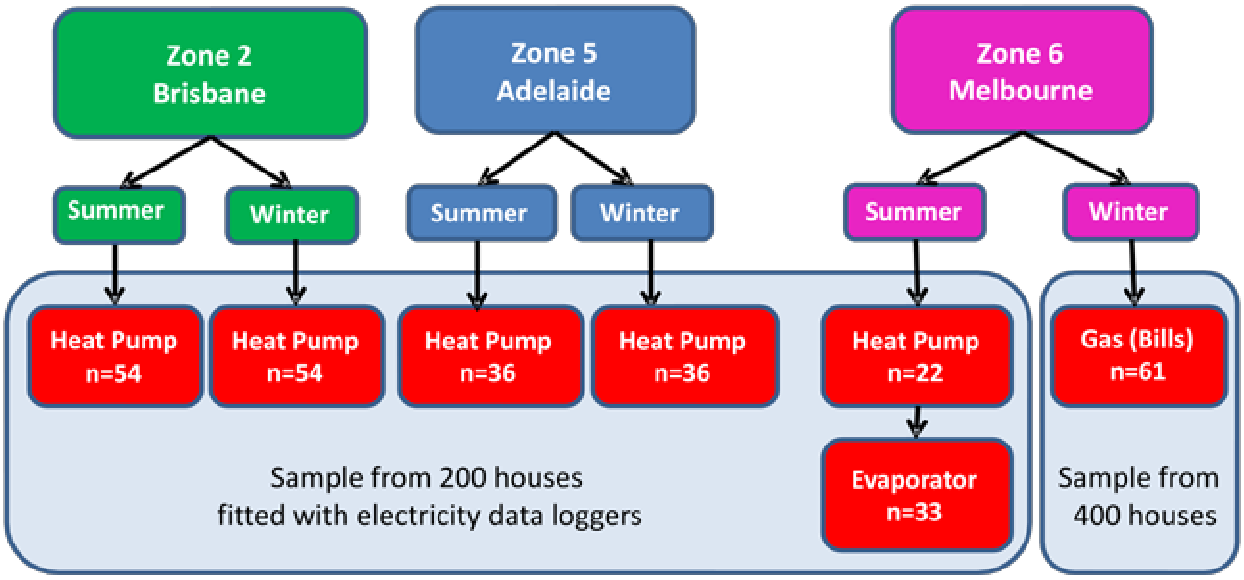
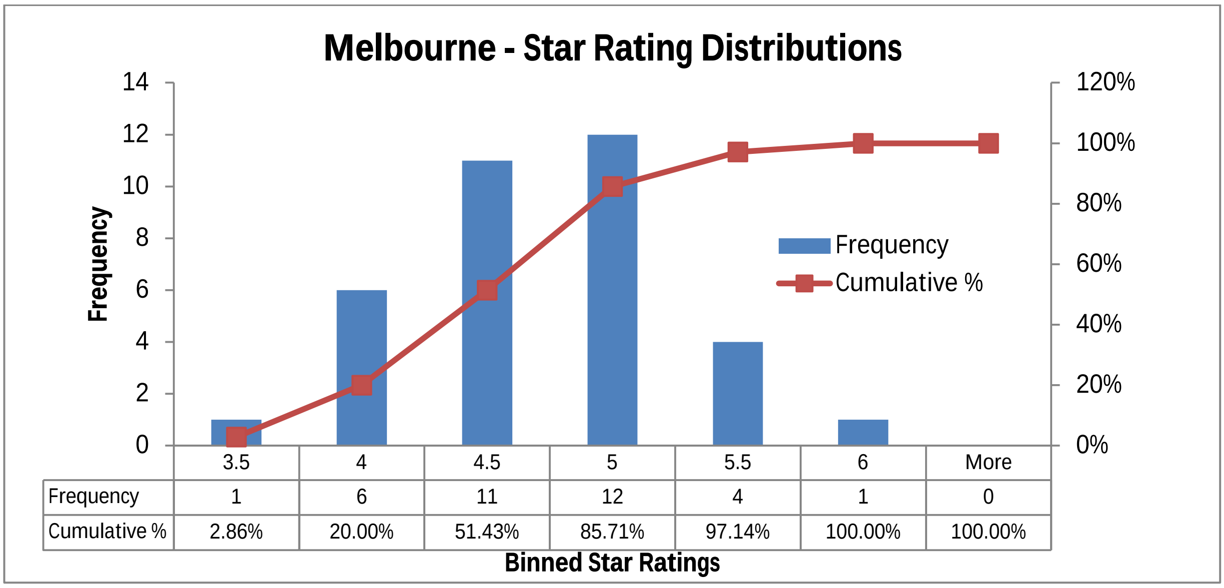


Figure 10-1 Subgroups for assessment including sample numbers and appliance types

We chose the linear regression approach because it was likely to provide the most accurate results, given the statistical distributions of the data. This is described in more detail in Appendix A – Methodology.

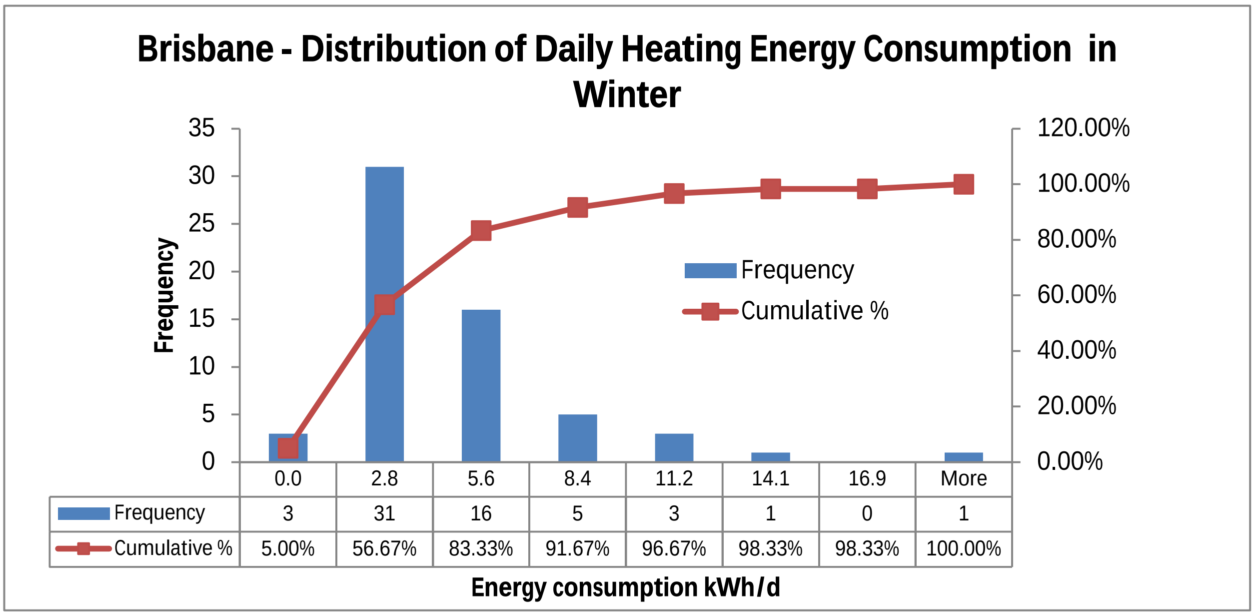
The house star ratings followed Gaussian (bell-shaped) distributions (e.g. Figure 10-2). Ideally, we would have selected houses so that all star ratings were evenly represented. However, we did not know the star ratings of the houses before they were recruited, and therefore had to recruit houses by year of construction as a proxy for star rating for recruitment only. The analysis itself used directly and consistently reassessed star-rating values.



	3.5	4	4.5	5	5.5	6	More
Frequency	1	6	11	12	4	1	0
Cumulative %	2.86%	20.00%	51.43%	85.71%	97.14%	100.00%	100.00%

Figure 10-2 Distribution of star ratings in a Melbourne sample

The measured energy values had skewed (exponential) distributions (e.g. Figure 10-3). These distributions appeared to be a fundamental characteristic of the sample population, with the number of energy users increasing as their energy use reduced. This was unrelated to the type of heating or cooling appliance or to the shift to a higher star-rating range described below. This distribution may suggest a possible correlation with household income. Unfortunately, data was not available to explore this variable.



	0.0	2.8	5.6	8.4	11.2	14.1	16.9	More
Frequency	3	31	16	5	3	1	0	1
Cumulative %	5.00%	56.67%	83.33%	91.67%	96.67%	98.33%	98.33%	100.00%

Figure 10-3 Distribution of daily heating energy for houses in Brisbane in winter

The regression analysis approach allowed us to fit a linear model to the data across a broad range of star values. We then applied the regression coefficients to calculate the difference in energy consumption within the NatHERS rating band from 3.5–4 stars to 5 stars to compare with the results of Section 9.

Regression analysis

A wide range of single and multi-variable linear regressions were performed to check for possible correlations between the seasonally averaged consumption of energy in the fixed space conditioning appliances, expressed as kilowatt hours per day per square metre of conditioned floor area, with possible explanatory variables. These possible explanatory variables included:

- house star rating
- the average seasonal outdoor temperature taken from the nearest Bureau of Meteorology (BoM) weather station
- the average seasonal indoor temperature measured in the main living area of each house (whether or not the air conditioner was operating)
- the difference between the average seasonal indoor and outdoor temperatures (as above)
- the average seasonal outdoor dewpoint taken from the nearest BoM weather station
- quality of building construction
- householder self-reported energy efficiency behaviour

A regression analysis (Equation 1) showed a significant linear dependence of energy consumption on star rating and temperature:

$$E = k_{\mathbf{a}}.\mathrm{Star} + k_{\mathbf{b}}.\Delta T + k_{\mathbf{c}} \qquad \textbf{....(1)}$$

Where

E is the seasonal average daily house heating or cooling energy per unit floor area of the house air-conditioned space (kWh d^{-1} m^{-2})

Star is the re-rated star value of the house

ΔT is the temperature difference between the main living area and the nearest BoM weather station (°C)

The coefficients obtained from the regression were:

$k_{\mathbf{a}}$ (kWh d^{-1} m^{-2} $star^{-1}$)

$k_{\mathbf{b}}$ (kWh d^{-1} m^{-2} $°C^{-1}$)

$k_{\mathbf{c}}$ (kWh d^{-1} m^{-2}).

Other variables did not have a recognisable influence on energy consumption.

Interestingly, an even more statistically significant correlation was typically seen between house star rating and the difference between the average seasonal indoor and outdoor temperatures. This can be seen in a linear regression of temperature against star rating (Equation 2):

$$\Delta T = k_{\mathbf{d}}.\mathrm{Star} + k_{\mathbf{e}} \qquad \textbf{....(2)}$$

The coefficients obtained from the regression were:

$k_{\mathbf{d}}$ (°C $star^{-1}$)

$k_{\mathbf{e}}$ (°C).

This second regression analysis suggests that as star rating changes, there is a noticeable change in house internal temperature. For example, in winter, higher-rated houses were measurably warmer. In physical terms, this has been interpreted to mean that there were three types of energy savings:

- observed savings, i.e., the energy actually saved
- inferred savings, i.e., energy being consumed that could have been saved if the temperature in the higher-rated houses was kept the same as in the lower-rated houses. If an inferred energy saving is available, it takes a positive sign in the modelling, because the inferred saving is actually a consumption and only potentially a saving
- total savings, consisting of the observed saving and the inferred saving.

The total energy saving dependence on star rating is represented by k_a from Equation 1. This is because the regression evaluates k_a at a constant temperature for all star ratings.

The inferred energy saving dependence on star rating is represented by ($k_b.k_d$), where k_b gives the dependence of energy consumption on temperature and k_d gives the dependence of temperature on star rating.

The observed energy saving dependence on star rating can be obtained by adding the inferred energy saving to the total energy saving, and is represented by ($k_a+k_b.k_d$): noting that for a saving, k_a takes a negative value, and that for an inferred saving, k_b and k_d take positive values. This is because temperature differences (k_b) were usually positive in winter, and energy consumption per degree Celsius (k_d) is also expressed as a positive value. Where there is an inferred energy saving, it is only a potential saving, and therefore appears as a positive value indicating an actual consumption.

A p-value limit of 0.05 was set, above which the likelihood that there was an energy saving was rejected as being statistically uncertain. A related parameter, the confidence interval, was set at 95% for each constant. This described the range of values likely for any house in 95% of the sample population. A low p-value indicated whether the model estimate of the average energy saved was reasonable; it did not indicate the level of energy saving expected for any particular house. Likewise, a broad confidence interval did not by itself invalidate the estimates of average values for energy saved.

Values obtained for these constants, together with their corresponding energy reduction estimates, are given in Table 10-1 to Table 10-7. Each constant was associated with a p-value (giving an indication of whether the linear correlation is not a correct hypothesis; the lower, the more certain). The model coefficient values are expressed in the figures and tables as the best fit values with 95% confidence intervals. The energy reduction estimates are given as modulus (signless) values.

10.2Results

10.2.1 IMPACT ON HOUSE HEATING ENERGY IN BRISBANE

Figure 10-4 shows the multivariable linear regression of heating energy against NatHERS star rating. With a p-value of 0.14 and a very low value for k_a, it was concluded that there was no significant dependence of energy consumption on star rating. This may be because the low levels of energy consumption make it harder to measure such a trend. However, (i) the dependence of energy consumption on temperature difference (Figure 10-5) and (ii) the dependence of temperature difference on star rating (Figure 10-6) were both statistically significant, indicating that on average, temperatures increased by 0.6 °C for houses with higher star ratings.

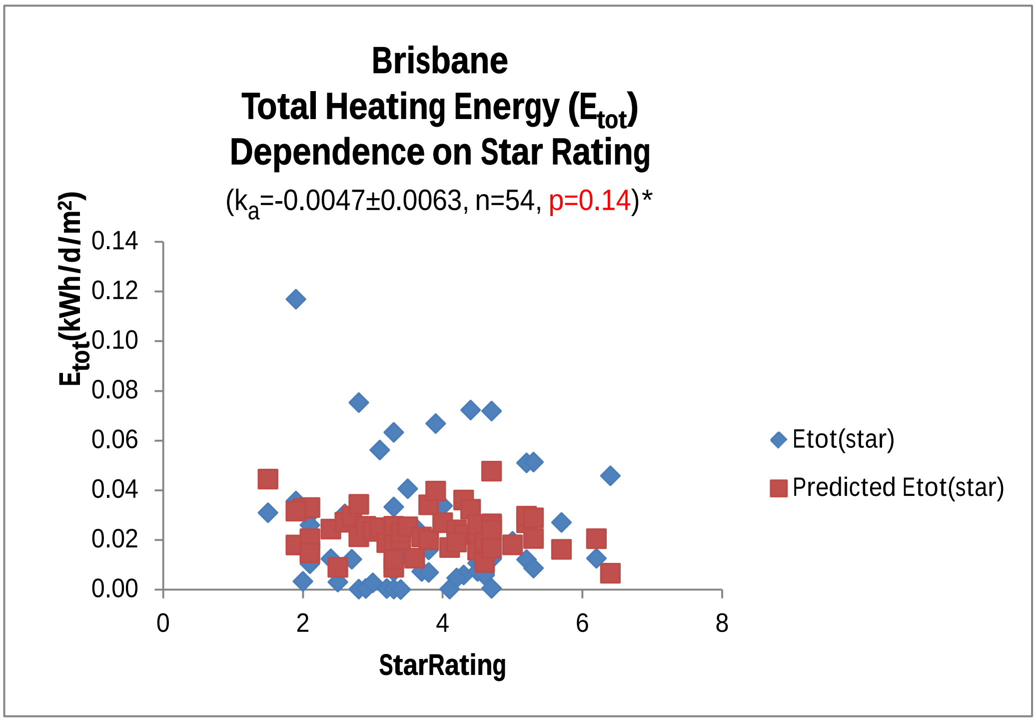


Figure 10-4 House heating energy dependence on star rating – Brisbane

** Regression coefficients in figures and tables are expressed as the value with 95% confidence intervals, together with the sample number n and the p-value. Where a null conclusion is indicated, the p values are shown in red.*

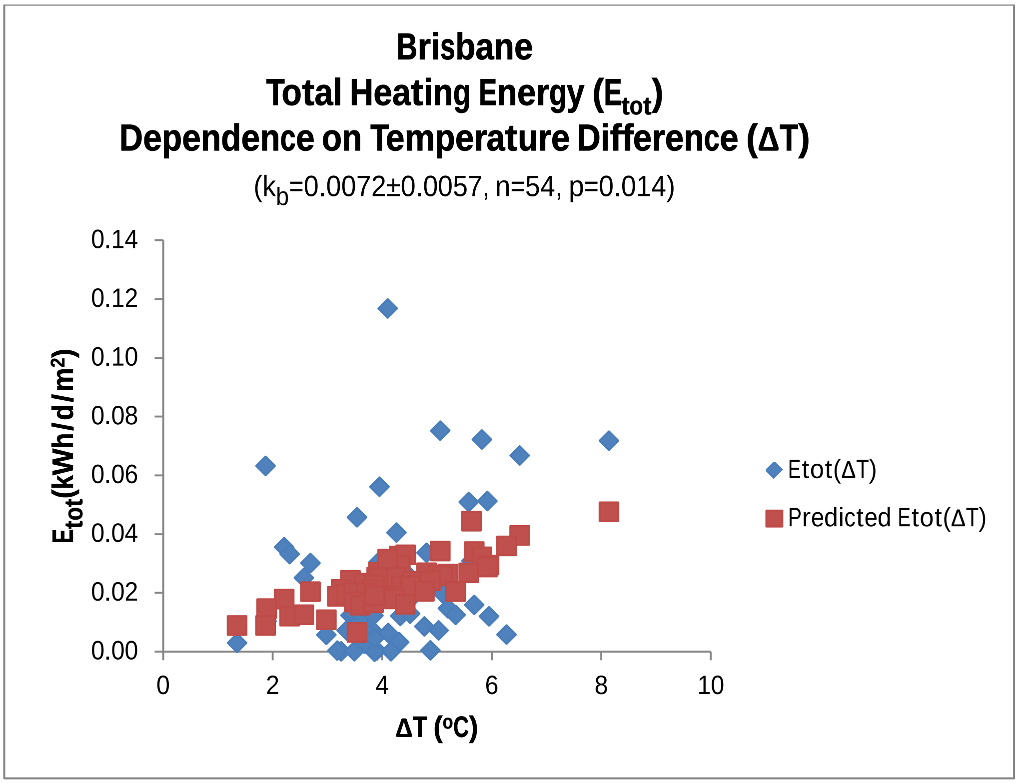


Figure 10-5 House heating energy dependence on temperature difference – Brisbane

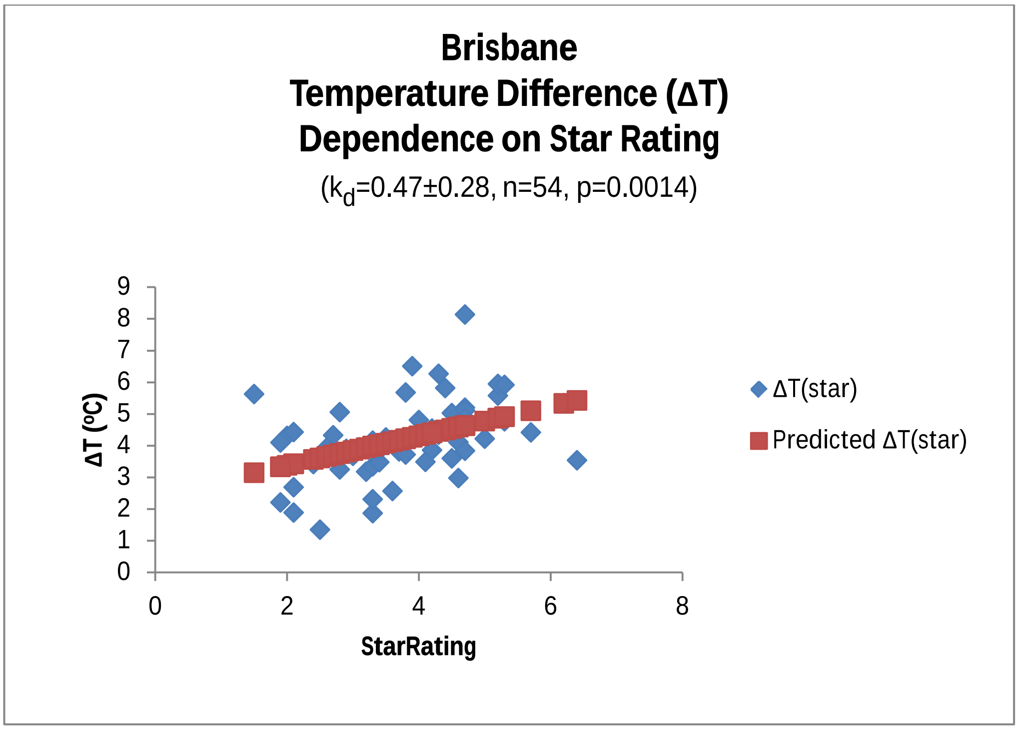


Figure 10-6 Internal to external temperature difference dependence on star rating – Brisbane

Table 10-1 summarises the energy savings for the sample of houses with higher star ratings compared with houses with lower star ratings during the Brisbane winter season. The reduction in energy consumption in higher-rated houses was not measurable. However, the reduction in energy consumption that was subsequently used in raising the house temperature was 0.39 kWh m^{-2}.

Table 10-1 Winter quarter energy saving in Brisbane (heat pumps)

Key model parameters		
k_a (kWh d^{-1} m^{-2} $Star^{-1}$)	N/A	Not statistically significant (n=54, p=0.14[a])
k_b (kWh d^{-1} m^{-2} $°C^{-1}$)	0.0072 ± 0.0057[b]	By multiple regression (n=54, p=0.014)
k_d (°C $Star^{-1}$)	0.47 ± 0.28	By single regression (n=54, p=0.0014)
Inferred $K_b.k_d$ (kWh d^{-1} m^{-2} $Star^{-1}$)	0.0034	
Estimated winter savings between cohorts		
Observed energy saved	Not statistically determinable	
Inferred energy	0.39 kWh m^{-2}	
Total potential saving	0.39 kWh m^{-2}	Inferred energy only
Consumption in the lower star-rating cohort		
Average energy (lower star ratings)	1.9 kWh m^{-2}	n=25
Percent total potential saving		20% of average of low star rating cohort

[a] *Where a null conclusion is indicated, the p values are shown in red*

[b] *Regression coefficients in figures and tables are expressed as the value with 95% confidence intervals*

10.2.2 IMPACT ON HOUSE HEATING ENERGY IN ADELAIDE

Adelaide houses were generally equipped with either gas or reverse-cycle heat pumps for house heating. There were too few gas-heated houses to make statistically significant conclusions. However, there were sufficient houses with heat pump air conditioners for their electricity consumption to be assessed.

Figure 10-7 gives the dependence of heating energy on NatHERS star rating. There was a substantial reduction in the average energy consumption as the NatHERS star rating increases. The spread of values among individual houses is large, ranging over ±75% of the mean. However, the p values are sufficiently low to give confidence in the mean value for energy saving.

Figure 10-9 appears to show a temperature dependence on NatHERS star rating, although the effect is not statistically robust (p=0.14). The slope is positive, with a value of 0.66°C $Star^{-1}$, indicating that on average, the main living area may be warmer by 0.8 °C in houses with higher NatHERS star ratings. The spread of temperature values among individual houses is large, ranging over ±140% of the mean.

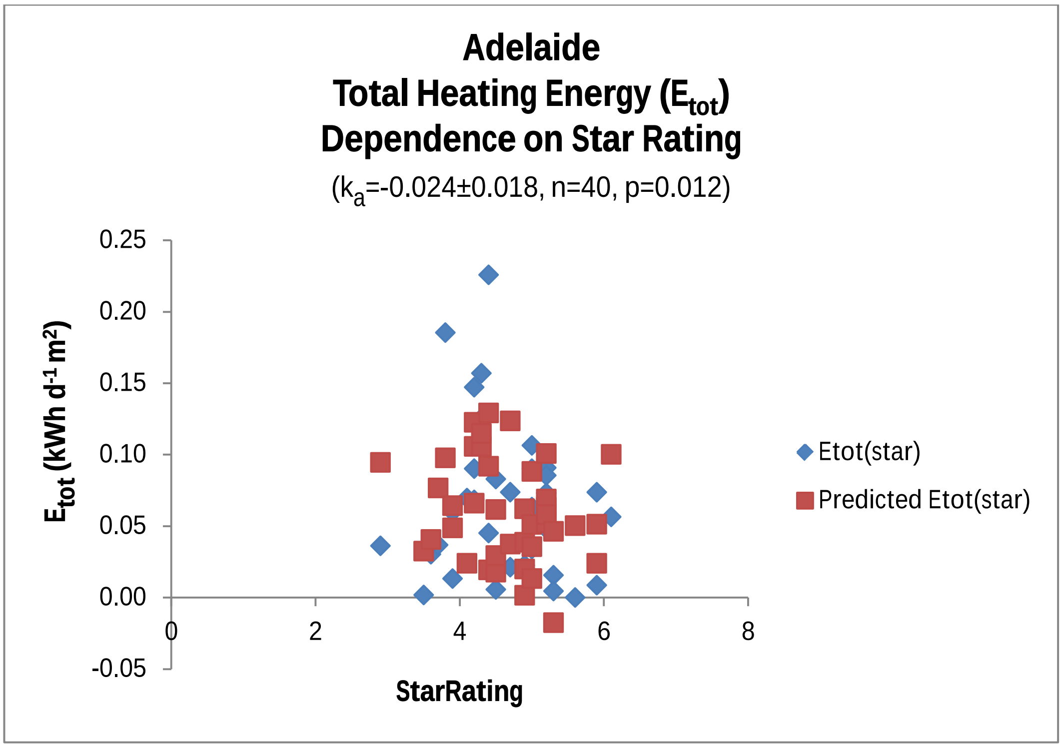


Figure 10-7 House heating energy dependence on star rating – Adelaide

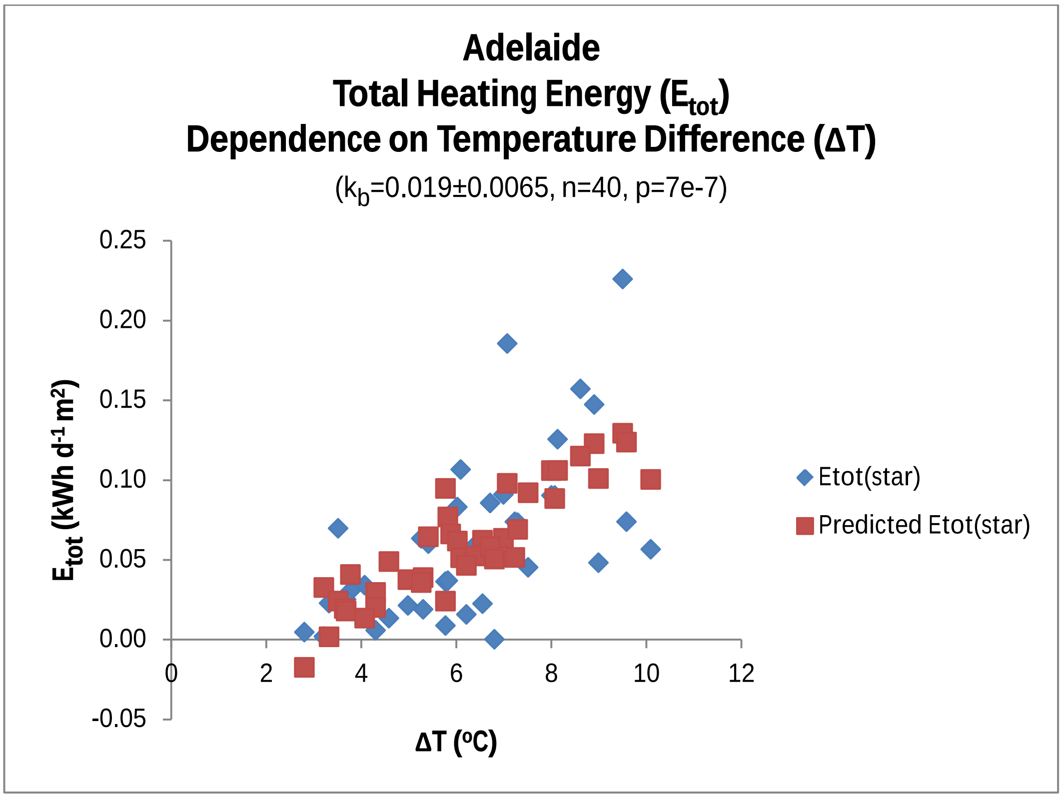


Figure 10-8 Total heating energy dependence on temperature difference – Adelaide

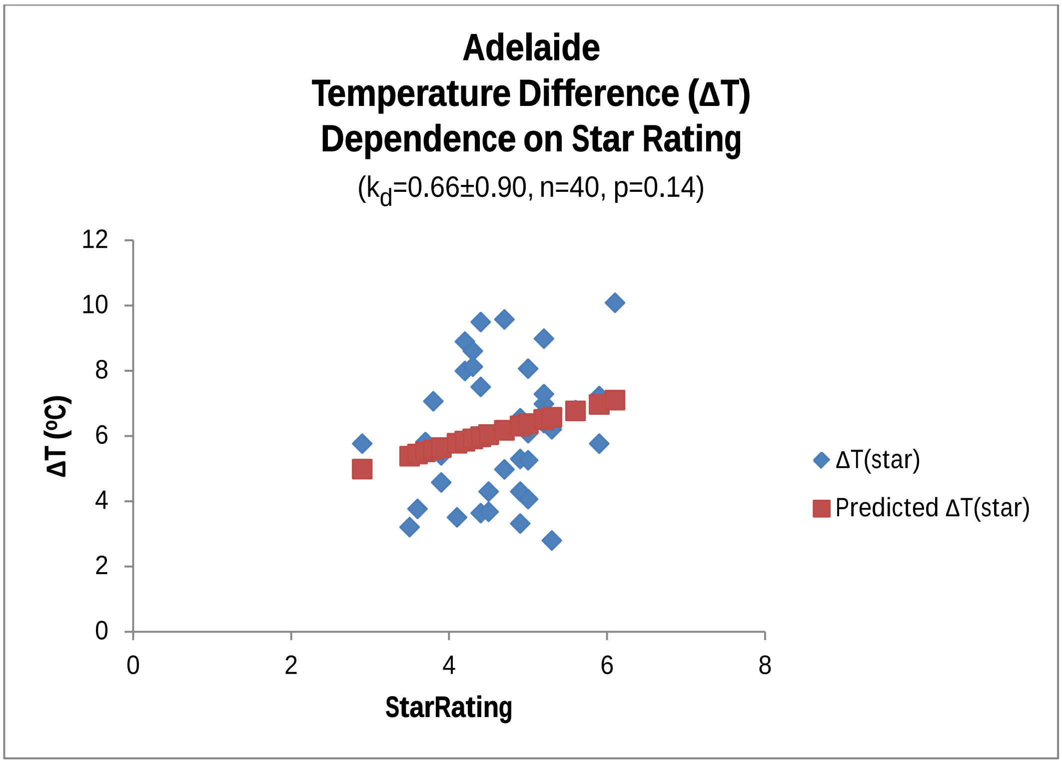


Figure 10-9 Temperature difference dependence on star rating – Adelaide

Table 10-2 summarises the energy savings for the sample of houses with higher star ratings compared with houses with lower star ratings, during the Adelaide winter season. The average actual saving was 1.3 kWh m^{-2} over the winter season. There was some indication (p=0.14) of an inferred reduction of 1.4 kWh m^{-2}, with the average house temperatures about 0.8 °C higher in the higher-rated houses than in the lower-rated houses. However, the spread of these temperature differences was very broad and their p-values were high.

Table 10-2 Winter quarter energy saving in Adelaide (heat pumps)

Key model parameters		
K_a (kWh d^{-1} m^{-2} $Star^{-1}$)	–0.024±0.018	By multiple regression (n=40, p=0.012)
K_b (kWh $°C^{-1}$ d^{-1} m^{-2} $Star^{-1}$)	0.02±0.0065	By multiple regression (n=40, p=7.e-7)
k_d ($°C^{-1}$ $Star^{-1}$)	0.66±0.90	By single regression (n=40, p=0.14)
Inferred $K_b.k_d$ (kWh d^{-1} m^{-2} $Star^{-1}$)	0.0124	
Estimated winter savings between cohorts		
Observed energy saved	1.28 kWh m^{-2}	
Inferred energy	1.42 kWh m^{-2}	
Total potential savings	2.71 kWh m^{-2}	
Consumption in the lower star rating cohort		
Average energy (lower star ratings)	6.9 kWh m^{-2}	n=19
Percent total potential saving		39% of average of low star-rating cohort

10.2.3 IMPACT OF THE STAR RATING ON HOUSE HEATING ENERGY IN MELBOURNE

Gas heaters were the principal appliances used for house heating in Melbourne. We did not directly measure gas consumption in this study, but relied on the winter and summer gas bills. Our measure of gas heating for each house was to subtract the average summer-time value from the winter-time values, to account for appliances that were not used for house heating. These typically included cooking appliances and hot water systems.

The impact of solar hot water on gas consumption in houses with higher NatHERS star ratings

In estimating house heating energy, we at first assumed that solar hot water gas savings were not correlated with the NatHERS star rating. However, it was found that both the relative proportion of houses and the capacity of solar hot water systems varied considerably with the date of installation over the period for which star ratings were being assessed. The net effect was that houses with higher NatHERS star ratings tended to use more gas to boost their water heaters in winter than houses with lower star ratings. This is described further in Appendix E . After removing houses with gas-boosted solar hot water systems from the data set, the regressions showed that the houses with higher NatHERS star ratings, on average, used less heating energy in winter, and also had higher temperatures in their main living areas.

The regression analysis

Figure 10-10 shows the dependence of heating energy on star rating when houses with solar hot water have been removed from the sample. The regression slope has a value of - 0.25 kWh d^{-1} m^{-2}. This indicated average savings of 25 kWh m^{-2} for the higher star rating cohort over the winter season.

Figure 10-12 shows the dependence of temperature difference on star rating in Melbourne. The slope for the dependence of temperature difference on the NatHERS star rating is positive, with a value of 0.54°C/Star, indicating that on average the main living area is 0.7 °C warmer in houses with higher NatHERS star ratings. This temperature dependence on star rating, together with the value for k_b from Figure 10-11, suggests an inferred energy saving of 3 kWh m^{-2}.

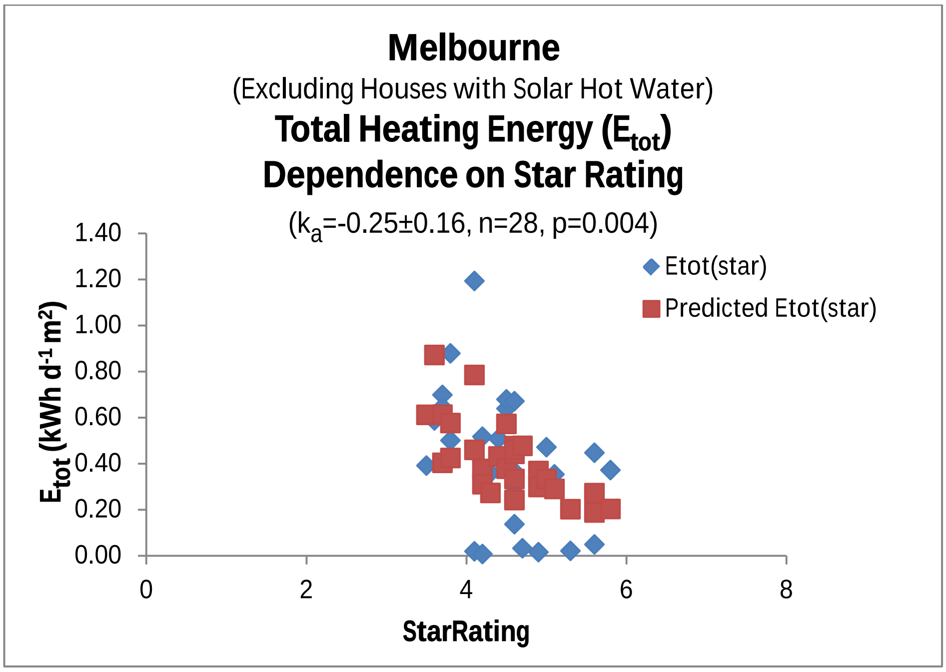


Figure 10-10 House heating energy dependence on star rating – Melbourne (houses with solar hot water excluded)

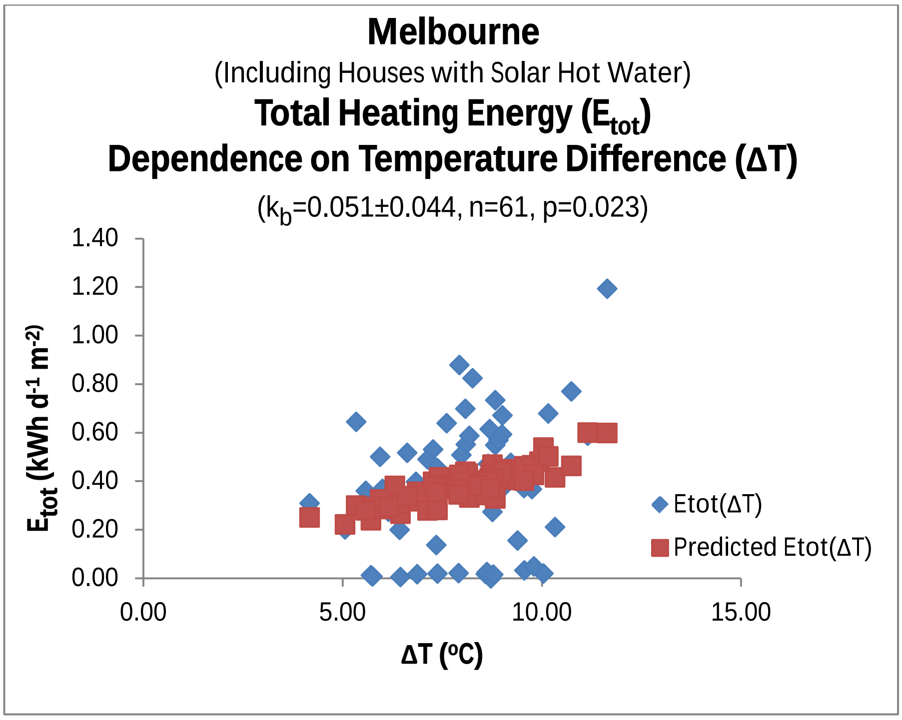


Figure 10-11 Total heating energy dependence on temperature difference – Melbourne (houses with solar hot water included)

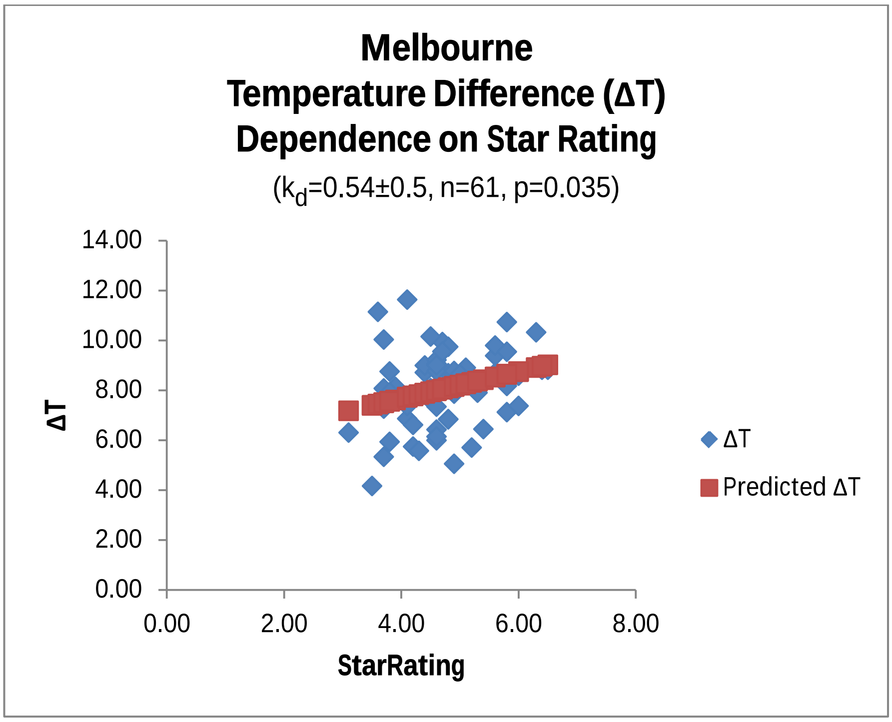


Figure 10-12 Temperature dependence on star rating – Melbourne (houses with solar hot water included)

Table 10-3 summarises the energy savings for the sample of houses with higher star ratings compared with houses with lower star ratings during the Melbourne winter season. The reduction in energy consumption in higher-rated houses was substantial, with a comparatively small amount contributing to raising the house temperature. The actual energy saving was 25 kWh m^{-2}. Another 3.2 kWh m^{-2} was available due to the increased temperature.

Table 10-3 Winter quarter energy saving in Melbourne (gas)

Key model constants		
Total K_a (kWh d^{-1} m^{-2} $Star^{-1}$)	- 0.25±0.16	By multiple regression (n=28, p =0.004)
K_b (kWh d^{-1} m^{-2} $°C^{-1}$)	0.051±0.044	By multiple regression (n=61, p = 0.023)
K_d ($°C^{-1}$ $Star^{-1}$)	0.54±0.5	By single regression (n=61, p=0.035)
Inferred $K_b.k_d$ (kWh d^{-1} m^{-2} $Star^{-1}$)	0.027	
Estimated winter savings between cohorts		
Observed energy saved	25.4 kWh m^{-2}	
Inferred energy	3.2 kWh m^{-2}	
Total potential savings	28.6 kWh m^{-2}	
Consumption in the lower star-rating cohort		
Average energy (lower star ratings)	50.6 kWh m^{-2}	Solar hot water houses excluded (n=14)
Percent total potential saving		56% of average of low star-rating cohort

10.2.4 IMPACT ON HOUSE COOLING ENERGY IN BRISBANE

The summer cooling energy consumption of houses in Brisbane is illustrated in Figure 10-13, which shows that cooling electricity consumption increased with increasing star rating. There was no apparent dependence of temperature difference on star rating. However, this may have been hidden, because the temperature difference cycled between positive and negative values throughout the season. Table 10-4 gives values for the increase in seasonal energy consumption.

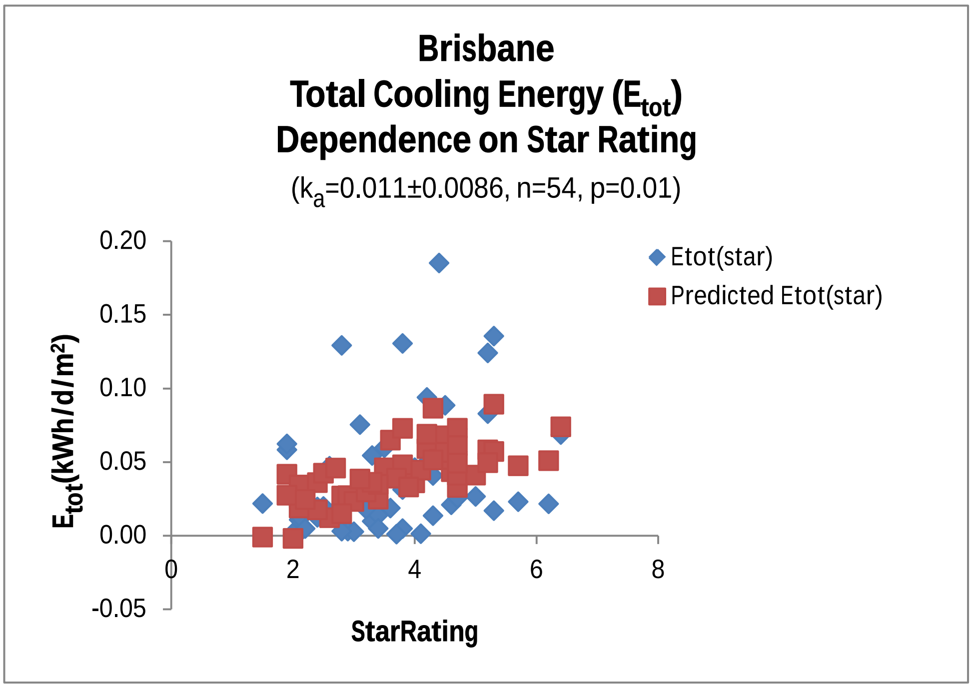


Figure 10-13 House cooling energy dependence on star rating – Brisbane

Table 10-4 Summer quarter energy consumption in Brisbane (heat pump cooling)

Key model constants		
K_a (kWh d^{-1} m^{-2} $Star^{-1}$)	0.011±0.0086	By multiple regression (n=54, p =0.01)
Estimated summer savings between cohorts		
Additional energy consumed	1.29 kWh m^{-2}	(Increase in consumption with star rating)
Consumption in the lower star-rating cohort		
Average energy (lower star ratings)	4.10 kWh m^{-2}	n=22
Percent additional total consumption		31% of average of low star rating cohort (Increase in consumption with star rating)

10.2.5 IMPACT ON HOUSE COOLING ENERGY IN ADELAIDE

There was no statistically significant difference in cooling energy consumption between houses with higher or lower star ratings in Adelaide (Figure 10-14). There was also no apparent dependence of temperature on star rating, though again, this may have been hidden because the temperature difference cycled between positive and negative values throughout the season. Table 10-5 gives values for the increase in seasonal energy consumption.

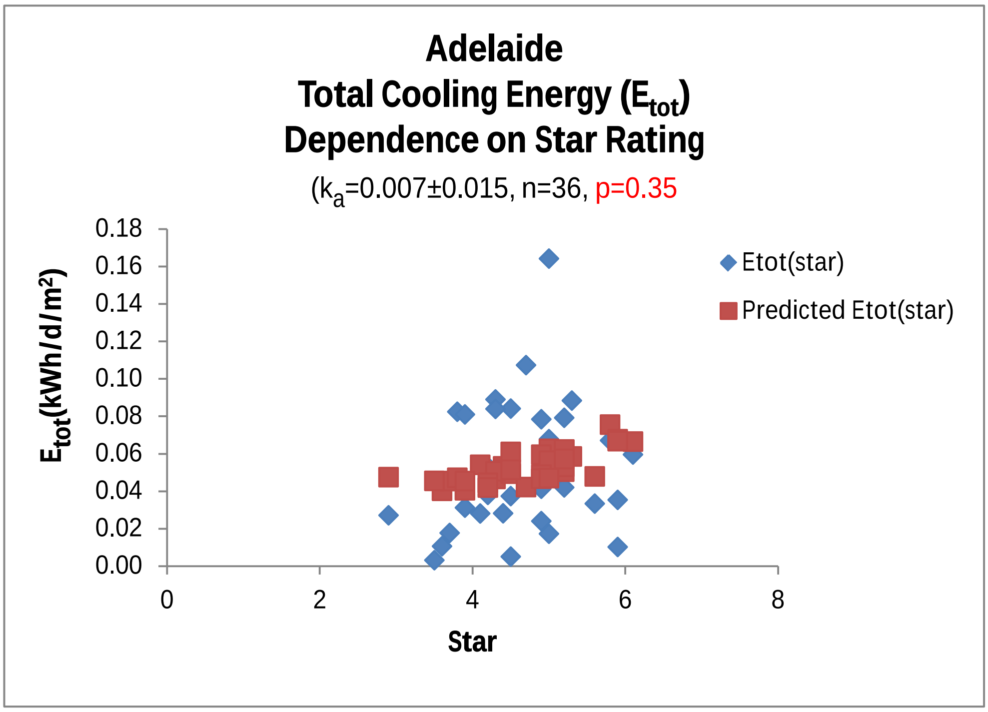


Figure 10-14 House cooling energy dependence on star rating – Adelaide

Table 10-5 Summer quarter energy consumption in Adelaide (heat pump cooling)

Key model constants		
K_a (kWh d^{-1} m^{-2} Star^{-1})	0.0072±0.015	Not statistically significant (n=36, p =0.35)
Estimated summer savings between cohorts		
Actual energy saved	Not statistically determinable	
Consumption in the lower star rating cohort		
Average energy (lower star ratings)	3.99 kWh m^{-2}	n=17
Percent total potential saving	Not statistically determinable	

10.2.6 IMPACT ON HOUSE COOLING ENERGY IN MELBOURNE

In Melbourne, the cooling energy consumption increased when heat pumps were used in houses with higher star ratings (Figure 10-15**).** There was no apparent dependence of temperature on star rating, possibly due to the temperature difference cycling between positive and negative values throughout the season.

Table 10-6 gives the associated increase in consumption.

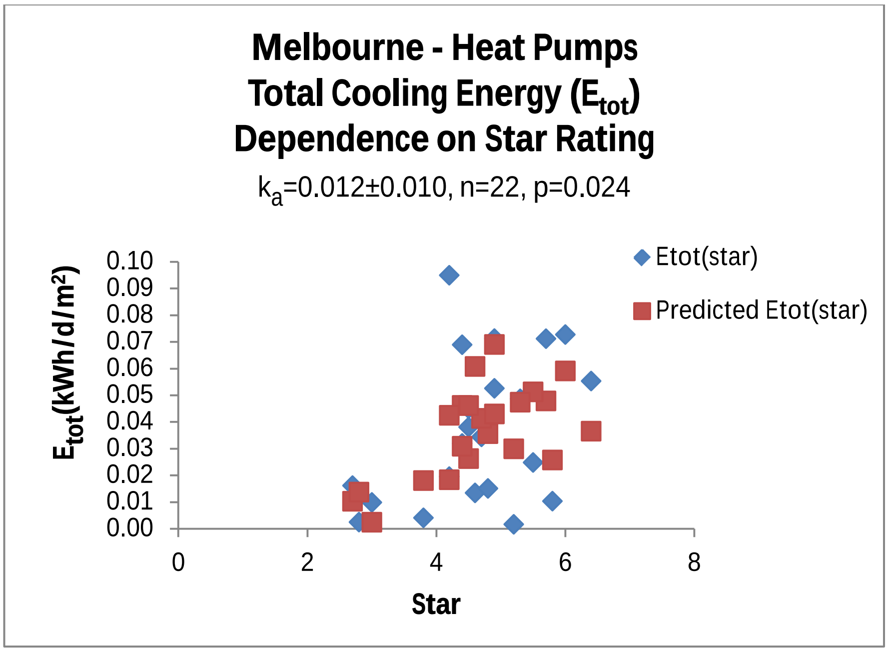


Figure 10-15 House cooling energy dependence on star rating – Melbourne (heat pumps)

Table 10-6 Summer quarter energy consumption in Melbourne (heat pump cooling)

Key model constants		
K_a (kWh d^{-1} m^{-2} $Star^{-1}$)	0.012±0.010	By multiple regression (n=22, p =0.024)
Estimated summer savings between cohorts		
Actual additional energy consumed	1.35 kWh m^{-2}	(Increase in consumption with star rating)
Consumption in the lower star-rating cohort		
Average energy (lower star ratings)	3.51 kWh m^{-2}	n=8
Percent additional total consumption		38% of average of low star-rating cohort (Increase in consumption with star rating)

Regressions were also performed to determine the impact of star rating on the cooling energy consumption when evaporative coolers were used (Figure 10-16). The evaporative cooler sample may be problematic, because energy consumption is significantly influenced by rated air flow, rather than achieving set point air temperatures based on house energy efficiency. It is also possible that some houses may have had other appliances on the electrical circuit of the evaporative cooler.

The cooling energy consumption appears to increase with increasing star rating. Again, there was no apparent dependence of star rating on temperature, possibly due to cycling between positive and negative values throughout the season. Table 10-7 gives the associated increase in consumption. In this instance, the percentage increase is very high. Nevertheless, the absolute value of the cooling energy consumption is about half that of the cohort of houses with heat pumps in Melbourne.

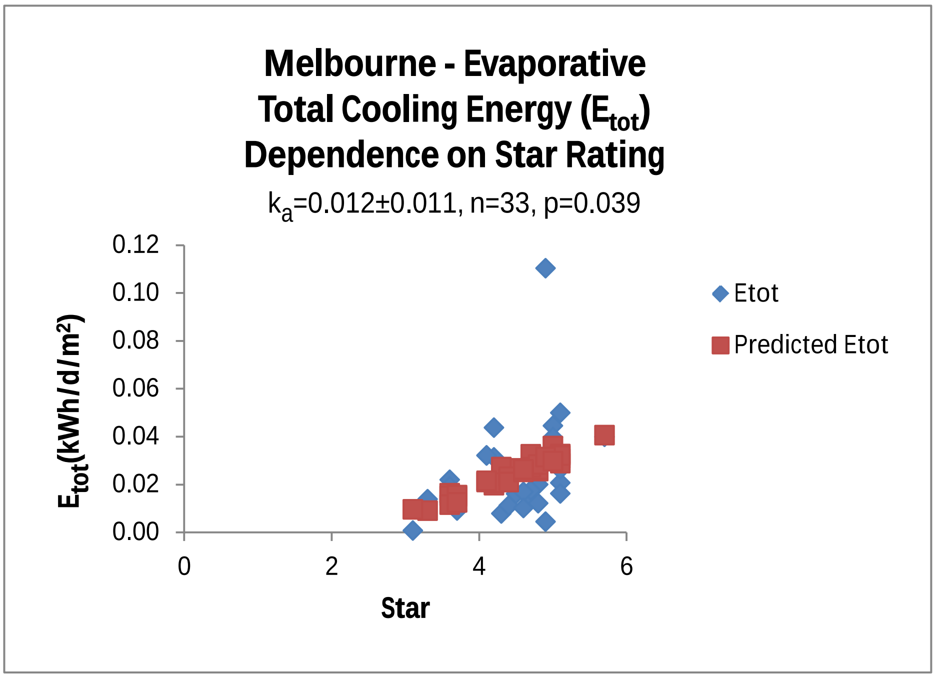


Figure 10-16 House cooling energy dependence on star rating – Melbourne (evaporative cooling)

Table 10-7 Summer quarter energy consumption in Melbourne (evaporative cooling)

Key model constants		
K_a (kWh d^{-1} m^{-2} $Star^{-1}$)	0.012±0.011	By multiple regression (n=33, p =0.039)
Estimated summer savings between cohorts		
Actual additional energy consumed	1.35 kWh m^{-2}	(Increase in consumption with star rating)
Consumption in the lower star-rating cohort		
Average energy (lower star ratings)	1.69 kWh m^{-2}	n=17
Percent additional total consumption		80% of average of low star-rating cohort (Increase in consumption with star rating)

10.2.7 WINTER HEATING

In all three cities, the higher-rated houses had a warmer indoor temperature over winter. There are a number of possible explanations for this temperature increase.

- Householders may have set their thermostats higher in the higher-rated houses.
- The increased temperature could be due to the several degrees Celsius of 'dead band' in the temperature controller. Such dead bands are designed into air conditioner temperature controllers to improve their stability. Comparing, for example, two groups of houses, the higher-rated house would tend to have lower thermal leakage and perhaps greater thermal mass. As a result, the cycling time of air conditioners would be increased in the higher-rated houses, giving them time to reach a higher average temperature within the temperature controller's dead-band.
- End user behaviour may have been to ignore set points and instead, for example, turn the appliance on maximum when they feel cold and then switch it off when they go to bed. In this way, the higher-rated houses (which have reduced heat leakage) would arrive at a higher equilibrium internal house temperature where the maximum capacity of the appliance matches the heat leakage from the house.

10.2.8 SUMMER COOLING

The impact of the NatHERS rating system on house cooling energy consumption was difficult to assess in all three climate zones. Interestingly, the average seasonal temperature of the houses in summer was not significantly below the average outside ambient temperature. It appears that periods of house cooling below ambient are being cancelled out (on average) by periods where the house is significantly above ambient (e.g. when no one is home). It may be that the seasonal temperature difference vs. star rating regression approach is less valid, because of the hour-by-hour oscillation between positive and negative values, compared with the hour-by-hour winter temperature difference which is essentially always positive. However, an analysis of peak usage resolved to half hourly intervals is given in section 12.4.2 that is consistent with the above seasonal analysis. The unexpected trend appears to be that energy consumption increases with star rating.

Possible explanations for this phenomenon are given below.

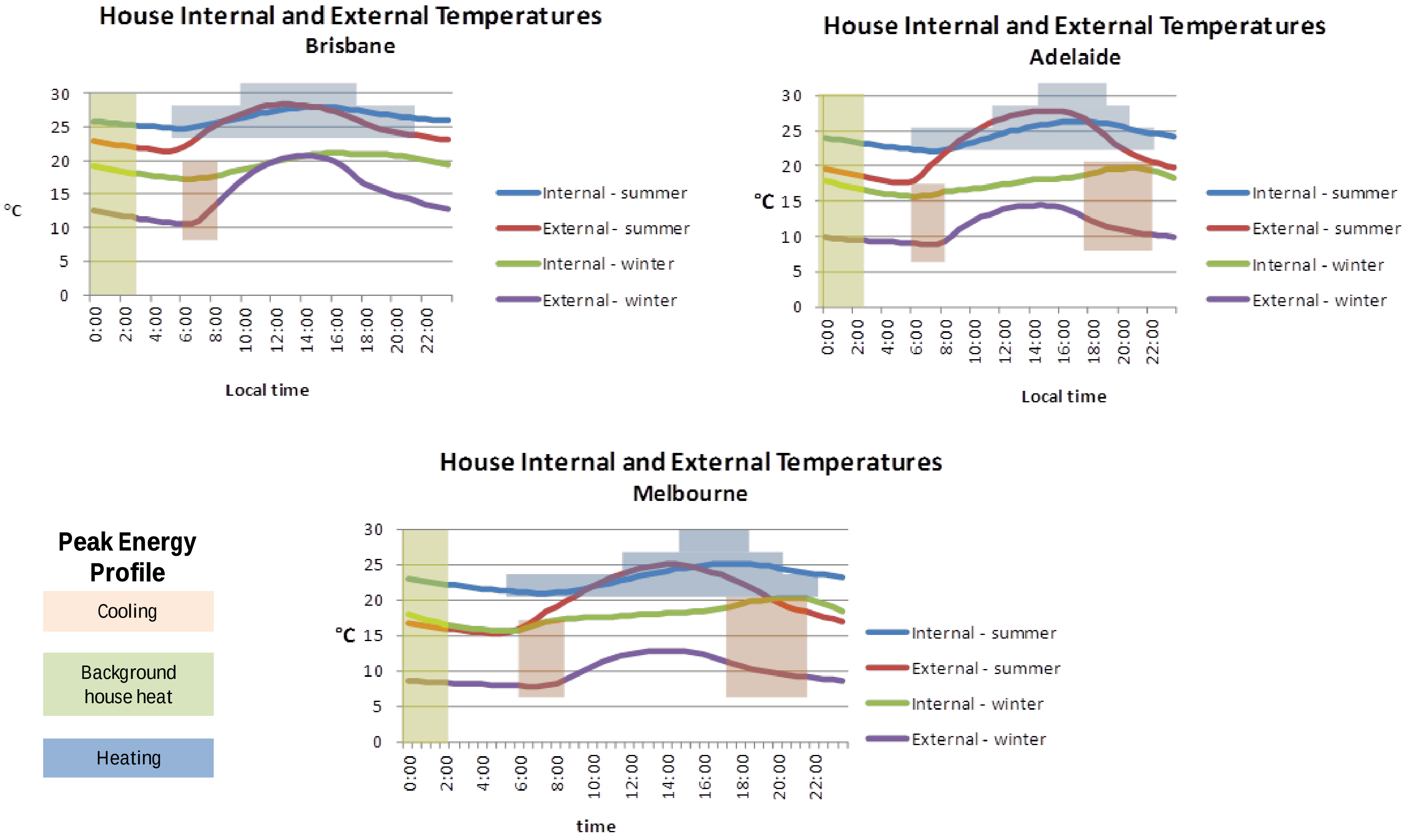
i. If air conditioners were largely operating at full capacity, their energy consumption would no longer reflect the thermal efficiency of the house. This could be due to end-user behaviour being to ignore the use of set points, and put the air-conditioners on maximum cooling when used at all (a corollary of the explanation of the winter house temperature rise effect discussed above). Alternatively, it could be due to undersizing of air conditioners relative to the heat load at the time of installation, or to the warmer-than-average weather conditions for the summer of 2012–13. In any case, if air conditioners are predominantly running on maximum, then the measurements would primarily be reporting the capacity of the cooling appliances, rather than the efficiency of the house.

   To test this theory, we compared the average nameplate maximum electricity consumption of the installed air-conditioning appliances against the average demand of the house sample over a typical summer day. This analysis measured peak power loads averaged across all houses in each city (Section 12.2).

ii. Data input assumptions to the NatHERS methodology may not adequately represent typical end user behaviour and the typical quantities of internal heat loads from appliances. Of particular importance is the assumption that people use air conditioner set points to maintain a relatively steady temperature in the house over waking hours, and that they open windows to provide additional ventilation when appropriate. If an air conditioner is turned off in summer and the house is shut up (e.g. if people are away from home), then stored heat is likely to build up in the fabric of the house. This may not be being adequately accounted for in the current data input assumptions.

    It is interesting to look at average diurnal summer and winter temperature profiles for the sample houses in each of the three cities (**Error! Reference source not found.**). In the small hours of the morning (at night) on a summer day in Brisbane, the internal temperature of the houses is well above the outside temperature. This is one example that would suggest that people are not taking advantage of the opportunity for passive cooling through ventilation. Ventilation is a particularly important concept that can be used to encourage occupants to save energy and achieve comfort, as described in Figure 10-18.

iii. Some differences in occupancy between lower and higher-rated houses were reported in sections 3.1 and 3.2. If significant, these might influence the dependence of energy consumption on star rating. The potential impact of a difference in occupancy was tested by assessing energy consumption during peak usage times of the day (Section 12.4.2). The results were consistent with the seasonal energy consumption reported here, suggesting that the differences in occupancy were insufficient to make a significant difference in energy consumption. Likewise, such influences would not explain why heating energy was saved in winter in higher-rated houses, whereas it was not possible to see such a saving in summer. Nevertheless, this should be studied further.



The widths of the peak energy profiles indicate time corresponding to the local time axis
The heights of the peak energy profiles indicate relative energy consumption

Figure 10-17 Daily internal and external temperature and peak heating and cooling energy profiles

Ventilation can do more than just cool a room – it can also transfer useful heat from one room to another. Shown here is a sun room, with a blue dividing wall separating it from a living room. A fan and a vent are located near the top of the wall next to the open door. The fan blows warm air through the vent below it into the living room, while a vent at the bottom of the wall takes cool air from the living room to be warmed in the sun room. (CSIRO Home Energy Saving Handbook)

An unusual but effective forced ventilation system – on a hot day this large fan with automatic louvres takes just a minute to suck the hot air out of the top of the house and bring cooler air up from below. (CSIRO Home Energy Saving Handbook)

Figure 10-18 **Low-energy, low-cost heating and cooling with forced ventilation**

10.3Summary of results

10.3.1 WINTER

In winter in all three cities, energy was saved in higher NatHERS star-rated houses compared with lower-rated houses, where the temperature difference between the interior and exterior of the houses was held constant. Higher NatHERS star-rated houses had significantly higher temperature differences than lower-rated houses.

- In Brisbane, there was no statistically significant decrease in heating energy consumption with NatHERS star rating. However, the higher-rated houses were on average 0.6 °C warmer than the lower-rated houses. This was equivalent to a heating energy to achieve this temperature difference of 61 kWh over the winter season.
- In Adelaide, heating energy consumption decreased by 155 kWh for the winter period for higher-rated compared with lower-rated houses. Additionally there was some indication that the higher star rated houses were 0.8 °C warmer than the lower-rated houses, though this was within an 85% confidence interval and needs further measurement. This corresponds to an inferred saving of 172 kWh over the winter season. The total saving (actual+inferred) was 39% of the average heating energy used during this period by the lower-rated houses.
- In Melbourne, heating energy consumption decreased by 4421 kWh for the winter period in higher-rated compared with lower-rated houses. The higher-rated houses were warmer than the lower-rated houses by 0.7 °C, so on this occasion it would have been possible to save 549 kWh by reducing house temperatures to the average for lower-rated houses. The total saving (actual+inferred) was 56% of the average heating energy used during this period by the lower-rated houses.

10.3.2 SUMMER

In summer in Brisbane and Melbourne, there appeared to be a significant increase in energy consumption in higher-rated houses. However: i) relatively few houses in Brisbane had ratings greater than 5 star; ii) in Melbourne the evaporative cooling data may have been affected by factors other than house thermal efficiency, such as air flow rates; and iii) the unusually hot summer may have meant that air conditioners were running at full capacity, so that their energy consumption would not accurately reflect house thermal efficiency.

- In Brisbane, cooling energy consumption increased by 1.3 kWh/m^{-2} for the summer period for the higher-rated houses. This was 31% of the average cooling energy use by the lower-rated houses.
- In Adelaide, no statistically significant relationship was found between cooling energy use and star rating.
- In Melbourne, the cooling energy consumed by heat pump cooling increased by 1.4 kWh/m^{-2} for the summer period. This was 38% of the average cooling energy use during the same period by the lower-rated houses.
- In Melbourne, the cooling energy consumed by evaporative cooling increased by 1.4 kWh/m^{-2} for the summer period. This was 80% of the average cooling energy use during the same period by the lower-rated houses.

Part 3 Supporting data

11 Overview of data – heating/cooling performance

11.1 City impact – heating/cooling energy

The annual impact of changes over the entire stock of new constructions within each city can be assessed using dwelling units approvals data. Australian Bureau of Statistics (ABS) data for total new house approvals in 2012 shows that Brisbane had 18,602 approvals, Adelaide had 6,611 approvals and Melbourne had 28,032 new house approvals (Australian Bureau of Statistics, 2013). Although the three cities do have multiple climate zones within them, the vast majority of the building approvals are contained in the capital cities of each state, and these align with the climate zones used in this study. The ABS data used does not include approvals of apartments or units; these dwelling types have been excluded, because they were not included in this study.

Applying these annual approval numbers to the energy consumption data for the two star-rating cohorts provides an indication of the impact of the star rating requirements for each city, as well as the total impact for the combined study area.

Table 11-1 shows that the combined heating/cooling energy impact over the three cities of having all new house construction built to a 5-star standard, rather than a below 5-star standard, is an annual energy saving of 78 GWh. However, the energy savings have mainly been achieved through reduced gas consumption in Melbourne (82 GWh), and the impact is reduced by a 4-GWh increase in electricity consumption. This fuel source shift has an impact on the greenhouse gas emissions, due to the high greenhouse gas emissions coefficients for electricity compared with gas. However, an overall decrease in greenhouse gas emissions of 11 kilotonnes is still achieved.

Table 11-1 Annual star rating impact on heating/cooling energy by city

	Electricity (GWh)	Gas (GWh)	Total (GWh)	Cost ($'000)	Greenhouse gas (kt CO_2e)
< 5 stars – Brisbane	25	0	25	6,237	21
5 stars or more –Brisbane	28	0	28	6,990	24
< 5 stars – Adelaide	11	0	11	4,166	7
5 stars or more – Adelaide	11	0	11	4,153	7
< 5 stars – Melbourne	12	158	170	14,754	44
5 stars or more – Melbourne	13	76	89	9,321	30
Saving/cost	**–4**	**82**	**78**	**4,693**	**11**

11.2 City impact – total energy

Table 11-2 shows that the annual total whole-of-house energy saving impact over the three cities of having all new house construction built to a 5-star standard, rather than a below-5 star standard, is an annual energy saving of 195 GWh. This translates to a total annual energy cost saving of $11.6 M. However, again the energy savings have mainly been achieved through reduced gas consumption in Melbourne (204 GWh). A 9-GWh increase in electricity consumption reduces this impact. Nevertheless, greenhouse gas emissions are decreased by 25 kilotonnes, which is the equivalent of removing 5208 cars off the road each year. [3]

Table 11-2 Annual star rating impact on total energy by city

	Electricity (GWh)	Gas (GWh)	Total (GWh)	Cost ($'000)	Greenhouse gas (kt CO_2e)
< 5 stars – Brisbane	135	0	135	34,256	116
5 stars or more – Brisbane	132	0	132	33,571	114
< 5 stars – Adelaide	43	0	43	15,728	28
5 stars or more – Adelaide	41	0	41	15,130	27
< 5 stars – Melbourne	164	374	538	74,944	263
5 stars or more – Melbourne	177	170	348	64,632	242
Saving/cost	**–9**	**204**	**195**	**11,594**	**25**

11.3 Cost effectiveness of the standard, and the market adjustment vs. predictions

As is customary before any regulatory changes are enacted, a RIS was prepared for the proposed move to a 5-star energy efficiency requirement. RIS 2006-1, "Proposal to Amend the Building Code of Australia to increase the Energy Efficiency Requirements for Houses" (Australian Building Codes Board, 2006) was released in March 2006, ahead of the proposed changes to the BCA 2006 in May 2006. The RIS investigated the nationwide impacts from the introduction of the increased requirements, with a particular focus on the financial, energy consumption and greenhouse emission impacts.

The financial impacts looked at construction costs, avoidable energy costs, appliance costs and a total lifetime cost. Energy consumption looked at savings in gas and electricity consumption, while the overall reduction in greenhouse gas emissions was estimated. Two summary impact measures were reported. The benefit/cost ratio for impacts on the lifetime cost of housing, with no dollar value assigned to greenhouse savings, was calculated to be 1.27. The average net national cost of expected reductions in greenhouse emissions was calculated as –3.6 cents/kg of CO_2 equivalent.

The findings from this project provide some useful (but not conclusive) evidence relevant to the assumptions and predictions used in the RIS. The RIS was based on an effective life of the regulation

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[3] Based on average consumption of 10.9 litres per 100 km, annual travel of 18 500 km, and greenhouse gas emissions of 4.8 t CO_2-e per car per year

of 10 years, from 2007 until 2016, by which time it was planned to be reviewed. Consequently, this study is approximately half way through this period. It is important to note that since the release of this RIS a further increase in energy efficiency requirement has occurred, from May 2011. RIS 2009-6 was undertaken to implement this increase (Centre for International Economics, 2009). However, the assumptions and predictions used in this RIS have not been investigated in this report, because only a small number of houses in the study have been subject to the increased standard.

11.3.1 FINANCIAL IMPACTS

The RIS estimated the construction costs for all eight climate zones as defined in the Building Code of Australia. However, for the purpose of this study, only the three climate zones that we focused on will be examined. The RIS also based costs on four different house designs and two different floor systems for each design (concrete slab and suspended timber), to give a total of eight different designs and construction costs. Table 11-3 lists the estimated additional costs from the RIS for the four designs based on the use of a concrete slab floor as well as a 'representative house' that was used as an average. The table also shows the costs as estimated through this study.

The RIS found that on average, there would be a cost increase in all cities, although for the passive solar design there was a small cost saving in Adelaide and Melbourne. In contrast, this study found that there was a reduction in costs in all cities.

Table 11-3 Additional estimated construction costs (AU$) from RIS compared to study

City	Additional construction cost – RIS 2006-1					Additional construction cost – Study
	Small single-storey	Large two-storey	Cross-ventilated	Passive solar design	Representative house	
Brisbane	97	1458	295	1957	791	–7,474.63
Adelaide	115	1712	137	–230	415	–5,711.29
Melbourne	124	1410	–	–296	400	–5,044.75

11.3.2 BENEFIT/COST RATIO

The RIS calculated a benefit/cost ratio of 1.27. However, results from this study make it impossible to calculate a comparison ratio, because no costs have actually been incurred. Indeed, costs associated with meeting the standards have reduced, while appearing to still be delivering small energy and greenhouse gas savings. A fuel shift appears to have also occurred with increased electricity consumption, but this is countered by reduced natural gas consumption. This fuel shift means that the greenhouse gas savings are not as significant as the energy savings, because a larger greenhouse gas coefficient is applied to electricity (especially in Melbourne) than natural gas.

Overall, energy, energy costs and greenhouse savings have been achieved in all three cities, although seasonal variations do occur, and the summer energy increases require further investigation. These savings have been achieved for no additional construction costs; instead, indirect construction cost savings may have been achieved. Furthermore, it is possible that consumers have elected to translate the savings achieved by their home's thermal performance to increase comfort levels by keeping their houses warmer in winter.

12 Key factors affecting the statistical assessment

12.1 Energy consumption

An essential precursor to assessing the impact of the NatHERS star rating on heating and cooling energy was to understand how energy use varied with different locations and at different times of the year. This section describes how levels of consumption changed between climate zones and over the times of greatest use in winter and summer. It also describes changes in consumption depending on when and where different types of heating, ventilation and air-conditioning (HVAC) appliances were used most often.

12.1.1 CLIMATE ZONES AND HOURS OF HVAC USAGE

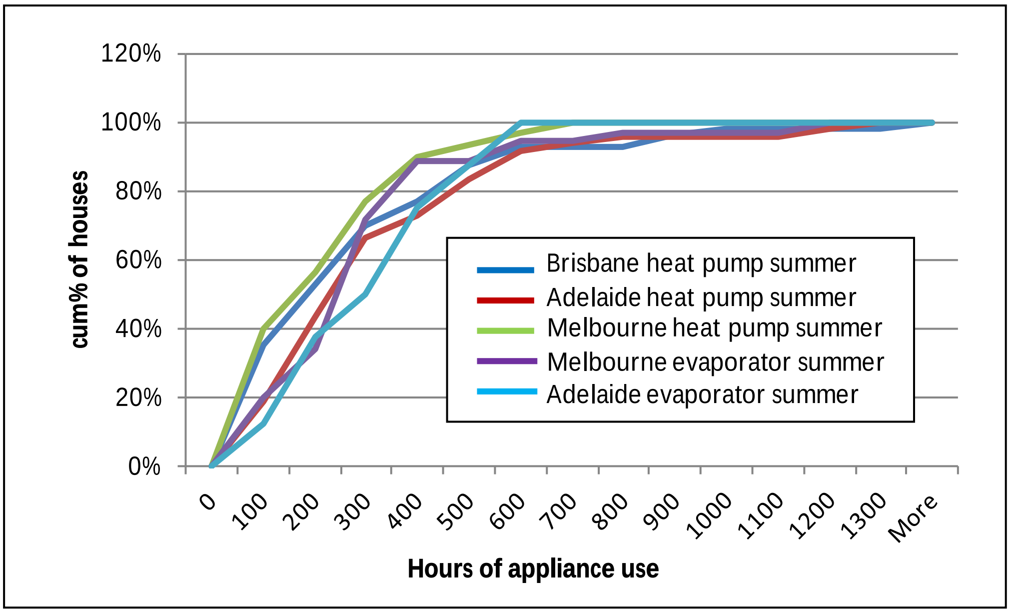
When heating and cooling appliances are operating at their maximum power and duty cycle, their energy consumption cannot be used to accurately determine the amount of energy saved in houses with higher star ratings. This is because when operating at full capacity, energy consumption does not change with small differences in load. Because of this, we assessed the extent to which HVAC equipment may have been operating at full capacity by measuring how often they were operating at full power and with a high level of usage. The term ‘usage’ in this report describes the duration for which a heating or cooling appliance was actively heating or cooling. It incorporates periods of operation by householders, as well as the appliance thermostatically controlled duty cycle.

Figure 12-1 and Figure 12-2 show heating and cooling appliance usage as a cumulative percentage of hours per season. A value of 100% corresponds to about 60 houses each in Brisbane, Adelaide and Melbourne. In winter, the maximum possible usage corresponds to 2208 hours with the appliance on 24 hours a day, seven days a week; in summer, it is 2160 hours. The percentage use may reflect both household behaviour in switching the appliance on or off, and automatically controlled switching of the appliance.

Conclusions from the usage across climate zones were consistent with expectations, in that:

- Adelaide and Melbourne have considerably more usage hours than Brisbane for winter heating, and Melbourne has more usage hours than Adelaide.
- All three cities showed similar levels of cooling usage hours.
- Brisbane used more hours for summer cooling than for winter heating.
- Adelaide and Melbourne used more hours for winter heating than for summer cooling.

Peak periods were assumed to be approximately six hours per day. This amounts to a maximum of 552 hours in winter and 540 hours in summer. Figure 12-1 indicates that during the 2012 winter, Adelaide and Melbourne may have had 40–50% of household heat pumps operating for longer than the peak period. Likewise, in the summer of 2012–13, about 20% of household heat pumps in all three cities may have been operating longer than the peak period. This suggests that a significant number of heat pumps were working at full capacity during peak periods of winter. The duty cycle of HVAC units is analysed in Section 12.2, where the management of peak power loads is considered for much shorter time intervals.



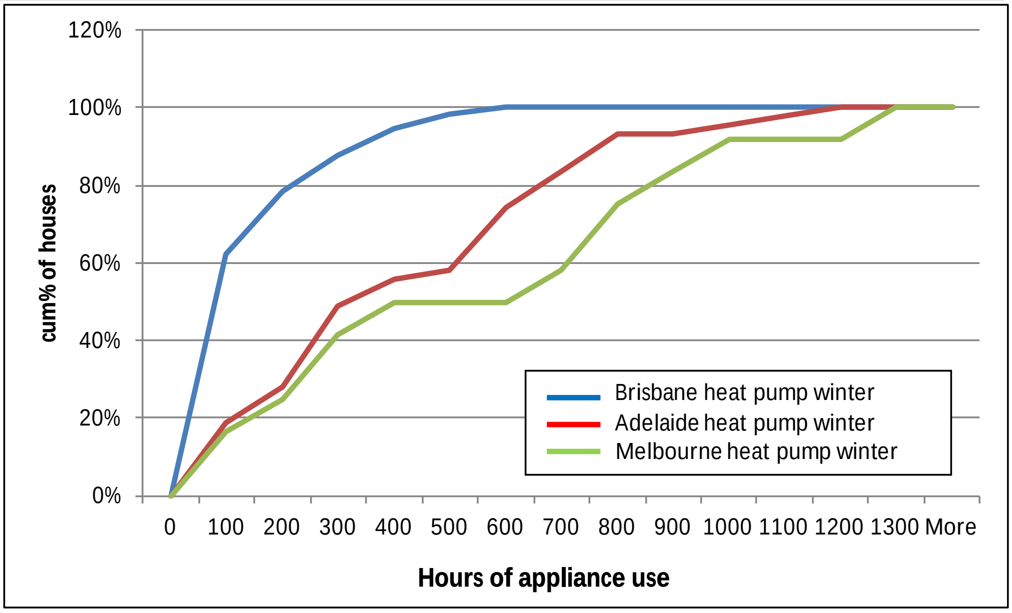


Figure 12-1 **Cooling and heating appliance usage between each city for winter and summer**

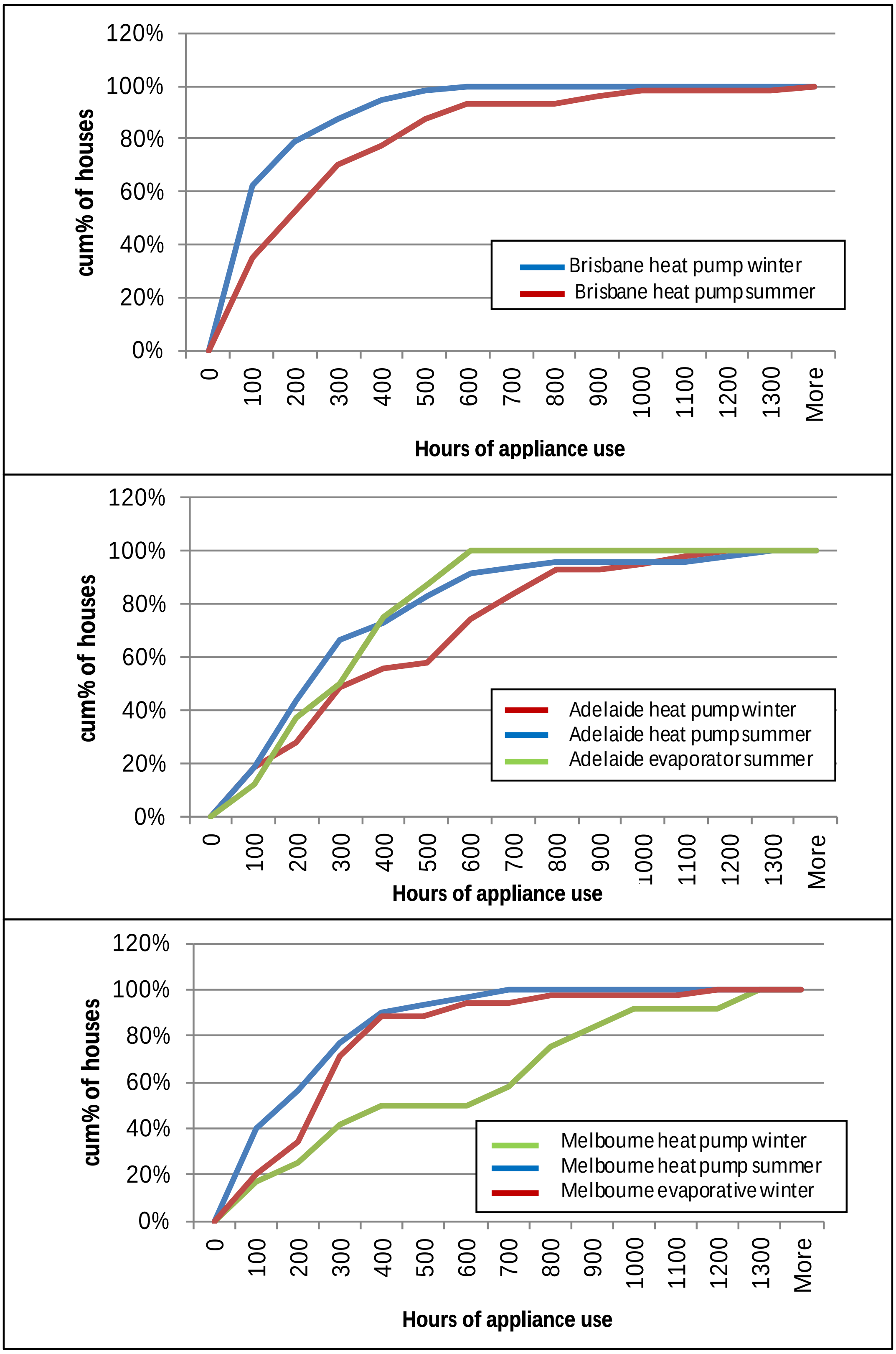


Figure 12-2 **Cooling and heating appliance usage between winter and summer for each city**

12.1.2 HVAC USAGE HOURS AND STAR RATING

The level of heating and cooling energy use in an appliance may be controlled by switching the appliance on an off, either manually, or using a thermostat. Measuring the hours of use or duty cycle of an appliance can therefore be a useful, but indirect, measure of energy consumption. Figure 12-3 and Figure 12-4 compare hours of appliance operation between the star-rating cohorts. There was only one case with a substantial difference, which was for winter heating in Melbourne, where heat pumps in the higher-rated houses were used much less than in the lower-rated houses.

Star rating and HVAC per cent usage in summer (Figure 12-3)

- In Brisbane, the lower-rated houses used slightly less hours of heat pump cooling. This may have been due to the pumps for the higher-rated houses having lower power ratings.
- In Adelaide, the hours of heat pump cooling were similar for both star-rating groups.
- In Melbourne, the lower-rated houses used slightly less hours of heat pump cooling, whereas for evaporative cooling, there was very little difference between the two groups.

Star rating and HVAC per cent usage in winter (Figure 12-4)

- In Brisbane, there was no difference between the lower and higher-rated houses, despite the tendency for higher-rated house to have heat pumps with lower power ratings than the lower-rated houses (12.3.2).
- In Adelaide, the higher-rated houses used slightly less hours of heat pump heating, whereas the opposite was true for Melbourne. The result for Melbourne should be treated with caution, because it had relatively low sample numbers for heat pumps due to the prevalence of gas heating in these zones, and because some heat pumps may have been supplementary to gas heating.

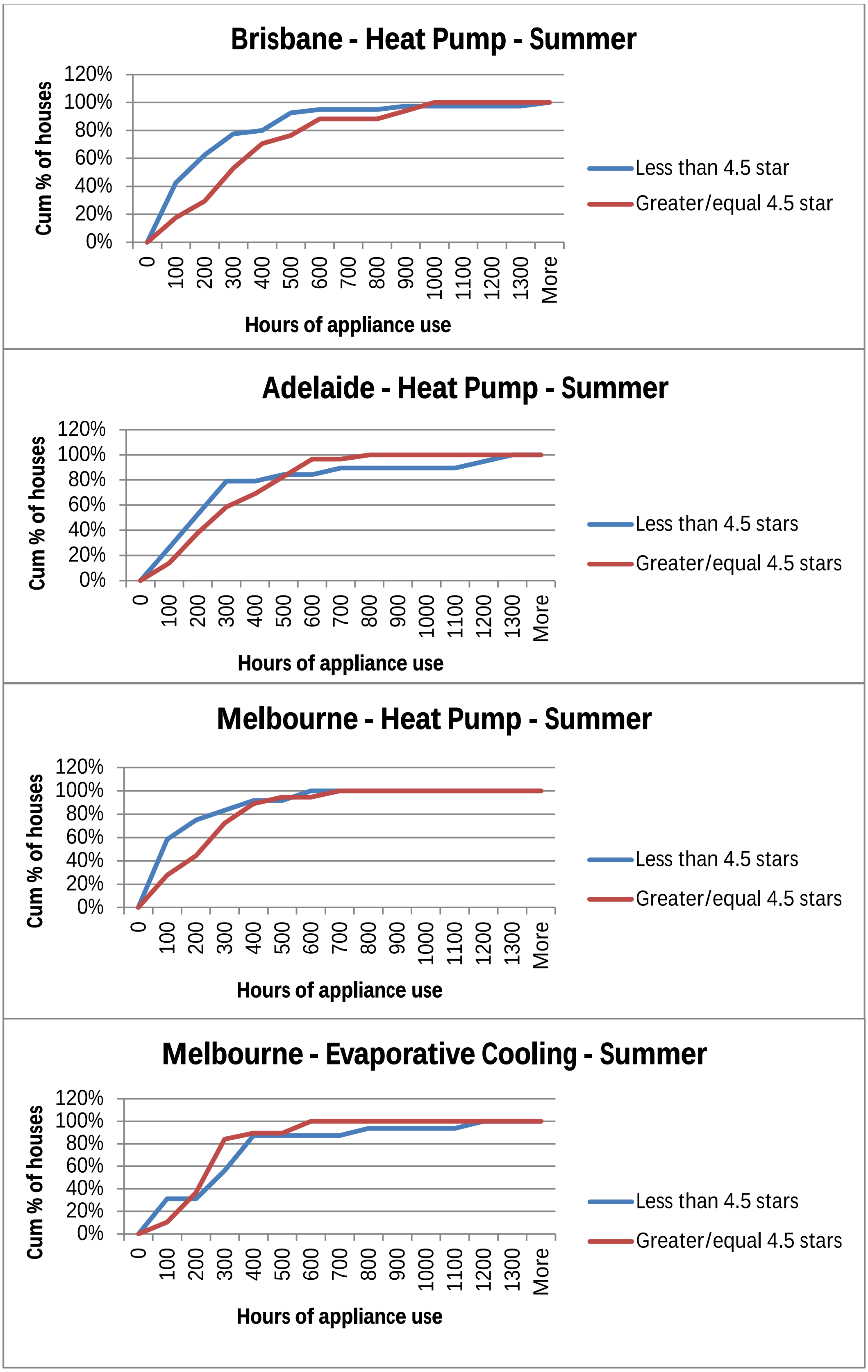


Figure 12-3 **Cooling appliance usage between star ratings for each city**

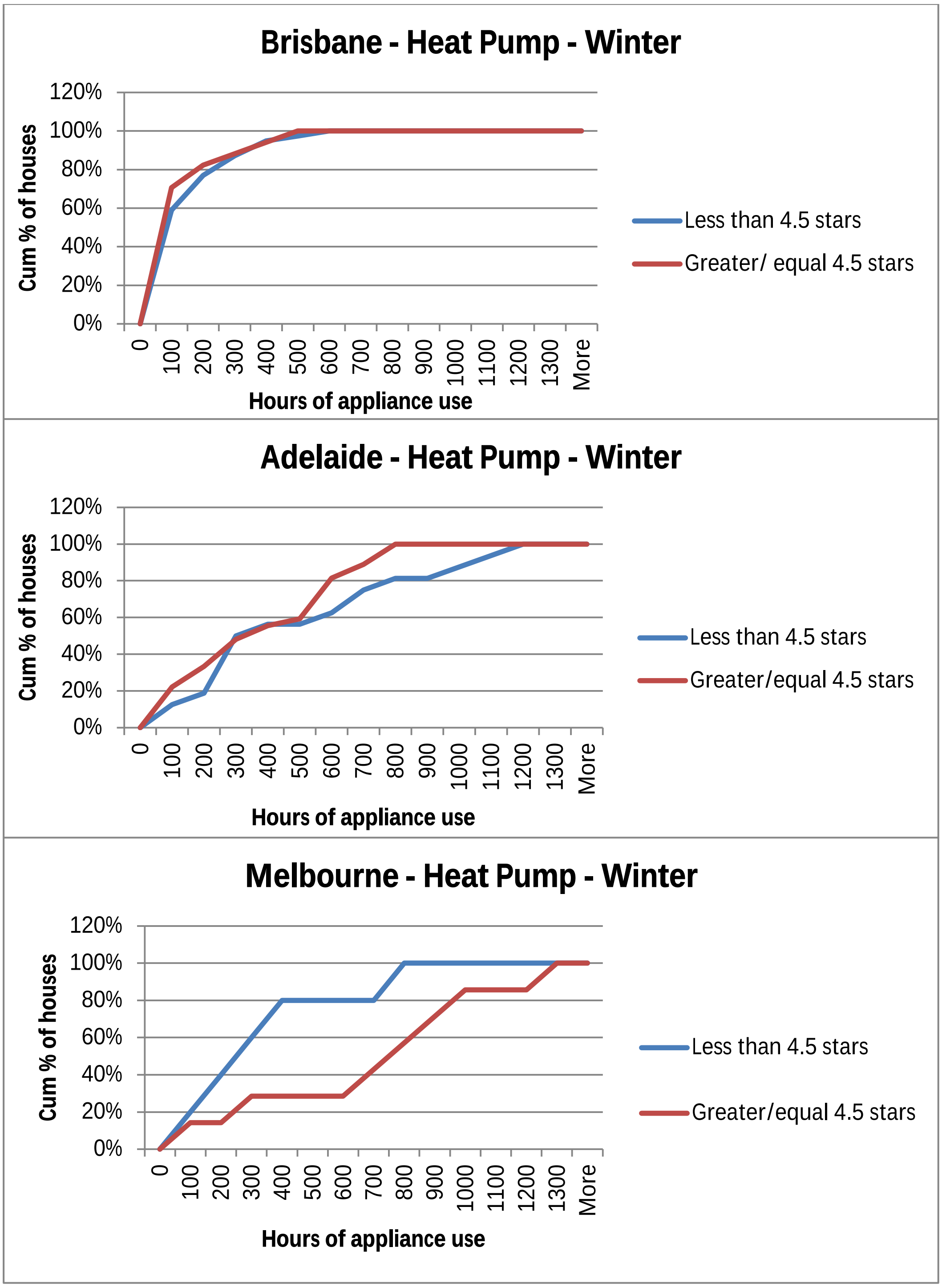


Figure 12-4 **Heat pump winter usage between star ratings for each city**

12.1.3 ELECTRICITY CONSUMPTION

When individual houses were assessed over the nine-month period, the electricity consumption data was quite scattered and could not be readily analysed. Much of the scatter in this data is due to interfering variables, such as: internal and external temperatures, human behaviour, occupancy, usage, and difference in electricity to thermal energy conversion factors associated with multiple appliance types. Conversion factors can vary by a factor of three or four between heat pumps and gas for heating, and between heat pumps and evaporative coolers. Appliance performance can also be significantly affected by appliance age, level of maintenance and humidity, making it impossible to accurately determine their operating efficiency.

These factors had a profound impact on the analysis for Adelaide and Melbourne. We had to segregate groups of appliances by type for the analysis, with a corresponding reduction in sample numbers. To reduce the influence of these sources of data noise from interfering variables, we have:

- focused on measurements made during seasonal and daily periods of high consumption
    - this was to increase the magnitude of any change in heating and cooling energy consumption compared to the data noise from interfering variables
    - to achieve this, we assessed data from the winter and summer seasons and three periods of high thermal energy usage during the day, including 06:30–08:30, 15:00–17:00 and 19:00–21:00
- partitioned the data into homogenous blocks by climate zone, appliance type and star rating
- identified key variables and compensated for their effect, where possible, using multiple regression.

Seasonal HVAC Electricity Consumption

Figure 12-5 and Figure 12-6 compare the average household electricity consumption of different appliance types in the three cities, in summer and winter, respectively. In particular, the results show that evaporative coolers consumed less electricity than heat pumps, although this difference is less significant in Melbourne. This may reflect the use of higher evaporative cooling air duct velocities in Melbourne. Or, electricians may be putting additional devices on the evaporative cooler electrical circuit in Melbourne, but not in Adelaide. The presence or absence of additional devices on the evaporative cooler electrical circuits was not recorded in the switch board, but was assessed by visual inspection of consumption patterns.

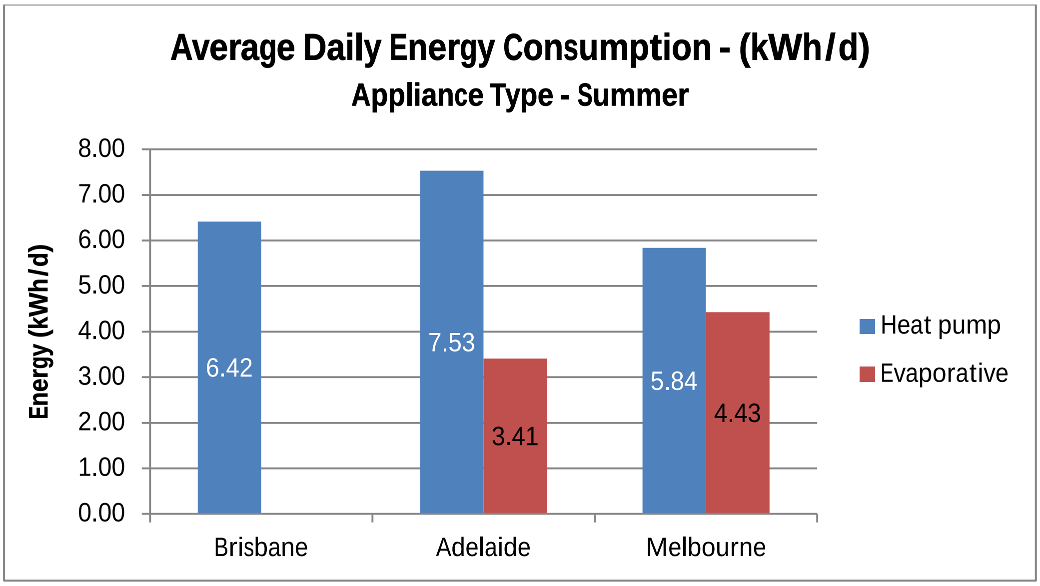


Figure 12-5 Daily average cooling appliance electricity consumption for each city

Average daily winter HVAC energy consumption was dominated by gas consumption in Melbourne (Figure 12-6). This is in part because of its colder winters, with an average temperature of 10 °C in 2012, compared to the Adelaide average of 15 °C and the Brisbane average of 16 °C. Gas energy consumption for heating in the Melbourne cohort is also very high compared to heat pump electricity consumption, possibly because of the availability of cheap, high-capacity gas heating. Another factor in the high gas energy consumption is that gas heater conversion of energy to useful heat is 70–80%, with significant heat lost in the exhaust and in ventilation. Conversely, reverse-cycle heat pumps run with a coefficient of performance (COP) of about 300%.

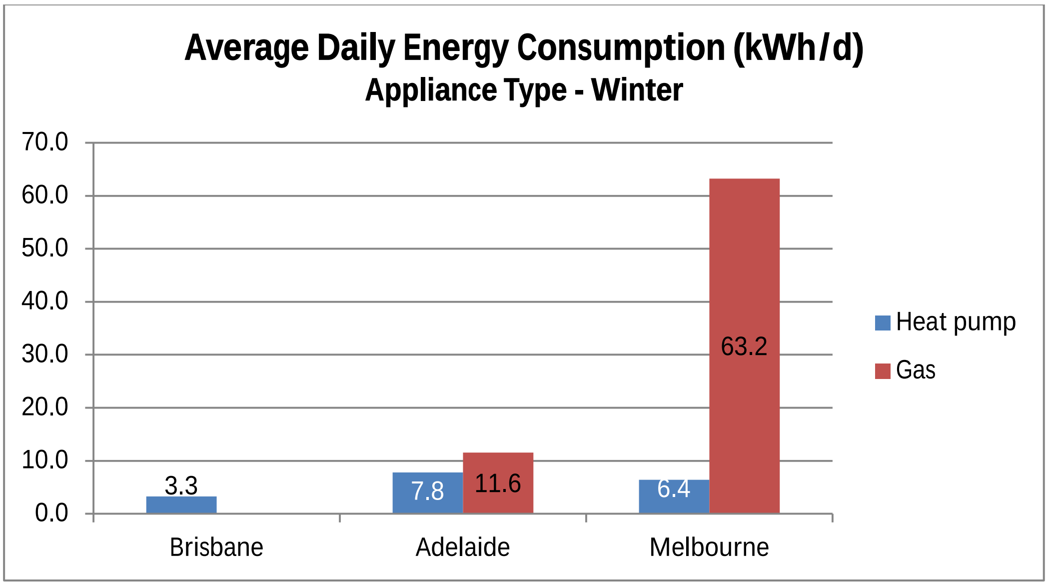


Figure 12-6 Daily average heating appliance energy consumption for each city

12.1.4 HOUSE TEMPERATURE AND TEMPERATURE DIFFERENCES

Figure 12-7 and Figure 12-8 show the internal temperature in the main living area, and the temperature difference between it and the nearest BoM weather station. In both winter and summer, the air temperature inside the house was consistently higher than at the nearest BoM weather station, though the temperature difference was considerably lower in summer than in winter. This only accounts for the air temperature, and does not include the temperature rise due to absorption of radiant heat. Occasionally, between 15:00 and 17:00, when the average air conditioner energy consumption was highest in summertime, the internal temperature did fall below the weather station temperature.

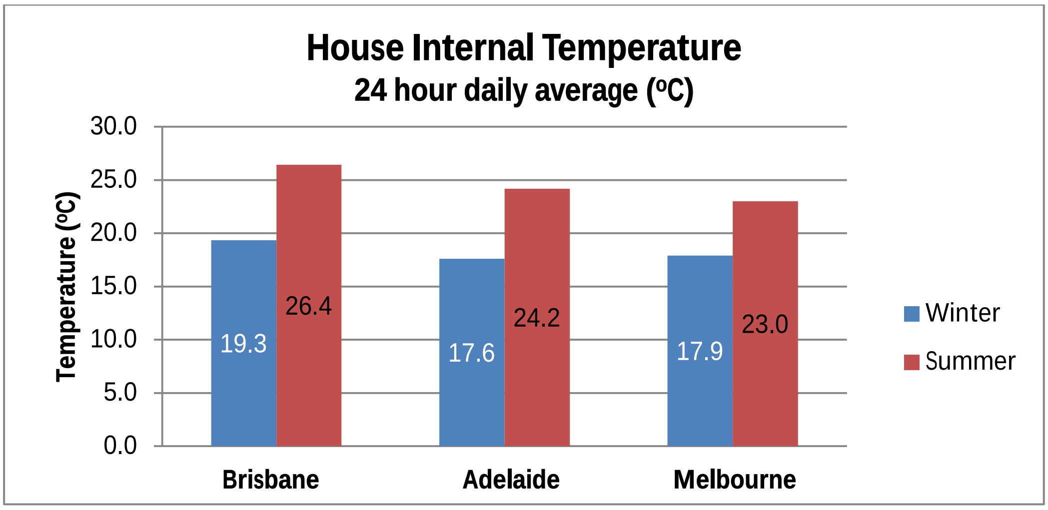


Figure 12-7 **Temperature in the main living areas**

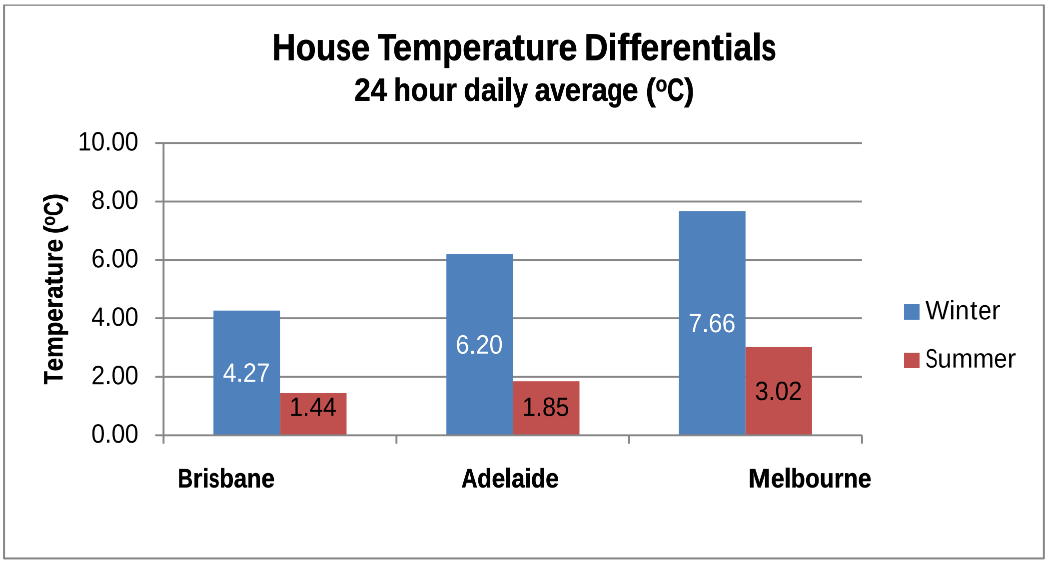


Figure 12-8 **Temperature difference between the main living area and external environment**

12.2 Peak power loads

The use of HVAC appliances was a key part of assessing the impact of NatHERS star rating on house heating and cooling energy consumption. This section assesses HVAC appliances, how they might be affected by the NatHERS star rating, and whether the occupants' appliance usage patterns might have unduly influenced the assessment of the NatHERS star-rating impact on heating and cooling energy consumption.

We measured the HVAC energy, power and duty cycle for summer days during periods of high occupancy to: i) check if higher star ratings were helping to reduce peak energy loads, and ii) see if limits to appliance cooling or heating capacity, combined with high thermal loads, explained the absence of a NatHERS star-rating impact on cooling energy consumption. Specifically, the methodology required investigation over three time periods:

- 06:30–08:30 (early morning)
- 15:00–17:00 (mid-afternoon)
- 19:00–21:00 (evening).

During these periods, measurements of HVAC energy consumption were taken only when the equipment was running, i.e., in use. In this report, the term 'in use' applies to the amount of energy consumed while a heating or cooling appliance was switched on, through either manual or automatic control. It does not include appliances that were not being used or that were running on standby. The in-use energy was estimated for each house as the energy used in each two-hour time period. The in-use power was calculated by dividing the in-use energy by the number of hours the appliance was switched on. The duty cycle was the average percentage of time the appliance was running during each two-hour period. The in-use energy and power and the duty cycle were calculated for all appliances that were consuming energy for heating and cooling, and for each day of the season. The average values are shown in Figure 12-9 to Figure 12-13.

In summer, the in-use power, energy consumption and duty cycle were highest in the early afternoon: about 14:00 local time for Brisbane, and late afternoon from 15:00–17:00 for Adelaide and Melbourne. In winter, the period 15:00–17:00 marked the lowest consumption for all zones and the power for appliances in Adelaide and Melbourne dropped with the winter energy consumption. In Brisbane in winter, the power reached its highest peak of the day while the energy consumption was at its lowest, suggesting that only a small number of heaters were switched on for a very short, intense burst. This may reflect a high level of changing activity in Brisbane households at this time, as suggested by the rapidly changing energy consumption described later in Section 12.2 and illustrated in Figure 12-25.

Peak power for heat pumps averaged across houses was estimated as 3 kW from their nameplate-rated power values (which were more readily accessible than those for evaporative coolers). Peak power for evaporative coolers, averaged across households, was measured at around 1 kW by the Ecopulse monitors. It was not possible to establish if HVAC systems were operating at capacity, because of the inability to distinguish manual from automatic switching of the appliances, and because in Brisbane the period set for evaluation in summer did not correspond to maximum usage. However, the preliminary indications from Table 12-1 are that many heat pumps in Brisbane and evaporative coolers in Adelaide may have been near capacity in summer, and likewise many heat pumps in Adelaide may have been near capacity in winter. There may be some rebound effect in the usage of evaporative air conditioners on the assumption that they are cheap to run.

Table 12-1 **Summary of peak heating and cooling power and duty cycle by time of day and city**

City	Season	Time	Peak power (kW)	Duty cycle (%)	Appliance
Brisbane	Winter	15:00–17:00	3.4	5	Heat pump
Brisbane	Summer	15:00–17:00	2.5	24	Heat pump
Adelaide	Winter	19:00–21:00	1.8	46	Heat pump
Adelaide	Summer	15:00–17:00	2.7	23	Heat pump
Adelaide	Summer	15:00–17:00	1.2	41	Evaporative
Melbourne	Winter	19:00–21:00	1.0	50	Heat pump
Melbourne	Summer	15:00–17:00	0.7	21	Evaporative
Melbourne	Summer	15:00–17:00	2.3	21	Heat pump

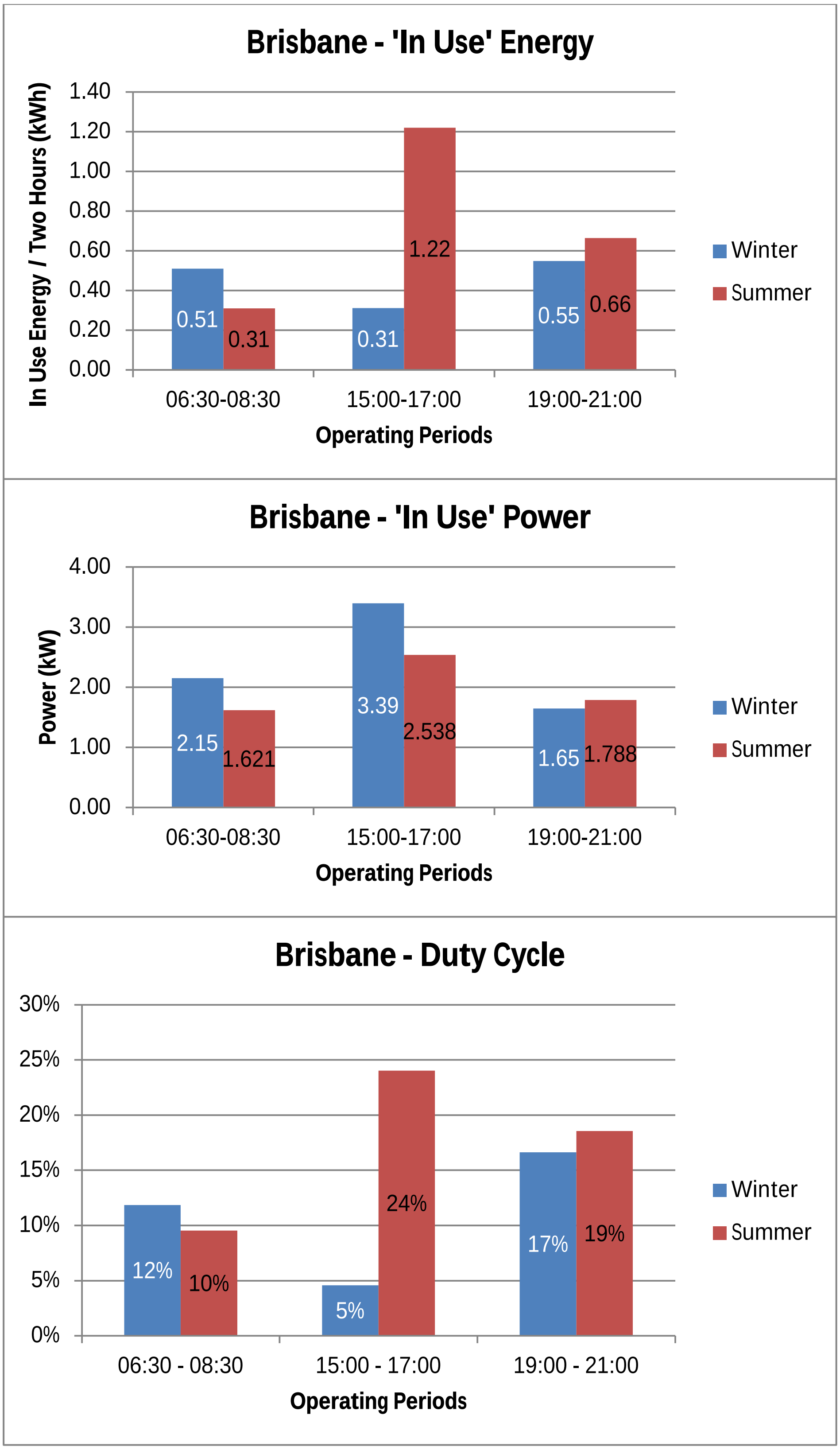


Figure 12-9 Daily average 'in use' energy, power and duty cycle – Brisbane

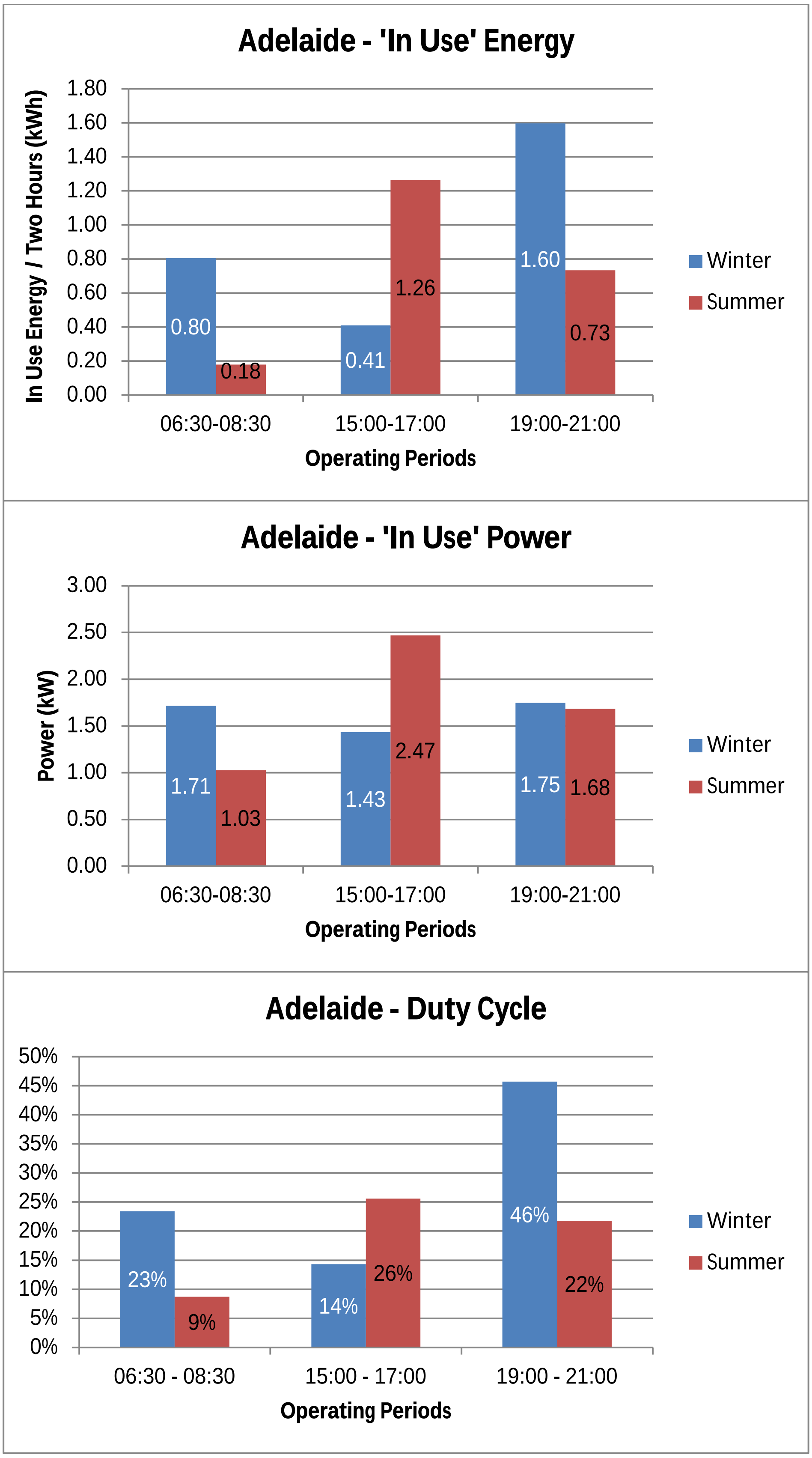


Figure 12-10 Daily average ‘in use’ energy, power and duty cycle – Adelaide

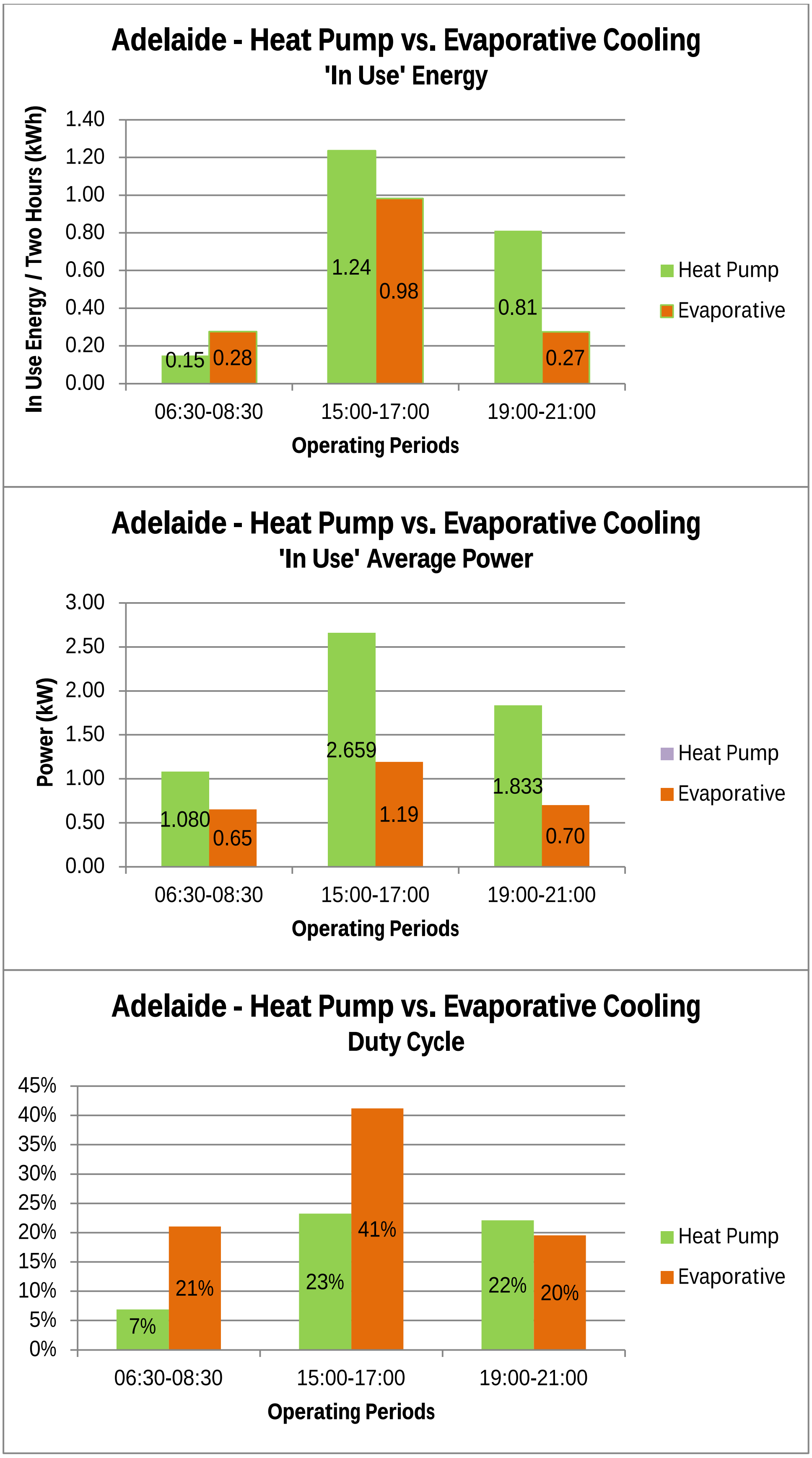


Figure 12-11 **Appliance type – Daily average 'in use' energy, power and duty cycle – Adelaide**

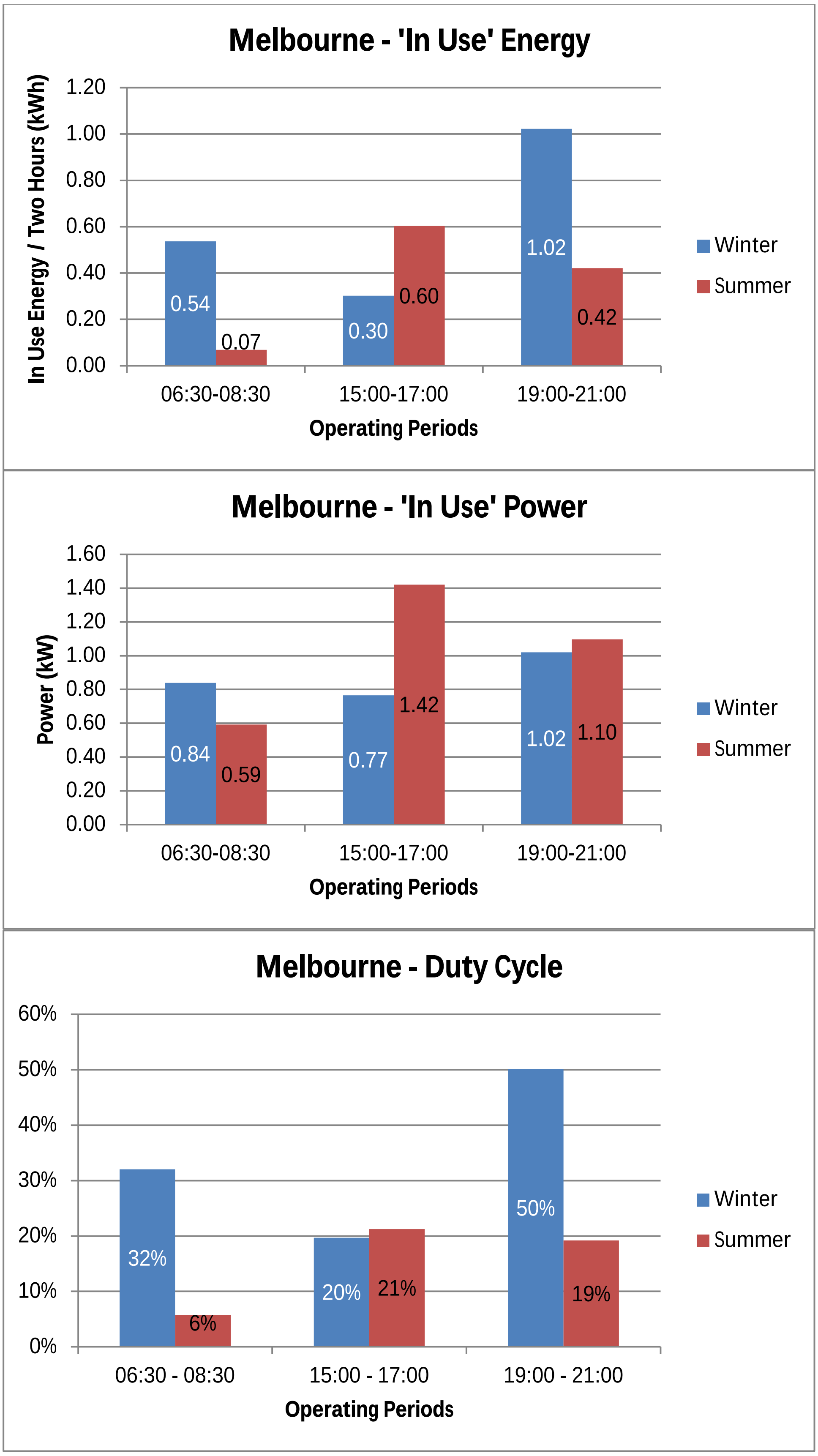


Figure 12-12 **Daily average 'in use' energy, power and duty cycle – Melbourne**

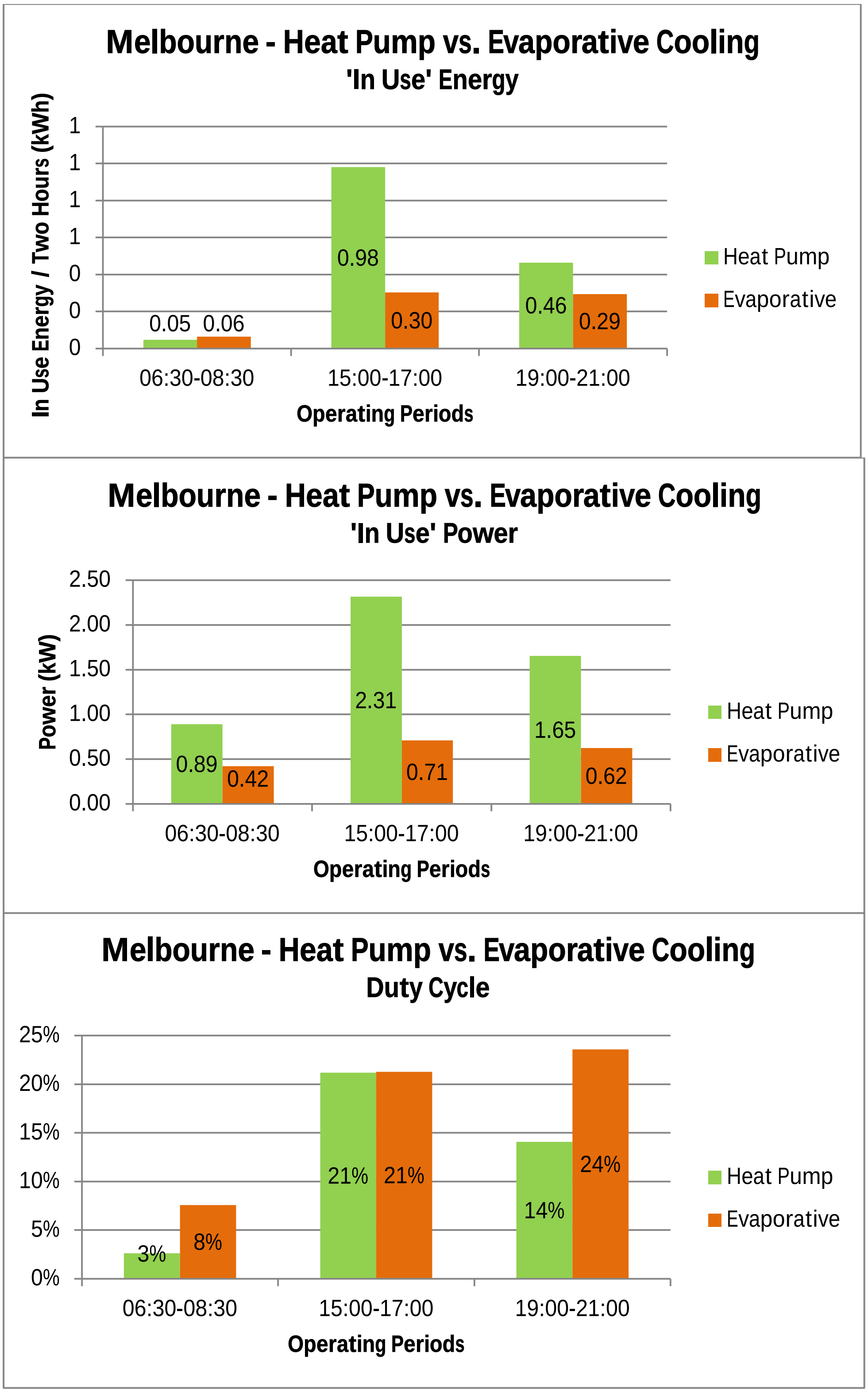
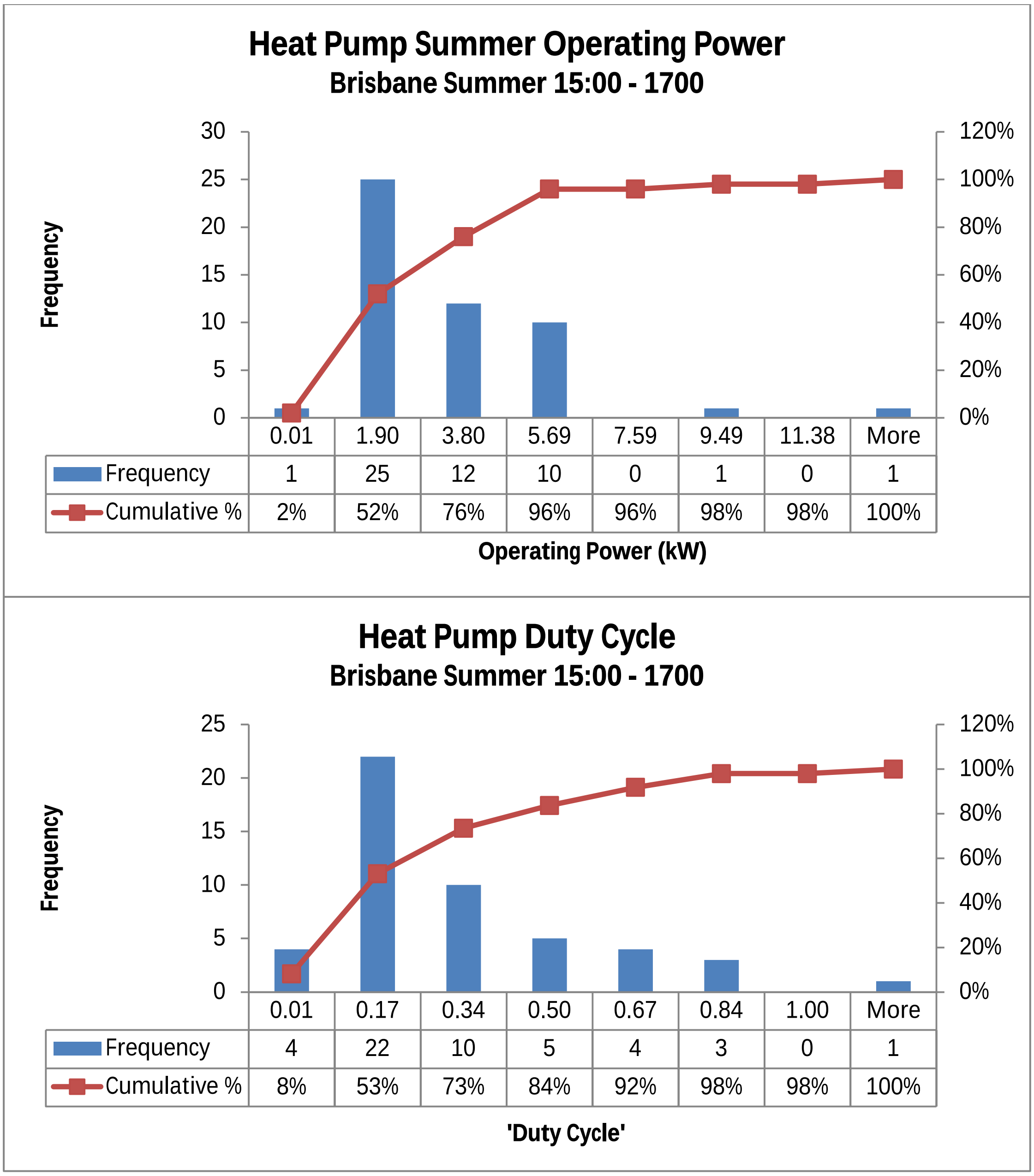


Figure 12-13 **Appliance type – Daily average 'in use' energy, power and duty cycle – Melbourne**

Figure 12-14 and Figure 12-15 shows the frequency distribution of operating powers and duty cycles for Brisbane and Adelaide, respectively.



	0.01	1.90	3.80	5.69	7.59	9.49	11.38	More
Frequency	1	25	12	10	0	1	0	1
Cumulative %	2%	52%	76%	96%	96%	98%	98%	100%

	0.01	0.17	0.34	0.50	0.67	0.84	1.00	More
Frequency	4	22	10	5	4	3	0	1
Cumulative %	8%	53%	73%	84%	92%	98%	98%	100%

Figure 12-14 Power/duty cycle distribution in heat pumps – Brisbane

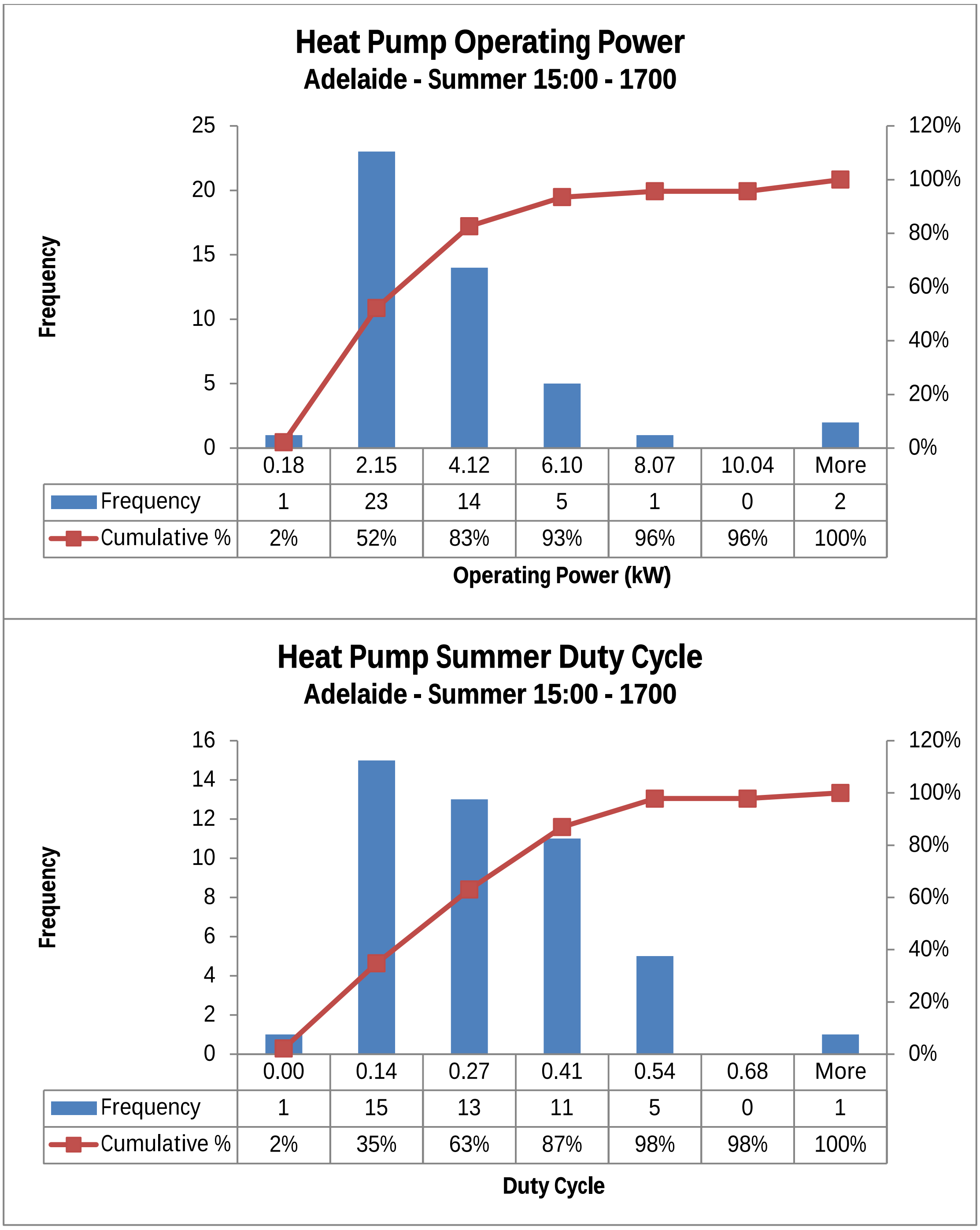


Figure 12-15 **Power/duty cycle distribution in heat pumps – Adelaide**

12.3HVAC selection

This section describes whether the distribution or characteristics of HVAC appliances used in the houses in the study were associated with the NatHERS star rating, and therefore, whether they might bias the assessment results.

12.3.1 DISTRIBUTION OF APPLIANCE TYPES BY CITY AND STAR RATING

Appliance Types and City

The distribution of appliance types across cities was predetermined for this study through screening volunteers. However, demographic constraints made it impossible to create an even distribution of appliance types. For example, Melbourne householders had an almost complete focus on gas for heating and a strong focus on evaporative cooling, whereas Brisbane residents predominantly used heat pumps for heating and cooling, and Adelaide residents used both heat pumps and gas. We tried to ensure that at least one heating and cooling modality, the heat pump, was strongly represented in all climate zones. Figure 12-16 shows how the principal modes were distributed across the cities.

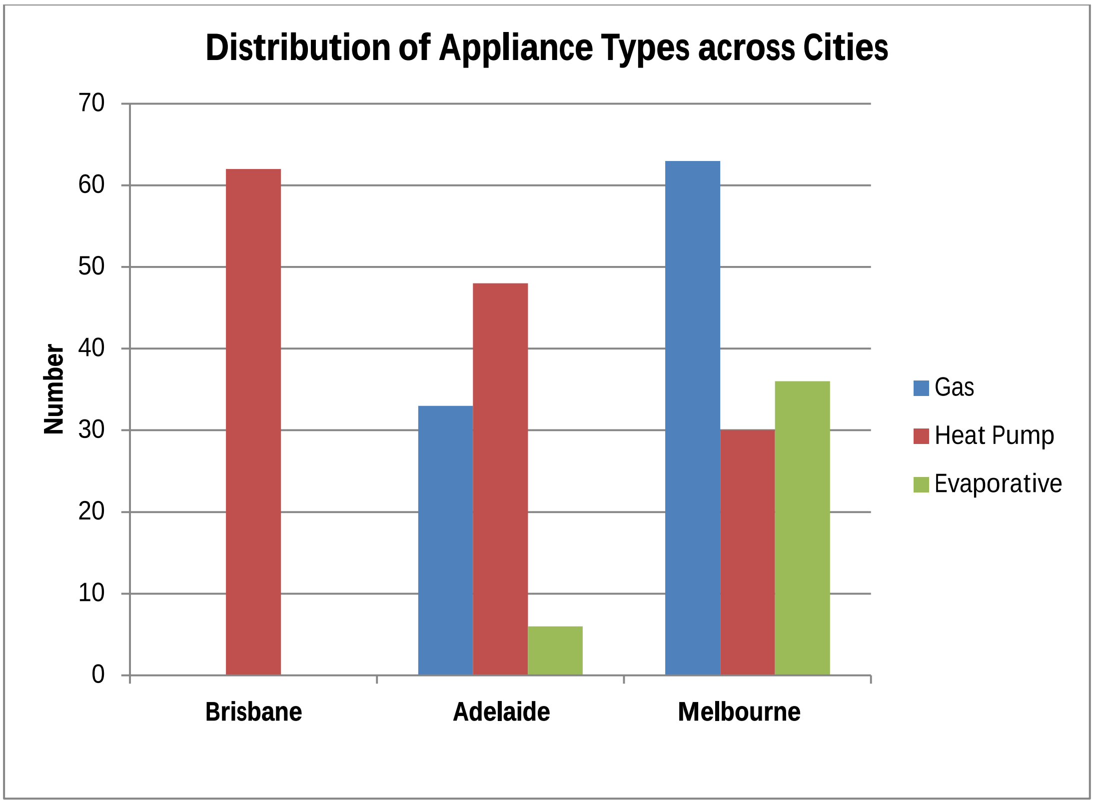


Figure 12-16 **Distribution of gas heaters, heat pumps and evaporative cooling across cities**

Appliance Types and NatHERS star rating

It was necessary to ensure that star ratings were as evenly distributed as possible for each appliance type to allow statistical analysis. However, no practical method was available to predetermine star ratings for houses across a large population of volunteers in the three cities tested. Consequently, we sampled by selecting houses distributed evenly according to their year of construction.

Figure 12-19 and Figure 12-20 show how star ratings were distributed across the heating and cooling modes. Heat pumps were evenly distributed for Brisbane, but shifted to higher star ratings for Adelaide and Melbourne, as many houses exceeded the NatHERS rating requirements. For this reason, we included a regression analysis across all sample points to determine a slope for energy consumption vs. star rating that would allow us to use better estimates for the lower star-rating values.

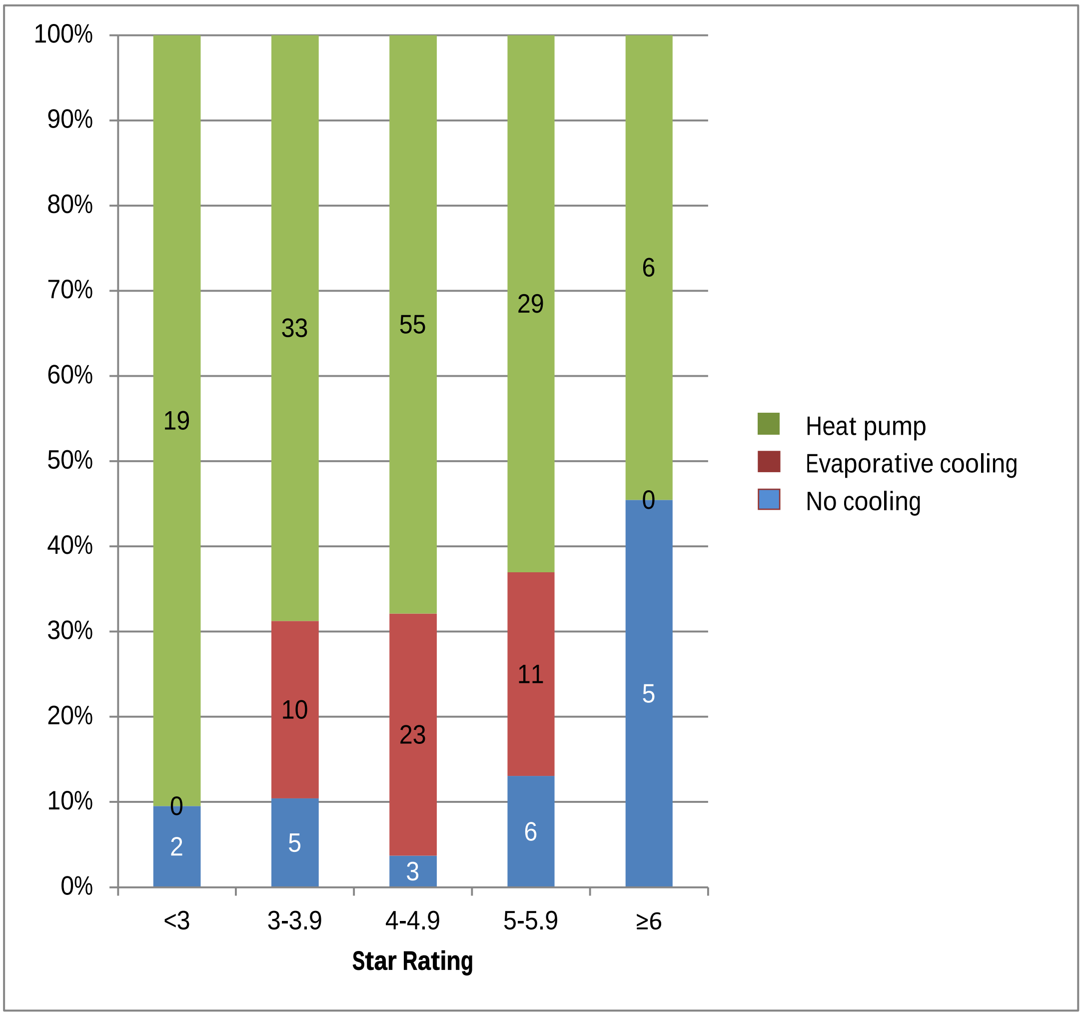


Figure 12-17 Distribution of heat pumps and evaporative cooling across NatHERS star ratings

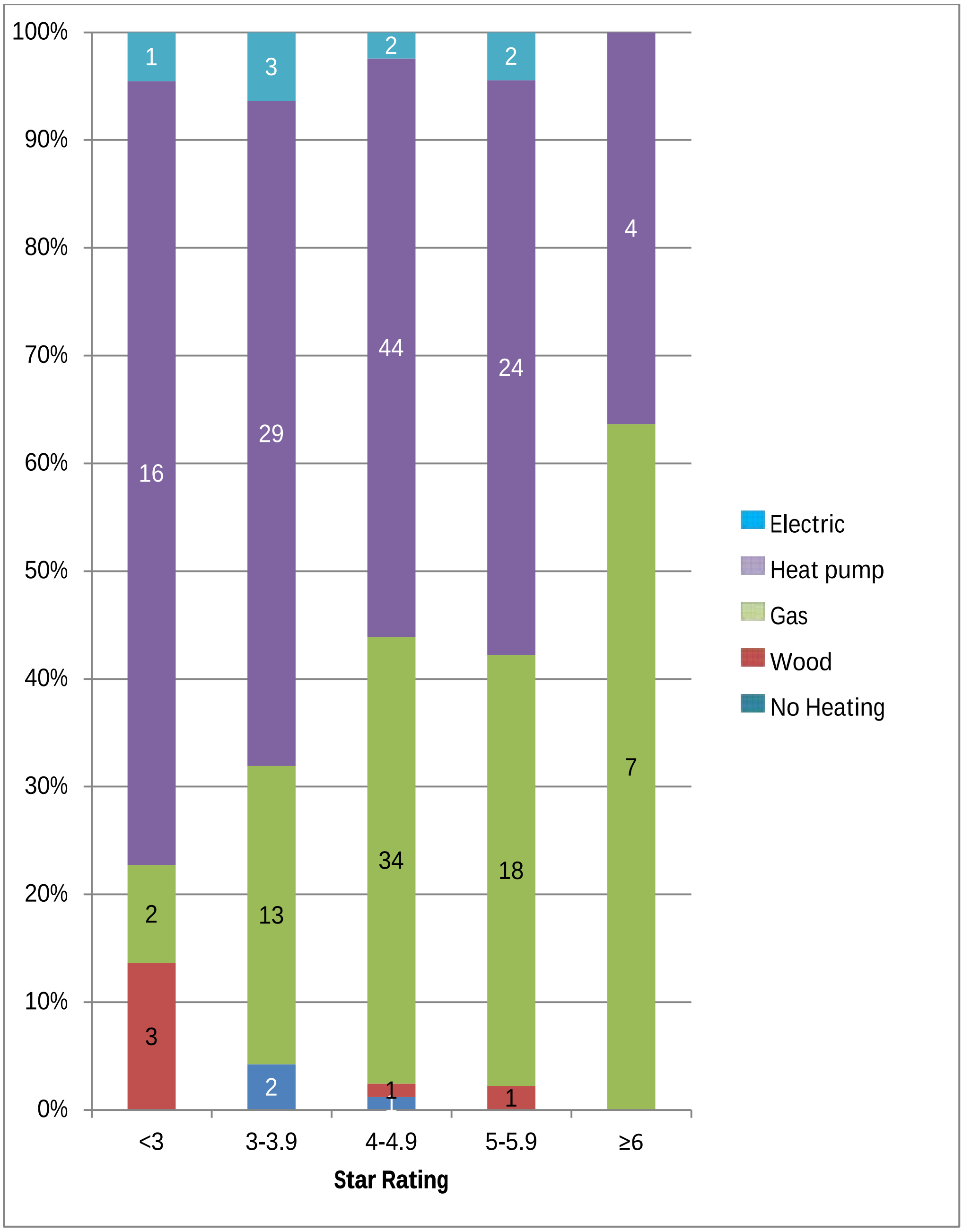
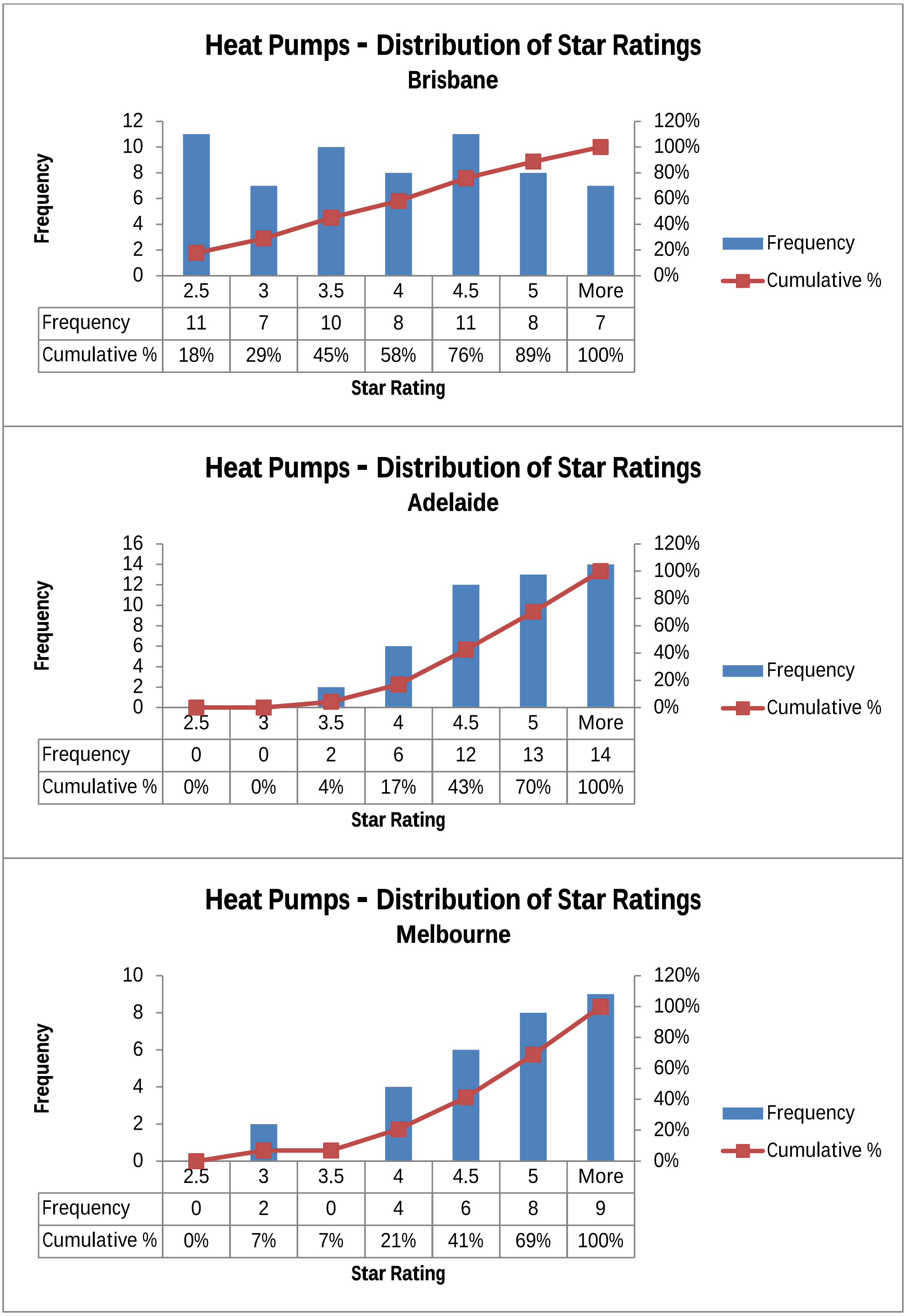


Figure 12-18 **Distribution of heating types across NatHERS star ratings**

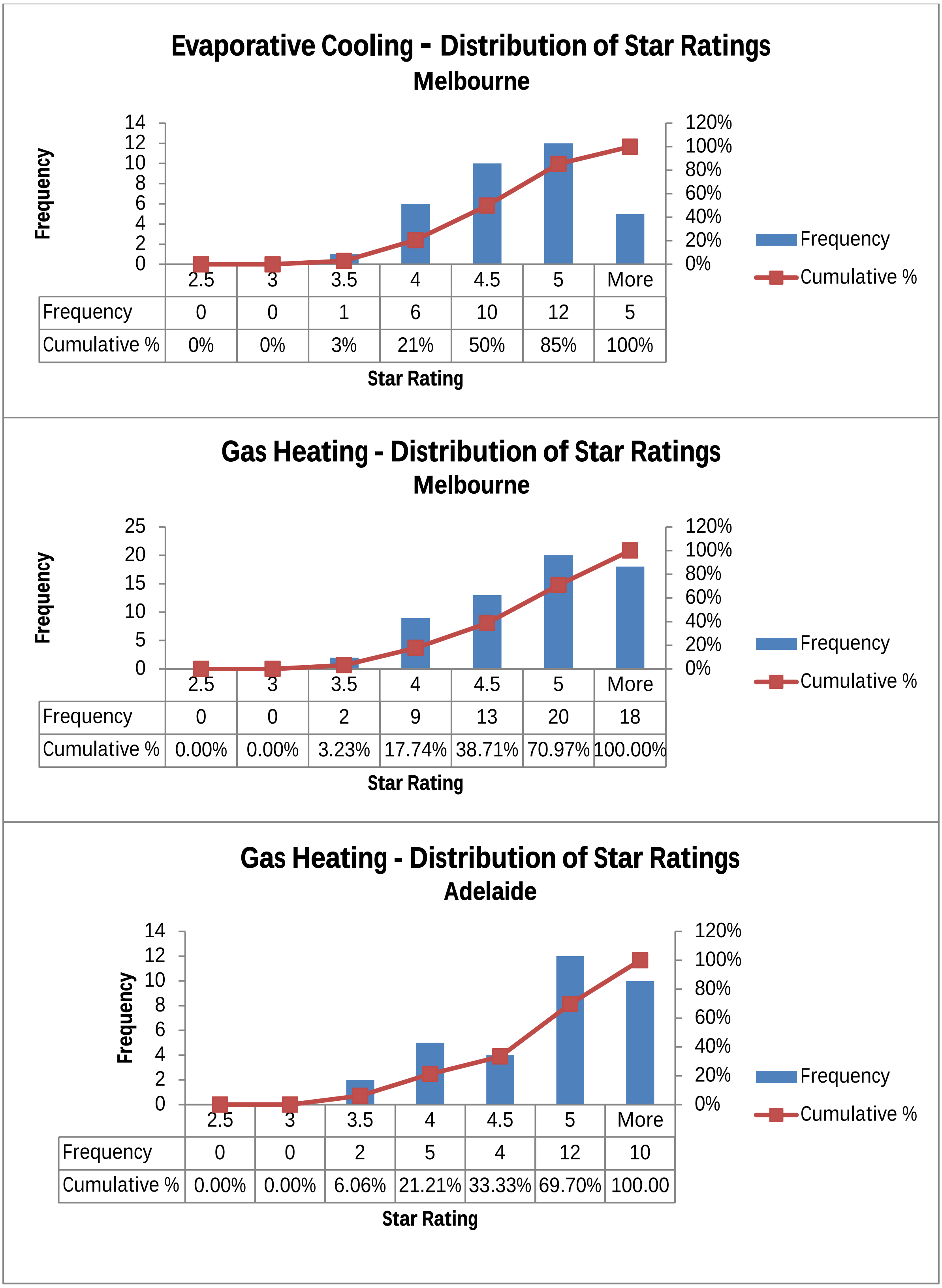


	2.5	3	3.5	4	4.5	5	More
Frequency	11	7	10	8	11	8	7
Cumulative %	18%	29%	45%	58%	76%	89%	100%

	2.5	3	3.5	4	4.5	5	More
Frequency	0	0	2	6	12	13	14
Cumulative %	0%	0%	4%	17%	43%	70%	100%

	2.5	3	3.5	4	4.5	5	More
Frequency	0	2	0	4	6	8	9
Cumulative %	0%	7%	7%	21%	41%	69%	100%

Figure 12-19 **Sample shift to higher star ratings in houses with heat pumps**



	2.5	3	3.5	4	4.5	5	More
Frequency	0	0	1	6	10	12	5
Cumulative %	0%	0%	3%	21%	50%	85%	100%

	2.5	3	3.5	4	4.5	5	More
Frequency	0	0	2	9	13	20	18
Cumulative %	0.00%	0.00%	3.23%	17.74%	38.71%	70.97%	100.00%

	2.5	3	3.5	4	4.5	5	More
Frequency	0	0	2	5	4	12	10
Cumulative %	0.00%	0.00%	6.06%	21.21%	33.33%	69.70%	100.00

Figure 12-20 **Sample shift to higher star ratings in houses with gas heating**

12.3.2 DEPENDENCE OF RATED POWER AND COEFFICIENT OF PERFORMANCE ON CLIMATE AND STAR RATING

HVAC appliances were a key part of the assessment of the impact of NatHERS on house heating and cooling energy consumption. However, they do not contribute to the NatHERS rating. Consequently, any energy consumption dependence between star rating and HVAC appliance might be evidence of bias in the assessment.

It was also of interest to see if there was a reduction in the rated power of the installed HVAC appliances associated with NatHERS energy rating, because of a calculated reduction in the need for energy at design conditions. This would not necessarily be correlated with energy consumption, and would itself be a useful outcome.

To assess these two issues, we inspected the HVAC appliances for each house in the study and obtained values of rated power where possible from their energy rating plates. Otherwise, we obtained details of the appliance from specifications in the appliance operating manual or from the Equipment Energy Efficiency (E3) Program's website www.energyrating.gov.au, which provided nominal COP values for most of the appliances.

Figure 12-21 and Figure 12-22 show that heat pumps in Adelaide had a slightly greater power rating than in Brisbane or Melbourne, and that the COPs of heat pumps were constant across all cities.

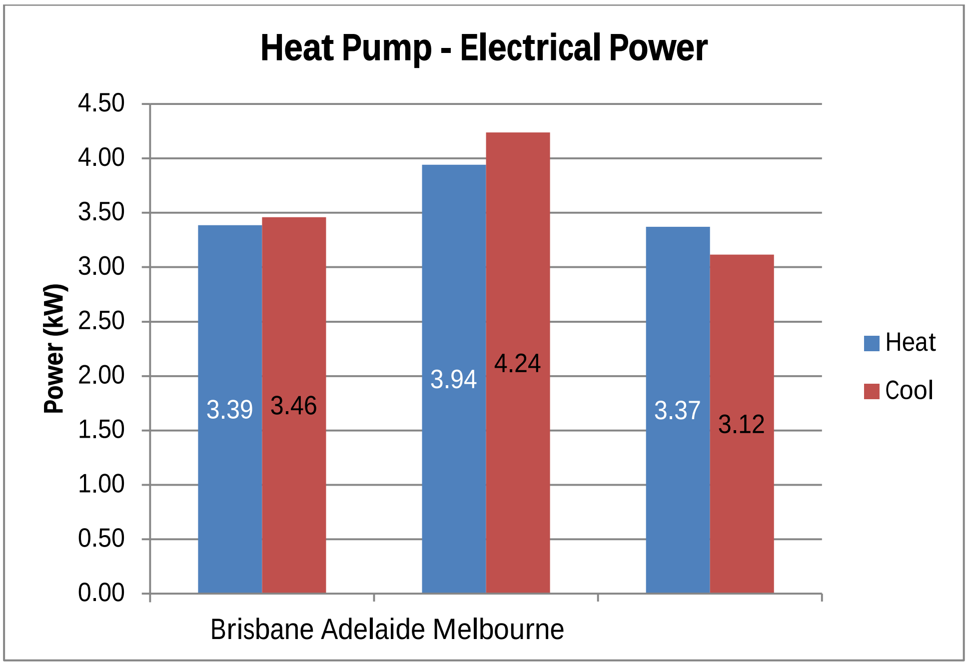


Figure 12-21 **Average heat pump power across cities**

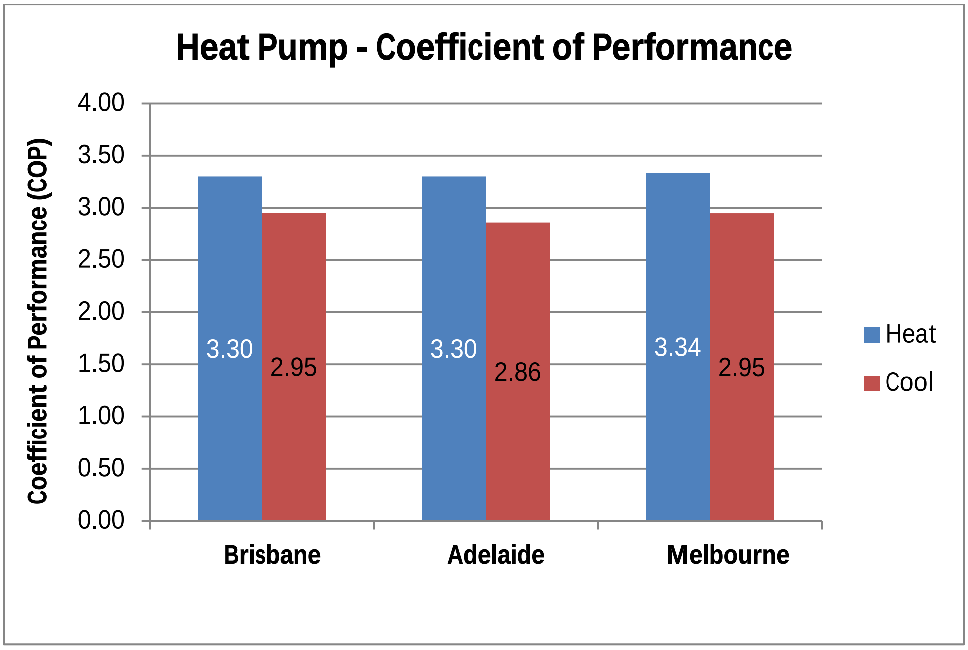
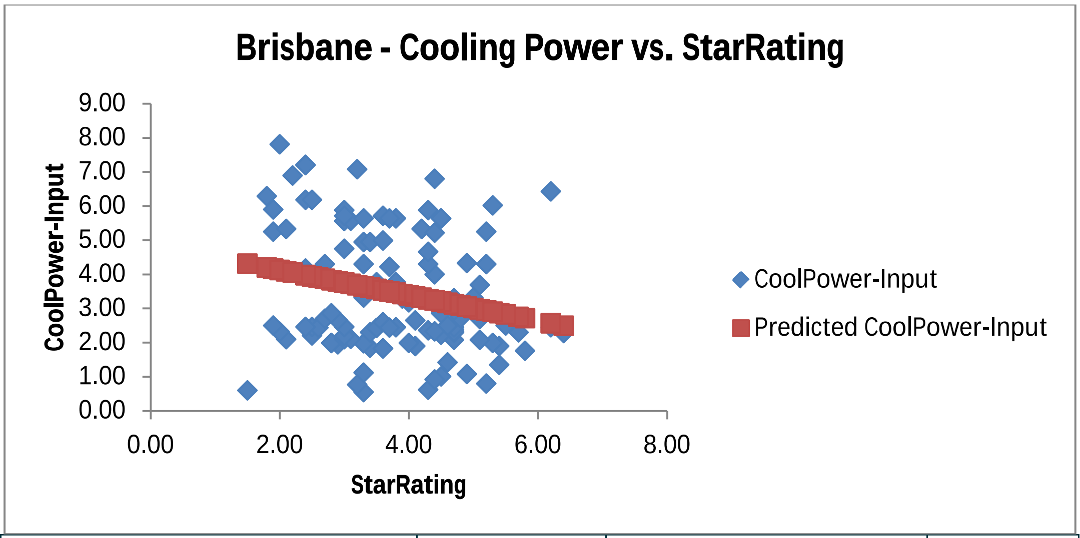


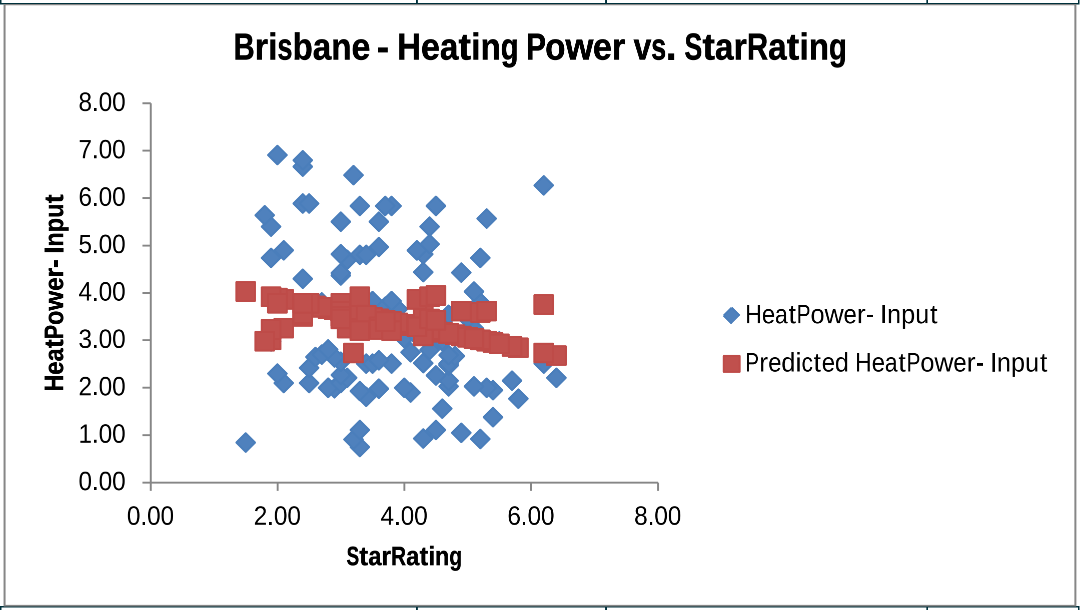
Figure 12-22 **Average heat pump coefficient of performance across cities**

Dependence of power rating on star rating

The assessment of the NatHERS star-rating impact on energy consumption also examined whether the star rating had resulted in house owners purchasing lower-powered air conditioners. Values of rated power were obtained, where possible, from the energy rating plates on heat pumps installed at each house. Otherwise, details of the heat pump were obtained from specifications in the appliance operating manual or from the E3's Energy Rating website. No dependence of rated power on star rating was found for Adelaide or Melbourne, but a significant reduction was found for Brisbane of 0.37 kW per star at a significance level of better than 95%. The results are shown in Figure 12-23.



Cooling Power vs. Star Rating	Coefficients	95% Confidence Interval	P-value
Star Rating	-0.371	±0.30	0.0149

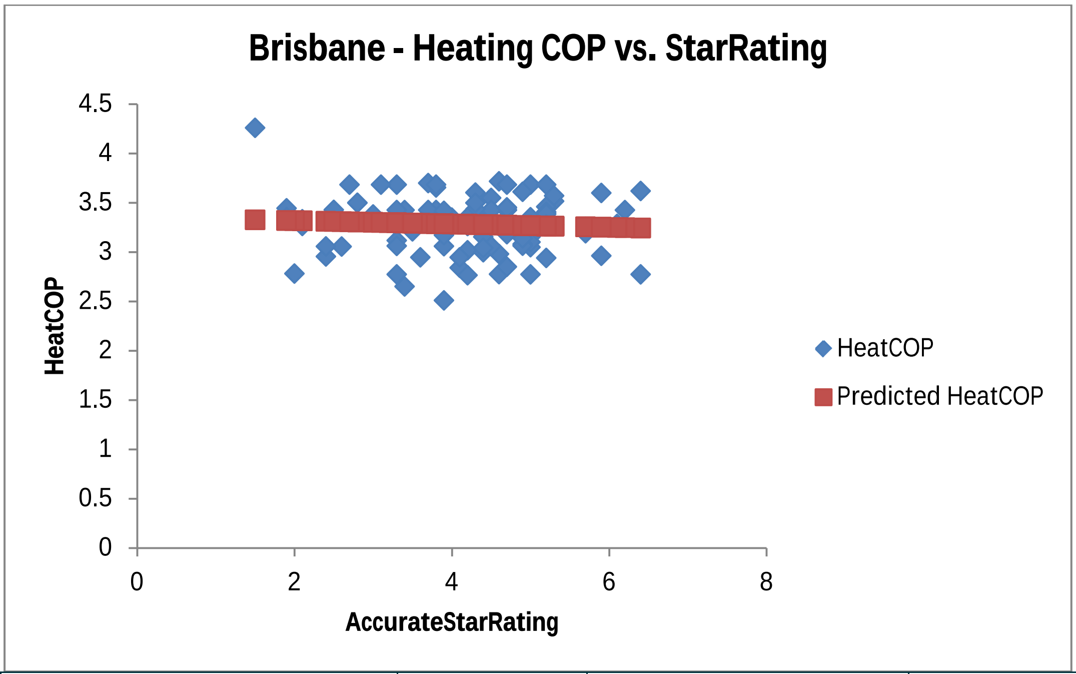


Heating Power vs. Star Rating	Coefficients	95% Confidence Interval	P-value
Star Rating	-0.276	±0.27	0.043

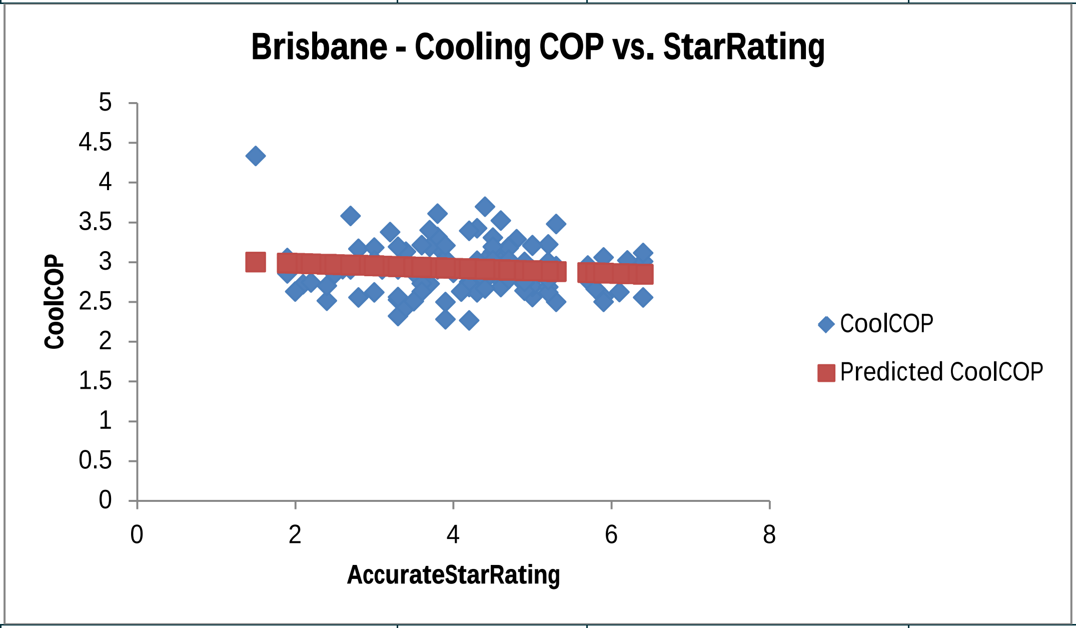
Figure 12-23 **Heat pump heating and cooling power dependence on star rating – Brisbane**

Dependence of coefficient of performance on city and star rating

A concern relating to the assessment of star rating impact on energy consumption was that heat pump COPs might be correlated with star rating, thus introducing a bias into the assessment. This could be as a result of progressively increasing air conditioner Minimum Energy Performance Standards, increased availability of higher efficiency models, and/or increased consumer concern for the environment. We tested this possibility using a regression fit, and found no dependence of COP on star rating (Figure 12-24).



Heating COP vs. Star Rating	Coefficients	95% Confidence Interval	P-value
Star Rating	-0.017	±0.056	0.54



Cooling COP vs. Star Rating	Coefficients	95% Confidence Interval	P-value
Star Rating	-0.031	±0.056	0.26

Figure 12-24 Heat pump coefficients of performance (COP) dependence on star rating – Brisbane

12.4 NatHERS star rating and daily variations in electricity consumption

We performed two assessments of the impact of NatHERS star rating on heating and cooling energy consumption. The first compared average values of energy consumption below and above the BCA star rating regulatory change. This produced results with unsatisfactory statistical significance, and has been reported in Section 9. The second assessment used statistical correlations of energy consumption with star rating over each of the summer and winter periods. This produced the most significant results, and has been reported in Section 10.

A third assessment investigated air conditioner usage over a set of three daily time intervals. We first describe measurements of daily variation in temperature and energy consumption, and then report whether a reduction in energy consumption can be observed during three daily two-hour periods (06:30–08:30, 15:00–17:00 and 19:00–21:00) for summer and winter. These results are reported in Section 12.4.2 and aim to improve the sensitivity of the assessment of the impact of star rating on HVAC energy consumption. The data also provides support for the regression model analysis in Section 10 and the potential for further energy savings by better understanding the interaction of ambient temperature changes with house thermal mass, insulation and ventilation.

12.4.1 DAILY VARIATIONS OF HEATING AND COOLING ENERGY CONSUMPTION

Figure 12-25 to Figure 12-27 show how the average electricity consumption varied throughout the day in each city, along with the temperature difference between the house interior and exterior. The figures also indicate the peak demand periods in the day in which it is important to assess the impact of star rating on energy consumption.

In Brisbane, peak demand is in summer between 13:00 and 15:00, which correlates with high outdoor temperatures (Figure 12-25). This peak does not match the timeslots in the previous analysis (Section 12.2). Winter peak demand, which occurs early in the morning, is much lower than the summer peak demand and is not sufficient to warrant further investigation.

In Adelaide and Melbourne (Figure 12-26 and Figure 12-27), peak demand in summer and winter are comparable in magnitude. The summer peak occurs in the 15:00–17:00 period, and the winter peak occurs between 19:00 and 21:00, with a smaller peak in the morning. These peaks are consistent with the analysis in Section 12.2.

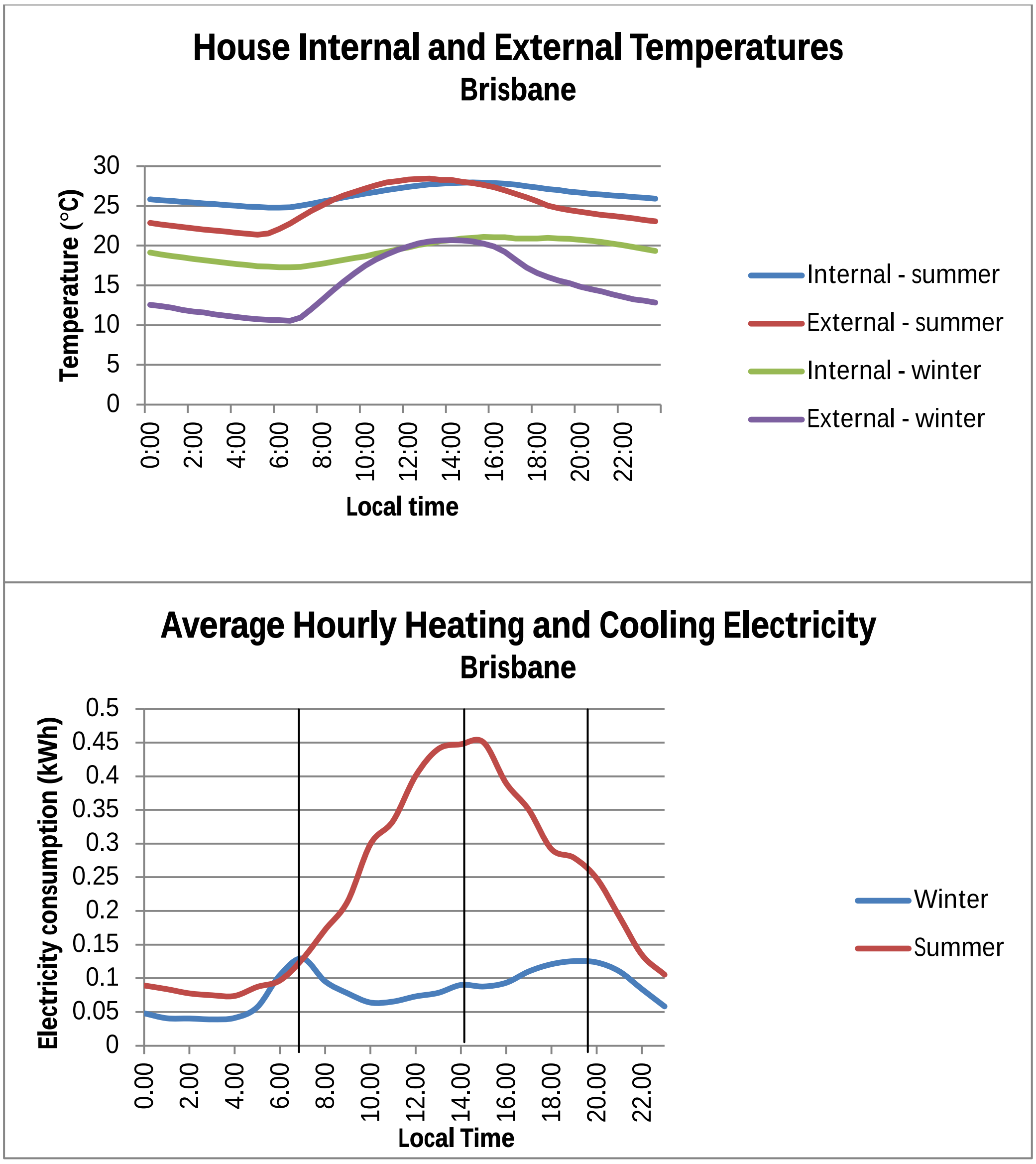


Figure 12-25 House temperatures and heating and cooling electricity consumption – Brisbane

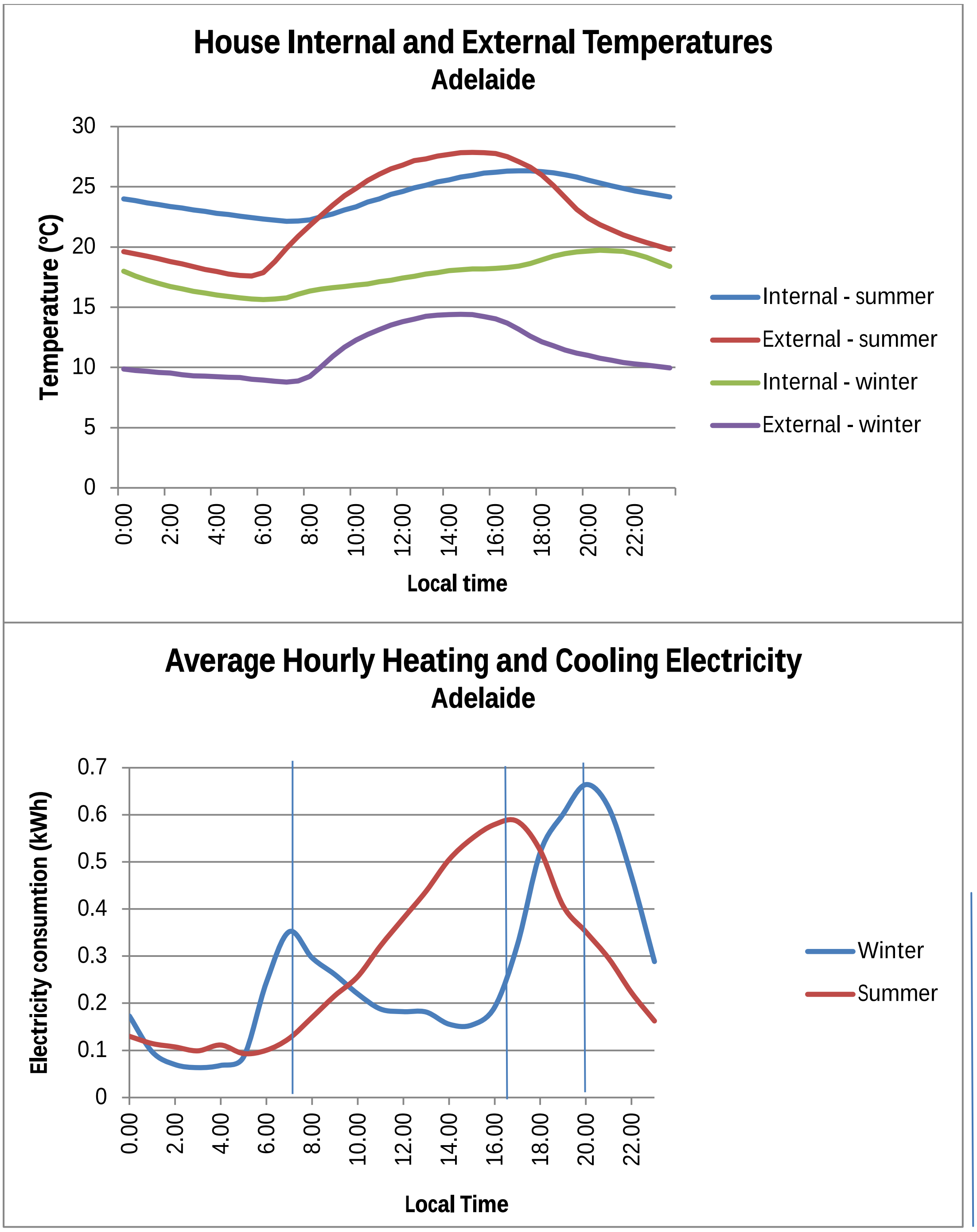


Figure 12-26 House temperatures and heating and cooling electricity consumption – Adelaide

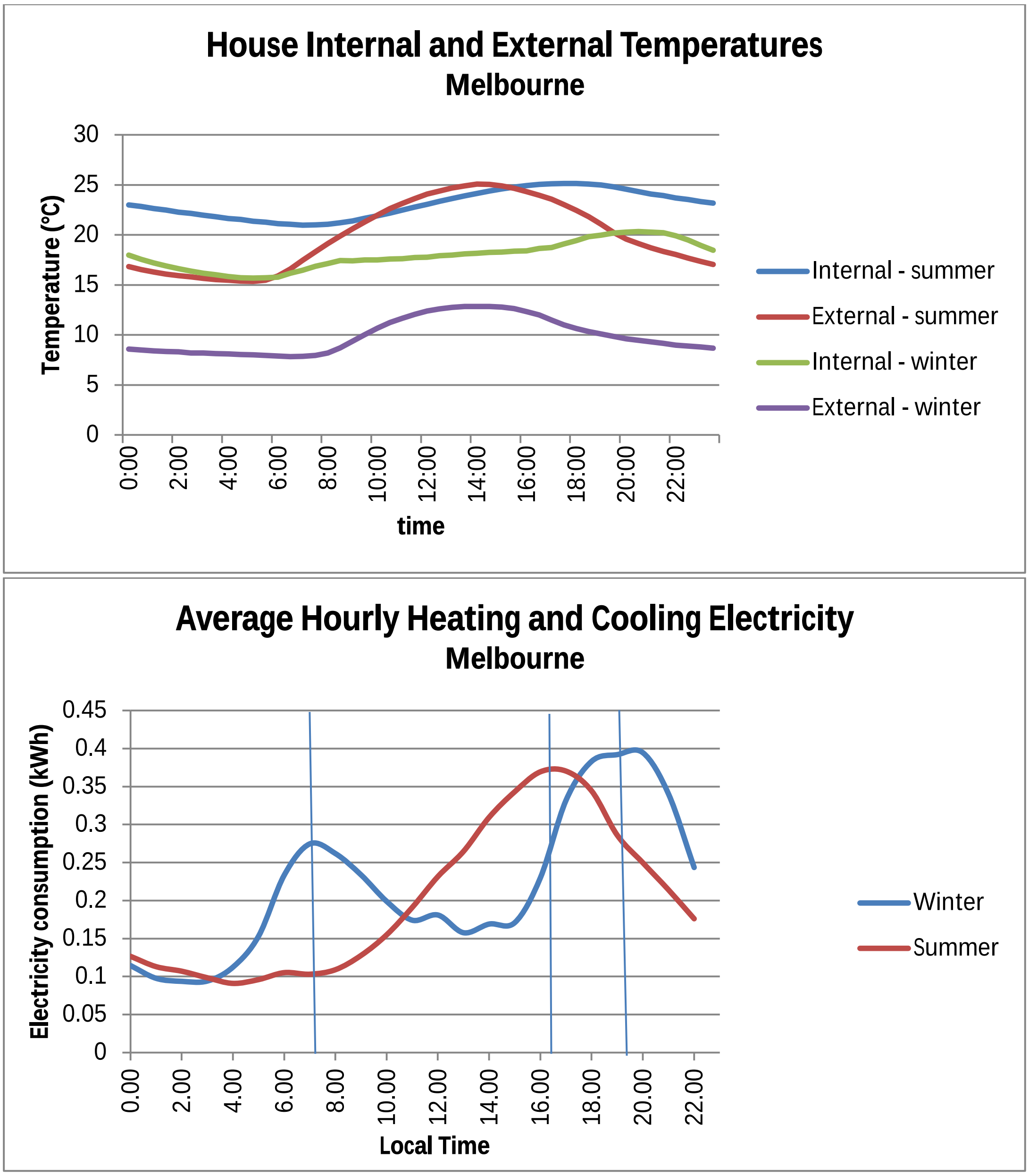


Figure 12-27 House temperatures and heating and cooling electricity consumption – Melbourne

In summer, the daily usage cycle remained substantially unchanged across all cities. In each city, consumption started at a relatively low value in the morning, rose to a peak in the afternoon, and in the evening dropped to a value between the morning and afternoon values. This tracked the BoM weather station temperatures. The afternoon peak in consumption for Brisbane is much earlier than anticipated in the original methodology.

In winter, two substantial peaks were observed at 7:00 am and approximately 8:00 pm in both Melbourne and Adelaide. The heating energy consumption was very low, with a short period of consumption at 7:00 am and a slow rise in consumption from 2:00 pm, peaking at 8:00 pm and falling at 10:00 pm.

Figure 12-28 provides more detail on energy consumption during the originally specified midday peak period for summer, and the morning and evening peaks for winter.

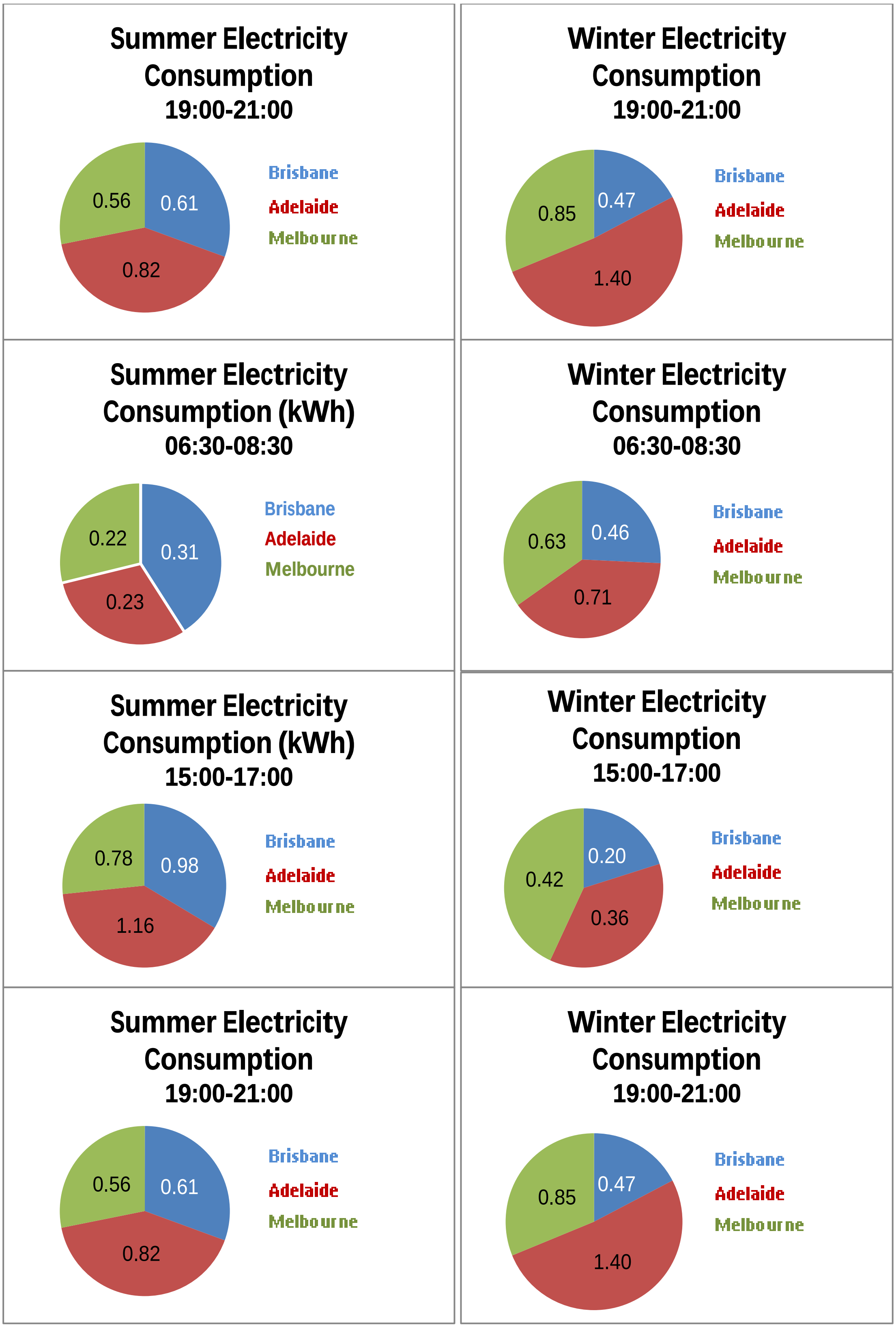


Figure 12-28 **Electricity consumption across cities for daily periods of high usage**

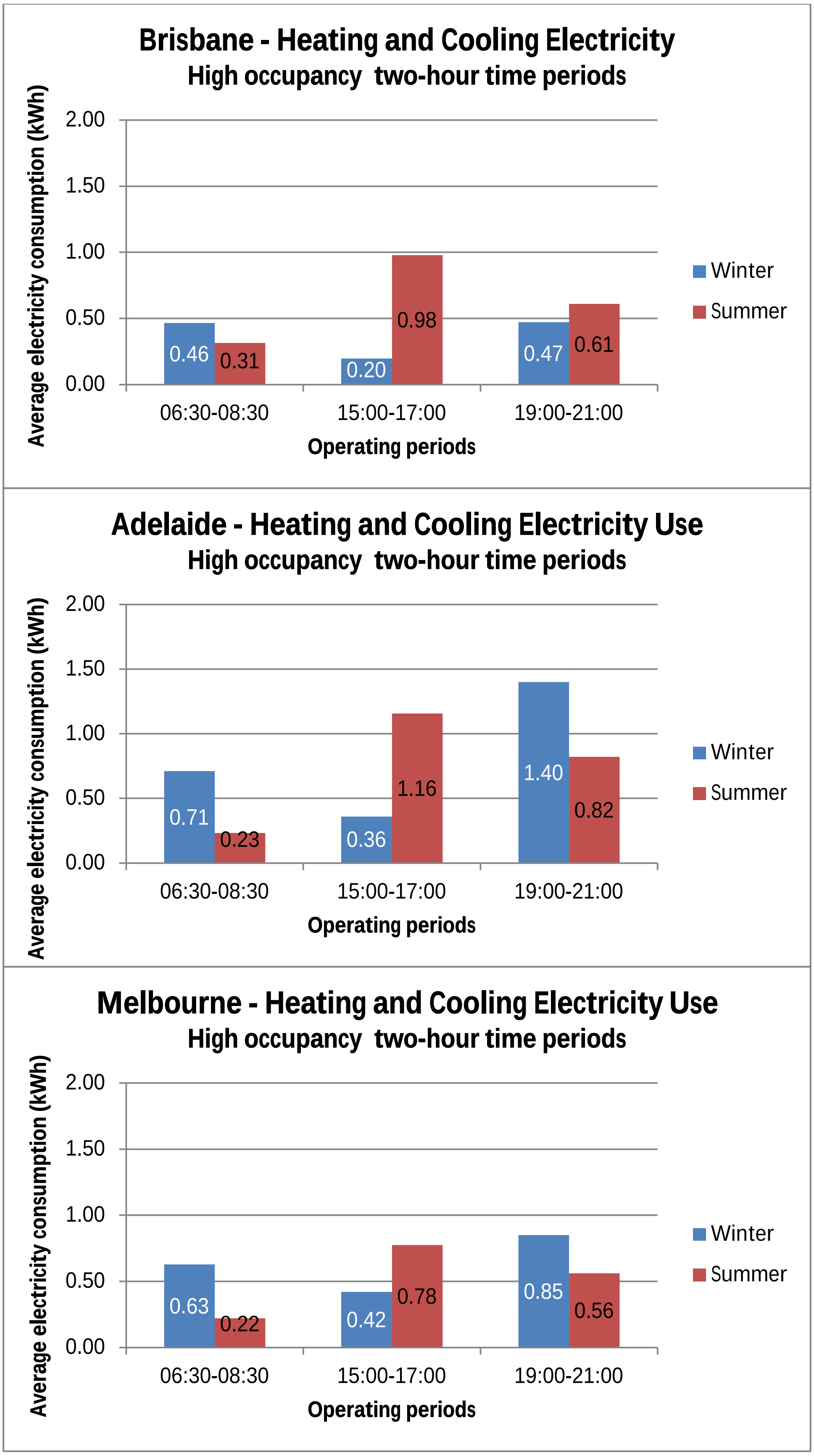


Figure 12-29 **Winter and summer electricity consumption for daily periods of high usage**

12.4.2 STATISTICAL ASSESSMENT OF ENERGY SAVING DURING HIGH USAGE PERIODS

The assessment tested whether a reduction in heating and cooling energy use could be observed during three high-energy-use intervals of two hours for each day as a result of star rating. Measurements of heat pump and evaporative cooling electricity use were compared with a simple model for energy consumption in a multiple regression analysis. The method is described in Section 10. The results of these assessments are given in Table 12-2 for the impact of star rating on energy consumption and Note*: The energy coefficients were derived from a multiple regression of energy consumed as the dependent variable vs. two explanatory variables: i) The difference between the temperature of the external environment (BoM weather station) and the internal house temperature (ΔT) and ii) the NatHERS rating (star).*

Table 12-3 for the dependence of the temperature difference on star rating.

In Table 12-2, four results were obtained for energy dependence on star rating, with p-values £5%. Four additional results with p-values £10% supported the results obtained with p-values of <5%.

Winter – house heating energy savings in higher-rated houses

In Brisbane, for the 92-day winter season, savings were observed of:

- 0.13 kWh m^{-2} between 19:00 and 21:00 at $p<0.05$.

In Adelaide, for the 92-day winter season, savings were observed of:

- 0.14 kWh m^{-2} between 15:00 and 17:00 at $p=0.1$
- 0.48 kWh m^{-2} between 19:00 and 21:00 at $p<0.05$.

No measurements were available for Melbourne, where gas heating predominated.

Summer – house cooling energy increases in higher-rated houses

In Brisbane, for the 90-day summer season, increases were observed of:

- 0.08 kWh m^{-2} between 06:30 and 08:30 at $p<0.05$
- 0.15 kWh m^{-2} between 15:00 and 17:00 at $p<0.1$
- 0.08 kWh m^{-2} between 19:00 and 21:00 at $p=0.1$.

In Melbourne, for the 90-day summer season, increases were observed of:

- 0.08 kWh m^{-2} between 06:30 and 08:30 at $p<0.1$
- 0.12 kWh m^{-2} between 15:00 and 17:00 at $p<0.1$
- 0.15 kWh m^{-2} between 19:00 and 21:00 at $p<0.05$.

The temperature difference between the house interior and the nearest BoM station

In Note*: The energy coefficients were derived from a multiple regression of energy consumed as the dependent variable vs. two explanatory variables: i) The difference between the temperature of the external environment (BoM weather station) and the internal house temperature (ΔT) and ii) the NatHERS rating (star).*

Table 12-3, four results were obtained for the temperature difference dependence on star rating, with p-values £5%. Two additional results with p-values £10% supported the results obtained with p-values <5%. In summer, there was no significant difference in temperature in lower and higher-rated houses. A temperature difference of 0.18 °C at $p<0.05$ in Brisbane at 06:30–08:30 was too low to be considered. In winter in Brisbane and Adelaide, the temperature difference values were significantly increased in the higher-rated houses.

> In Brisbane, for the 92-day winter season, increases in temperature difference in higher-rated houses were observed of:
>
> - 0.67 °C between 06:30 and 08:30 at $p<0.05$
> - 0.52 °C between 19:00 and 21:00 at $p<0.05$.
>
> In Adelaide, for the 92-day winter season, increases in temperature difference in higher-rated houses were observed of:
>
> - 0.61 °C between 06:30 and 08:30 at $p=0.1$
> - 0.95 °C between 15:00 and 17:00 at $p<0.05$
> - 1.05 °C between 19:00 and 21:00 at $p<0.05$.
>
> Temperature measurements are not assessed here for Melbourne, because heating energy data were only available from gas bills.

Compared with lower-rated houses, higher-rated houses in Brisbane and Adelaide tended to use less heating energy in winter, and in Brisbane and Melbourne they tended to use more cooling energy in summer. While Melbourne higher-rated houses did show a significant increase in electricity use, it is uncertain whether this is due to cooling energy alone, because evaporative cooling circuits can sometimes also support non-cooling appliances.

Table 12-2 Energy consumed during high usage periods vs. star rating

Energy consumed during daily two hour periods vs. star rating (kWh m^{-2})						
	Winter			Summer		
	06:30–08:30	15:00–1700	19:00–21:00	06:30–08:30	15:00–1700	19:00–21:00
Brisbane – heat pump						
Energy coefficient (kWh d^{-1} m^{-2} star^{-1})	0.0012	–0.000078	–0.0011	0.00069	0.0013	0.00070
95% confidence interval	± 0.0016	± 0.00037	± 0.0010	± 0.00057	± 0.0014	± 0.00086
p-value	0.14	0.68	0.02	0.018	0.076	0.1
Adelaide – heat pump						
Energy coefficient (kWh d^{-1} m^{-2} star^{-1})	–0.0013	–0.0012	–0.0042	–0.00005	0.00042	–0.00068
95% confidence interval	± 0.0025	± 0.0014	± 0.004	± 0.0017	± 0.0046	± 0.0034
p-value	0.29	0.1	0.04	0.95	0.86	0.69
Melbourne – evaporative						
Energy coefficient (kWh d^{-1} m^{-2} star^{-1})				0.00072	0.0010	0.0013
95% confidence interval				±0.00074	±0.0012	±0.0010
p-value				0.054	0.094	0.014

Note: The energy coefficients were derived from a multiple regression of energy consumed as the dependent variable vs. two explanatory variables: i) The difference between the temperature of the external environment (BoM weather station) and the internal house temperature (ΔT) and ii) the NatHERS rating (star).

Table 12-3 Temperature difference during high usage periods vs. star rating

Temperature difference (ΔT) vs. star rating						
	Winter			**Summer**		
	06:30–08:30	**15:00–1700**	**19:00–21:00**	**06:30–08:30**	**15:00–1700**	**19:00–21:00**
Brisbane – heat pump						
ΔT per NatHERS rating star (°C star^{-1})	0.67	0.075	0.52	0.18	–0.17	0.04
95% confidence interval	±0.36	±0.33	±0.3	±0.20	±0.33	±0.28
p-value	0.00062	0.66	0.0068	0.077	0.30	0.76
Adelaide – heat pump						
ΔT per NatHERS rating star (°C star^{-1})	0.61	0.95	1.05	–0.12	–0.20	0.36
95% confidence interval	±0.75	±0.7	±0.94	±0.44	±0.59	±0.60
p-value	0.1	0.0094	0.030	0.57	0.14	0.24
Melbourne – evaporative						
ΔT per NatHERS rating star (°C star^{-1})				0.18	0.13	–0.018
95% confidence interval				0.6	0.62	0.594
p-value				0.53	0.68	0.95

The temperature difference (ΔT) dependence on star rating was tested using a multiple regression of ΔT as the dependent variable vs. two explanatory variables: i) the heating or cooling energy consumption (kWh d^{-1} m^{-2}) and ii) the NatHERS rating (star).

12.4.3 SUMMARY OF THE ASSESSMENT FINDINGS

Assessment of the impact of star rating on HVAC electricity consumption

In winter in each city, higher-rated houses saved energy. However, some of this energy was then lost by raising the temperature of the higher-rated houses. If temperature differences had been kept the same in houses of all star ratings, then the higher-rated houses would have used even less energy. We refer to this additional energy saving as ‘inferred energy’ in our results**.** Estimates for energy saved and temperature rise were given in Section 10. The dependence of energy consumption on star rating was also observed for specific time intervals during the day:

- In winter in Brisbane and Adelaide, the electricity used for heating was reduced and the temperature increased by 0.5 °C to 1 °C.
- Measurements were not available for specific time periods in winter in Melbourne, where gas was the predominant heating mode and gas billing data was used.
- In summer in Brisbane, heat pump electricity consumption was greater in higher-rated houses for all three periods of the day.
- In summer in Melbourne, evaporative cooling electricity consumption rose in higher-rated houses during the morning and evening periods, but not during the middle of the day. The lack of statistical significance at midday may have been due to the cooling appliances operating at full capacity. The results may also have been susceptible to interference from other appliances on the same circuit as the evaporative cooler.

Summer temperatures and energy consumption

In summer, house temperature differences for Brisbane, Adelaide and Melbourne were lower than in winter, although the supply of thermal energy in summer was similar to or greater than that supplied in winter. One likely explanation for this is the substantial additional sources of heat in these houses, which may well be the heat contributed from electrical consumption by appliances such as ovens. It would also be worth investigating other factors, such as ventilation (e.g. open windows) that might render air conditioning less effective.

HVAC usage

While most air conditioners operated at full power, their usage time was typically between 25 and 50%. If air conditioners were used on average for half the days of summer, then many houses with heat pumps in Brisbane and Adelaide would have been operating near 100% duty cycle (i.e. near the limit of their capacity).

HVAC selection and star rating

- The coefficient of performance for heat pumps was constant across all cities and did not depend on star rating.
- Heat pumps in Adelaide had a slightly greater power rating than in Brisbane or Melbourne.
- There was no reduction in heat pump power rating associated with the NatHERS star rating in Adelaide and Melbourne. However, there was a significant reduction in Brisbane of 0.37 kW per star.

13 Bibliography

Australian Building Codes Board. (2006). *Proposal to Amend the Building Code of Australia to increase the Energy Efficiency Requirements for Houses.* Canberra: Australian Government.

Australian Bureau of Statistics. (2013). *8731.0 - Building approvals, Australia.* Canberra: Australian Bureau of Statistics.

Centre for International Economics. (2009). *Final Regulation Impact Statement for residential buildings (class 1, 2, 4 and 10 buildings).* Canberra: Australian Building Codes Board.

Centre for International Economics. (2012). *Gas demand forecasting SP AusNet, 2013-17.* Canberra: Centre for International Economics.

Department of Climate Change and Energy Efficiency. (2012). *Australian National Greenhouse Accounts.* Canberra: Department of Climate Change and Energy Efficiency.

Energy Efficient Strategies. (October 2006). *Standby Power - Current Status.* Equipment Energy Efficiency Committee (Dep't of Industry).

Higgins, A. (2011). *Statistics for a NSW study of house total energy consumption (personal communication A. Higgins, CSIRO).*

Rawlinsons. (2011). *Construction Cost Guide 2011.* Perth: Rawlinsons Publishing.

Reardon, C., Milne, G., McGee, C., & Downton, P. (2008). *Your Home - Design for lifestyle and the future.* Canberra: Department of the Environment, Water, Heritage and the Arts.

Part 4 - Appendices

Appendix A – Methodology

CHANGES TO THE ORIGINAL METHODOLOGY

The methodology that follows is a modification of the original methodology agreed upon prior to the commencement of this study. The need for significant modification arose when reasonable assumptions made prior to the study were invalidated as the study proceeded. These were:

i) A change from the original proposal to recruit climate zone 5 volunteers from NSW
ii) The unavailability of registers or substantial numbers of records for energy-rated houses in Adelaide, Brisbane and Melbourne
iii) House plan acquisitions took typically from one month to a year, requiring that measurements be commenced before plans were acquired
iv) The non-Gaussian distribution of energy consumption in the sample population, which instead followed an exponential distribution.

The changes principally affected the type of volunteer households that were recruited for the study and the method of analysis as follows:

i) The even distribution of star ratings across the volunteer sample had to be achieved without advance knowledge of the star rating, so year of construction was used as a surrogate. This resulted in an upward shift of half a star in the range of houses being tested in Adelaide and Melbourne, as many houses exceeded the regulatory rating requirements.
ii) Volunteers could not be recruited as matched pairs for star rating against different house types, or heating and cooling equipment, because it was not possible to determine star ratings before the study commenced. We therefore used a screening questionnaire to recruit volunteers, as far as possible, from a single house type and with a balanced proportion of HVAC types appropriate to each climate zone.

Given the non-uniform distribution of star ratings, the exponential or skewed distribution of energy consumptions and the number of variables that could no longer be organised as matched pairs, we decided not to carry out a direct statistical test for differences between populations of lower and higher-rated houses. We hypothesised instead a simple model that energy consumption would be linearly proportional to star rating, and used multiple regression to determine the goodness of fit to our data.

THE MODIFIED METHODOLOGY

The Department of Climate Change and Energy Efficiency (DCCEE) asked the Commonwealth Scientific, Industrial and Research Organisation (CSIRO) to ascertain the actual benefits and costs resulting from the introduction of the 5 Star Energy Efficiency Standard for Housing from 2006 in the Building Code of Australia (BCA). In particular, this addresses the two research questions:

1. “How effective has the standard been in reducing actual (not simulated) conditioning energy use (heating and cooling) relative to houses constructed to earlier energy efficiency standards, specified as between 3.5–4 stars in the 2003–2005 releases of the BCA”?
2. “What are the actual benefits and associated costs of the 5-star standard relative to the 3.5–4-star standard in terms of: construction costs, avoidable energy costs, heating and cooling appliance costs and total lifetime cost”?

The aim of this evaluation of building energy efficiency standards was to collect and analyse data to determine the past and likely future impact of changes to building energy efficiency requirements. This was to provide an evidence base for future building energy efficiency policy. The evaluation also responded to the Productivity Commission's inquiry into the Private Cost Effectiveness of Improving Energy Efficiency (report 36, recommendation 10.1) and the National Strategy on Energy Efficiency. The evaluation results were aimed at resolving uncertainties in the actual costs and benefits relating to the 5 Star Energy Efficiency Standards for Housing and inform governments, building regulators and industry of the effectiveness of the standards.

A.1 Outline of the task

The program of work investigated the efficacy of the house energy star rating standard in i) reducing energy consumption and consequent greenhouse gas emissions and ii) the cost benefit of this reduction. The approach to resolving these separate, but closely related questions is given below.

A.1.1 RESEARCH QUESTION 1 – ENERGY USE ASSESSMENT

The first research question addressed the impact of energy efficiency standards on heating and cooling energy in residential buildings, and asked:

> “How effective has the standard been in reducing actual (not simulated) conditioning energy use (heating and cooling) relative to houses constructed to earlier energy efficiency standards, specified as between 3.5–4 stars in the 2003–2005 releases of the BCA”?

Research approach

To determine how effective the house energy star rating standard was in reducing i) actual heating and cooling energy and ii) the associated greenhouse gas emissions, it was necessary to confirm the relationship between the NatHERS star rating and building thermal efficiency as determined by the standard, for each house measured. This was done by comparing NatHERS ratings against measurements of energy consumed by heating and cooling appliances in 209 households in Adelaide, Brisbane and Melbourne. A further 205 houses provided supporting information using NatHERS ratings, energy billing data, temperature measurements and surveys. The null hypothesis used in the comparison stated that:

> *“There is no significant improvement in thermal energy efficiency between houses designed and built to a NatHERS energy rating of less than or equal to 4.5 stars and those built to greater than 4.5 stars.”*

The accuracy and precision of this comparison accounted, as far as possible, for the effect on energy consumption of the independent variables that tend not to contribute to the house thermal efficiency, including: climate, seasonal and diurnal variation, householder behaviour, and the nature of the heating and cooling appliances. The resolution of the data was further improved by classifying heating and cooling equipment into types and comparing the energy consumptions of these separate sets against their star ratings. In the process of carrying out these ‘normalisations’, the data analysis aimed to reveal a number of subsidiary relationships, including:

1. Whether 5-star houses require less heating and cooling energy when heating and cooling is operating. This is relevant to the question of HVAC efficiency improvements.
2. Whether 5-star houses require less heating and cooling energy during the predefined common peak heating and cooling periods of 6:30 am to 8:30 am, 3:00 pm to 5:00 pm and 7:00 pm to 9:00 pm. This is relevant to the question of peak loads.
3. Whether 5-star houses require less heating and cooling energy during the heating and cooling seasons. This is relevant to the question of overall house thermal efficiency.
4. The relationships between space heating and cooling equipment capacity and mode of operation. This provides evidence-based characterisation of the relative efficiencies of appliance types, capacities and modes of operation.

Key assumptions relating to heating and cooling energy consumption

Where possible, we tested key assumptions and compensated for them. The assumptions within each group measured were that:

- Time-dependent degradation in equipment heating and cooling efficiency was small and uniformly distributed across star ratings.
- Heating and cooling equipment did not usually run at full capacity for extended periods. We tested this by measuring the average 'in use' power over half-hourly intervals and compared it against rated power. However, it was not clear if this assumption was valid for cooling in the summer season.
- The impact of solar hot water heating on gas consumption was uniform across all star ratings. This was not the case in Melbourne, and we excluded houses with solar hot water from the gas heating group.
- Heating and cooling equipment was in use during winter and summer. We excluded from the study any houses where the heating and cooling energy consumption was zero, but included houses where the controller was switched on, even if the heating and cooling energy was very low.
- Background heating, due to factors other than heating or cooling equipment, house design or the ambient temperature outside the house, was uniformly distributed across star ratings. We compensated for this by including a background energy constant in a multiple regression model and by using the temperature difference between the inside and outside of the house as an independent variable in the model.
- Human behaviour patterns related to heating and cooling were similarly distributed across star ratings.
- Variation in the quality of house construction was uniformly distributed across star ratings.
- In each climate zone, the energy efficiency was assumed to increase approximately linearly over the range of star ratings.

Measurements used to assess energy consumption and carbon intensity

The measurements that were used as the basis for addressing the research questions and subsidiary information described above included:

- Heating and cooling energy

  This was determined by direct measurement of power factor, voltage and electrical current through individual electrical circuits in the house meter box, as well as from historical energy billing data. For gas-fuelled heating, detailed measurement was more difficult, as reliance on gas billing data meant the analysis was restricted to seasonal performance and could not be carried out for shorter intervals. This data is reported as follows:

  a) For each house, the average of heating and cooling energy was measured and calculated while the heating and cooling equipment was operating, during the heating and cooling season, for pre-defined periods of time each day. This provided data on the degree to which heating and cooling appliances were operating near their rated capacity.

  b) For each house, the average of heating and cooling energy was also measured and calculated during the heating and cooling season for the same pre-defined periods of time each day, whether the equipment was operating or not. This provided data on the level of heating and cooling energy required to maintain comfort levels, and this was used to assess the thermal performance of the house.
  c) For each house, the total heating and cooling energy requirement during the whole heating and cooling seasons was measured.

  These measurements were supported by seasonal records from historical and ongoing energy bill meter data.

- Factors reducing average, seasonal and peak energy loads that were evaluated as possible influences included
  d) house thermal efficiency, as evaluated from the rating process and supported by thermal imaging
  e) household occupancy and behavioural characteristics, using survey data and temperature measurements from within the conditioned space as well as from the nearest Bureau of Meteorology station. For example, if significant differences in the indoor thermostat settings (the measured indoor air temperature) were identified among different householders, a proper correction method was designed to account for this occupant behaviour
  f) Relationship between HVAC unit size, mode of operation (inverter) energy consumption and star rating.
- Carbon impact of the standard

  The DCCEE handbook 'National Greenhouse Accounts Factors - July 2011' was used to evaluate the carbon impact of household space heating and cooling energy consumption.

A.1.2 RESEARCH QUESTION 2 – COST EFFECTIVENESS ASSESSMENT

"What are the actual benefits and associated costs of the 5-star standard relative to the 3.5–4-star standard in terms of: construction costs, avoidable energy costs, heating and cooling appliance costs and total lifetime cost"?

Research approach

The costs associated with improvements in energy efficiency were principally taken as the increased capital cost of house construction linked to achieving the standard. In evaluating construction costs and the cost effectiveness of the standard, it was necessary to consider market adjustment vs. predictions. The associated benefits were expected to include:

- Improved comfort for the occupants and the effect of house occupancy and use.

  The temperature difference between the external environment and the conditioned space was considered as a benefit without attempting to analyse whether the householder could manage with less heating or cooling. Such an analysis is possible, but would have required a radically different approach quantifying such considerations as culture, health considerations, perception, and ability to incorporate behavioural change, which were well beyond the scope of this study. The relationship between energy consumed for a given temperature difference as it varies with star rating was used and associated costs evaluated from i) energy billing data and ii) separately for a nominal fixed average tariff.

- Reduced greenhouse gas emissions associated with the level of 'comfort' achieved.
- Reduced energy bills for 5-star houses compared with 3.5-4 star houses – initially it had been hoped to carry out a matched-pair analysis based on occupancy, but the sample numbers were too small and the quantification of occupancy too unreliable to make this practical.
- Household space heating and cooling costs were evaluated from i) energy billing data and ii) separately for a nominal fixed average tariff.

Measurements used in assessing cost benefit and compliance

In evaluating cost benefit, it was considered desirable to identify specific aspects of house construction, their compliance with the house energy rating, their likely impact on improved thermal efficiency and their associated cost effectiveness. In this regard, the house assessment was supplemented by the following physical measurements:

- NatHERS re-rating of houses

  All houses in the study were re-assessed using the same standard protocol and given NatHERS star ratings. The ratings ranged from 2 to 6 stars. Heating and cooling energy consumption was measured by collecting readings of gas consumption from energy bills, and electricity consumption from half-hourly measurement of the electricity consumption for heating and cooling appliances. The temperature inside each house was measured in the principal air-conditioned living area and the external environmental temperature and dewpoint were taken from the nearest Bureau of Meteorology weather station.

  There were no registers for NatHERS star ratings in Adelaide, Brisbane and Melbourne. This was not anticipated and made it impossible to predetermine star ratings. This, together with a tendency for houses to be built to higher star ratings than the regulation required in Adelaide and Melbourne, meant that the range of star ratings for our populations of house samples in Adelaide, Brisbane and Melbourne, was shifted by about half a star to a higher range than planned for the study. We therefore used regression analysis to determine the slope of energy consumption vs. star rating, so that we could better estimate energy consumption for ratings below 4 stars.

- Pressure testing

  This was carried out on a subset of 20 houses in Melbourne – this principally reported on air leakage and by inference thermal leakage and was carried out as part of compliance testing.

- Thermal imaging

  The conditioned space of all houses was imaged, including those relying solely on energy billing data and not fitted with energy monitoring equipment. The results were quantified and de-identified and used to test the influence of thermal leakage.

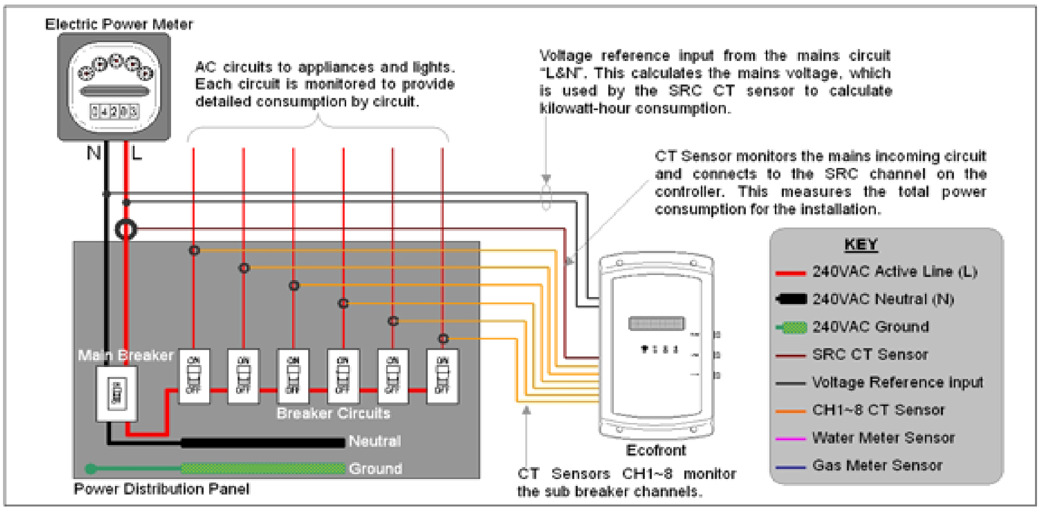
A.2 Implementation

The study was required to recruit a minimum of 400 households across three climate zones in Australia. These houses had their heating/cooling energy monitored for this study from the beginning of June 2012 to the end of February 2013, and monitoring is ongoing to allow follow-up studies. An adult householder representative from each house participated in a socio-demographic and behavioural survey.

A.2.1 ENERGY DATA COLLECTION

Electricity consumption data was collected using direct monitoring of electricity at the switch board of 70 houses in each of the three cities. No monitoring equipment was installed to directly measure gas consumption, so it was inferred from sets of gas bills for each house obtained from the total cohort of 415 houses. Sets of usable gas bills were obtained for 61 Melbourne houses and 33 Adelaide houses.

Electronic monitoring was done using a commercial energy monitoring system developed by Ecopulse Technologies (Figure A - 1). The device was installed by a licensed electrician and has a built in web server tailored for PC, MAC and iPad access. The Ecopulse units required a permanent Internet connection and the system's proprietary "Self DNS" feature allowed it to be accessed over the Internet without the need for a static Internet IP address or third-party Dynamic DNS services. A 3G mobile broadband router was used to allow remote access to the unit.



AC circuits to appliances and lights. Each circuit is monitored to provide detailed consumption by circuit.

Voltage reference input from the mains circuit "L&N". This calculates the mains voltage, which is used by the SRC CT sensor to calculate kilowatt-hour consumption.

CT Sensor monitors the mains incoming circuit and connects to the SRC channel on the controller. This measures the total power consumption for the installation.

CT Sensors CH1~8 monitor the sub breaker channels.

Figure A - 1 **Energy monitoring in a household switchboard (Ecopulse Technologies)**

Electrical measurements

Total electricity consumption, together with heating and cooling electricity consumption, was obtained by measuring the current and voltage for up to eight sub-circuits, and the power factor at the main circuit in the house mains switchboard. Total energy was calculated by summing all non-solar sub circuits. Measurements were taken every half hour for nine consecutive months, including the summer, autumn and winter seasons.

Each circuit was fitted with a current clamp transformer (EcoFront EFCTL10CLS80A-1.2m) with a measurement range rated from 10 mA to 80 A rms and a linearity over this range of less than ±0.1% (Figure A - 2). The analogue current signal was converted to a digital signal using Cirrus Logic CS5467 Watt Hour Meters with a linearity of ±0.1% of reading over a dynamic range of 1000:1. The rated energy measurement accuracy was 2-3% (main channels) and 5% (sub-circuit channels). The instrument met International Electrotechnical Commission, American National Standards Institute, and Japanese Industrial Standards accuracy specifications. If there were more than eight circuits, then where appropriate, they were combined in one current clamp; for example, lighting circuits from the same phase could be combined. Where three-phase circuits were used for air conditioning, a balanced load was assumed and only one phase was measured.

The heating and cooling circuits were identified using three checks: i) noting the switchboard label if available, ii) checking the diurnal and seasonal variation in each sub-circuit, and iii) asking the householder to switch appliances on and off while the data logger output was monitored. If solar power was installed, then no attempt was made to monitor total power at the meter; instead, the total power was determined by summing the individual sub-circuits.

Other factors that impacted accuracy included software reboots and firmware upgrades. For a software reboot, about 5 seconds would be lost. For the two firmware upgrades, up to 30 minutes of data could be lost. A system might experience two or three software reboots in a month due to telecommunications or power failures. Two firmware reboots were carried out on each unit throughout the nine-month monitoring period.

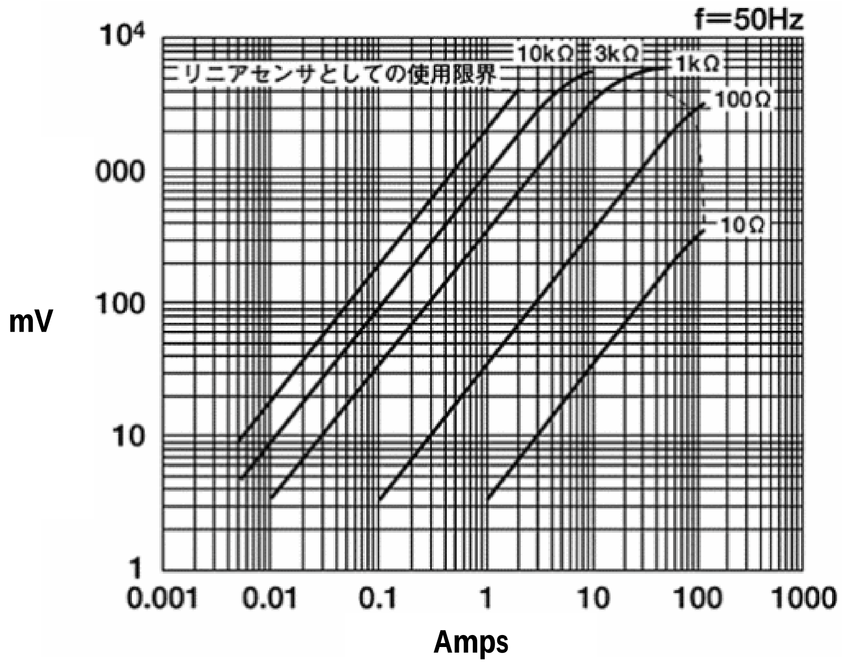


Figure A - 2 Dynamic range and linearity of Ecopulse data logger

Temperature measurements

Temperature measurements were measured and collected in each house using two Thermochron button cell data loggers (Figure 1-4). These were installed in the main living area positioned in a reasonably well-ventilated area, on a wall high enough to be out of reach of young children and pets, and away from any direct source of cooling or heating.

The two Thermochron temperature sensor/data loggers were supplied to volunteer householders, who were instructed in their installation. The installation was subsequently checked by personnel carrying out the house assessment. Sensor data loggers were changed over every 80 days by sending a package containing two replacement units and a colour-coded, stamped addressed envelope for return of the old units. A payment of $100 was made to the householder at the end of the study for looking after the temperature sensor/data loggers.

Measurements were taken at 60-minute intervals with the two cells synchronised and phase-separated by 30 minutes. This gave an average temperature measurement of the conditioned space at 30-minute intervals as well as providing data security. Each cell measured temperature from –30 °C to +70 °C, with a temperature measurement accuracy of +/- 1 °C, a resolution of 0.5 °C and a clock accuracy of ±2 minutes per month from 0 to 45 °C. The memory could store 2050 temperature records.

Data communication

Data was gathered at the Ecopulse unit and then communicated using a router modem plugged into the switchboard and connected to an external antenna. The modem became inoperable by third parties once removed from the system. The Telstra 3G network was used to transfer data to a CSIRO secure database. Surge protection was provided against power fluctuations and a timer reset relay was incorporated into the modem power supply to allow a reset every 24 hours in the event of a transient communication or power failure. Volunteers were promised access to a secure internet web page at the end of the assessment. This allows them to monitor their home energy saving. The same web page was used for rapid surveying of patterns of energy usage that allowed us to determine characteristic signals, for example, identifying HVAC appliance power circuits.

Data storage and validation

Data storage for the electrical measurements was at three levels:

i) Local data storage at the data logger was updated every half hour in the Ecopulse switchboard data logger and was available for inspection via an internet connection.
ii) Central data storage at a secure CSIRO server was updated twice a day via internet connections. These daily downloads could scan back for historical records over several days.
iii) A complete data download from the household units to the CSIRO server was carried out three times during the nine-month monitoring period. This was to accommodate telecommunications failures that might last longer than a few days. Such failures were commonplace in Brisbane during December and January, due to extreme weather events.

Data summary logs were inspected twice daily. This allowed fast response to equipment failures at any household. The three levels of data base storage were also cross checked for:

i) Missing data due to power failures, householder absences, and on one occasion, theft. This was done by testing all data points for loss of signal on all channels and was generally determined within 24 hours.
ii) Short-lived address conflicts that very occasionally occurred during telecommunications failures in the early phase of the project. An upgrade to the central polling software corrected this problem. The few errors caused by this

issue were corrected by checking for simultaneous step changes in value across significant numbers of channels for each house, cross checking across the twice daily and nine monthly data logs and cross checking average data for several weeks before and after each suspected event.

iii) False zeros caused by a firmware upgrade were corrected by cross checking the daily and the back filled data bases.

iv) Noise artefacts gave obviously extreme values and were removed.

A.2.2 CALCULATING ENERGY CONSUMPTION

Calculation of derived parameters

The physical properties that were used to assess energy use included:

i) Total energy, expressed as kilowatt hours (kWh).

ii) Rate of consumption of energy, expressed as either kilowatt hours per half hour to reflect the smallest unit of actual measurement or kWh d^{-1} for general comparisons.

iii) The rate of consumption (kWh d^{-1}) divided by the conditioned floor. This allowed comparisons with energy units in the AccuRate software.

iv) The temperature difference between the main living area of each house and the external environment.

The measurements were calculated as:

i) Total values of energy consumed. This included errors related to missing data. Total values were used where the actual measured value of costs and savings was required by the contract.

ii) Average values that excluded errors due to missing data. These were used for the assessment of the impact of the NatHERS rating on energy consumption.

iii) Coefficients of energy consumption or temperature difference against an explanatory variable. These were used to determine how the energy consumption varied with parameters such as star rating, temperature or dew point in assessments of energy consumption across cohorts for climate zones or seasons.

iv) Items i) to iii) were calculated with and without subtracting non-HVAC energy, including:

- for heat pumps: the standby energy for heating and cooling appliance control
- for evaporative cooling: the subtraction of energy consumption for appliances that shared the sub-circuit
- for gas bill data: the subtraction of summer from winter gas consumption.

The calculation of energy values with and without non-HVAC energy included was done because although the energies of standby operation, or from auxiliary equipment, could be accounted for in a regression analysis, they were possible sources of data noise and would also introduce a systematic error into percentage or per unit results.

For heat pumps, the standby energy value was taken as the average of readings measured at 2:00 am and 2:30 am each day for the monitoring period. It was assumed that while the heat pump controller might still be running, the heat pump would not be actively heating or cooling at this time. This was consistent with a manual survey of energy consumption measurements from Ecopulse units, covering each house in the study. The standby energy value was multiplied by 1.5 to account for variations in the standby energy consumptions, while not excluding the much higher values measured when equipment was actively heating or cooling.

For evaporative units, the energy consumption of auxiliary equipment sharing the sub-circuit was estimated as the average half-hour reading for the entire month of October 2012, as we assumed that the temperature was mild enough that no one would use the evaporative cooler, but that other appliances on the same circuit would still be operating. This was consistent with a manual survey of Ecopulse units, covering each house in the study.

A.2.3 ENERGY DATA NORMALISATION

NatHERS ratings assume a standard set of energy load conditions to enable comparison between different house types. In order to compare loads effectively between houses, it was necessary to take into account different appliance types, internal temperature settings, conditioned floor areas and hours of operation. Collecting actual energy consumption data meant that all of these predefined values were variables that either needed to be normalised to allow comparison among the various cohorts, or else treated as separate cohorts. In the absence of matched pairs, and because of insufficient accuracy in determining the performance coefficients of different appliance types, we used the largest possible number of samples for a restricted range of heating HVAC types, including only: gas heating, evaporative cooling and heat pump heating/cooling. Temperature variations were dealt with by including temperature as an explanatory variable in the regression analysis, and conditioned floor area was accounted for by including analyses where the house energy consumption was divided by the house conditioned floor area.

Appliance efficiency, type and power

Heating/cooling equipment rated power was determined either by examination of the rating plate power consumption, or from the appliance manual, or from the E3 Energy Rating web site. The rating plate was usually located on the side of the unit. The type of unit (e.g. ducted, space, split) was also recorded. Efficiency values were also obtained from the E3 Energy Rating web site. Where efficiencies were not available, a value of x3 was assigned to heat pumps and of x6 to evaporative coolers.

Hours of operation

The assessment included a requirement to make comparisons of energy consumption at common periods of the day (6:30 am to 8:30 am, 3:00 pm to 5:00 pm, 7:00 pm to 9:00 pm) when heating and cooling are commonly activated. Comparisons were as follows:

a) For each house, the average of heating and cooling energy measured and calculated only when the heating and cooling equipment was operating, during the heating and cooling season, within the same pre-defined periods.

b) For each house, the average of heating and cooling energy measured and calculated during the heating and cooling season, within the same pre-defined periods, whether the equipment was operating or not.

c) For each house, the total heating and cooling energy requirement during the whole heating and cooling seasons.

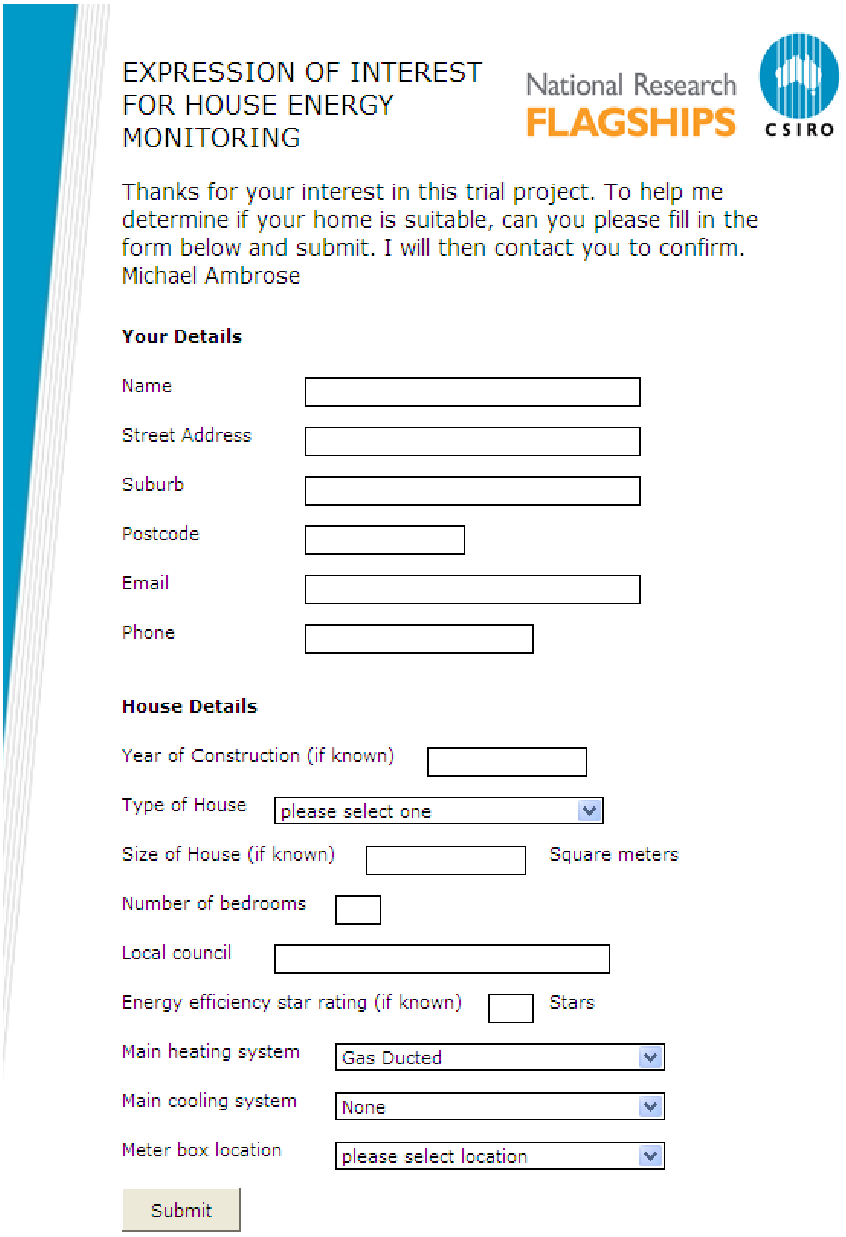
These three comparisons served different purposes: (a) whether 5-star houses require less heating and cooling energy when heating and cooling are activated (this is an indicator of capacity factor); (b) whether 5-star houses require less heating and cooling energy during the predefined common heating and cooling periods (hours); and (c) whether 5-star houses require less heating and cooling energy during the heating and cooling seasons.

Behavioural

Each household undertook a survey to determine their socio-demographic and energy-consumption behaviour. This survey was carried out either at the time the physical inspection was being undertaken or with a follow-up online survey at the household's convenience. The survey itself was brief and self guiding (that is, the residents were not interviewed by the research team). The survey was used to help identify the occupancy profile of the household (e.g. at home all day, home in afternoons only) and establish their energy consumption behaviour and attitudes (e.g. did they switch off lights, did they use CFL lighting). An example survey is included at the end of Appendix A. This example survey is based on work undertaken for the Australian Zero Emissions House project and was refined and tailored for this project.

Registration

Registration of volunteer households was done via an online form following on from an advertising and promotion campaign. A sample form is shown in Figure A - 3.



EXPRESSION OF INTEREST FOR HOUSE ENERGY MONITORING

Thanks for your interest in this trial project. To help me determine if your home is suitable, can you please fill in the form below and submit. I will then contact you to confirm.
Michael Ambrose

Your Details

Name
Street Address
Suburb
Postcode
Email
Phone

House Details

Year of Construction (if known)
Type of House: please select one
Size of House (if known) Square meters
Number of bedrooms
Local council
Energy efficiency star rating (if known) Stars
Main heating system: Gas Ducted
Main cooling system: None
Meter box location: please select location

Figure A - 3 **Sample registration form**

A.2.4 COST DATA

Building costs

Access to detailed working drawings allowed the construction variations to be noted and recorded. Those construction items linked to thermal performance, such as insulation upgrades, were identified and costed in both dollars at time of construction and in today's dollars. Construction cost data were obtained from industry references such as Cordell and Rawlinsons.

Costs in today's dollars were used to identify any reduction in high-performance material costs that may have occurred due to higher demand: for example, the cost of R3.0 insulation batts today versus ten years ago.

Over the research period, changes have occurred in the NatHERS process. This means that a house rated to 3 stars in 2003 would not necessarily rate at 3 stars today with the current NatHERS. These differences were taken into account in the re-rating process and consequent costing differences identified.

Operational costs

It was expected that improvements in the thermal efficiency of the building envelope would translate to reduced energy requirements for heating/cooling. These reductions in energy were to be translated into dollar savings being experienced by residents, taking account of fuel type.

In addition, CO_2-e intensities were also determined. CO_2-e emission factors for fuel sources vary in each climate zone, so appropriate factors were used in each climate zone.

National costs

The Regulation Impact Statement (RIS 2006-01) investigated the likely impact of changes to the BCA as a result of the improved energy efficiency standards. The RIS assumed that 115,000 houses would be constructed each year and estimated that, over 10 years, the additional construction cost would be about $429 million, but that there would be benefits totalling about $546 million, in 2006 dollars. The report also anticipated annual savings in gas and electricity consumption by 2010 of 507,145 GJ and 221,169 GJ respectively, and a corresponding annual CO_2-e saving of 87,109 tonnes.

An analysis was undertaken to determine the actual costs and benefits that have occurred using the results obtained for the three climate zones only, including estimates of:

- savings to date in gas and electricity consumption
- savings to date of CO_2-e
- construction costs to date to achieve the standard, assuming the same build rate as used in the RIS
- costs of the benefits to date using a revised costing methodology that incorporates information from the RIS, information from HIA and MBA members, previous CSIRO research and historical costing data from industry resources, such as Cordell and Rawlinsons.

A.3 Data processing and statistical analysis

A.3.1 APPROACH

The statistical analysis was required to provide:

- sufficient resolution to determine significant differences in the energy consumption associated with a fractional star rating, expressed as average, peak and total energies, over predetermined time periods
- estimates of the significance of data comparisons in a regression analysis
- the analytic capability to assess compliance with the applicable BCA energy efficiency measures.

The central problem was that the magnitude of the effect of star rating on actual energy consumption, and the levels of data noise, were both unknown prior to the study. This made it difficult to estimate the sample size required to discern an effect. The approach we used was to take a closely related sample: the total energy consumption of 800,000 households in NSW. Table A - 1 was derived from this study, and by normalising thermal energy consumption values to these total energy consumption statistics, we calculated what size effect might be identifiable using estimates of the smallest detectable difference between the two groups for different sample sizes.

Table A - 1 Statistics for a NSW study of house total energy consumption (A. Higgins, CSIRO)

Sample size	800,000	
Mean	7396	kWh
Median	6631	kWh
Standard deviation	3664	kWh
SD/mean	49.5%	

A.3.2 SAMPLE SIZE AND DETECTION THRESHOLDS

The data was originally intended to include both 3.5–4 and higher-rated houses in equal numbers. Based on this, and the assumptions given below, the instrumented sample of 240 was considered sufficient to detect a difference in energy consumption between 3.5–4 and 5-star houses down to approximately 33% of the maximum difference in consumption in each climate zone. Where gas was used for heating, we made the assumption that the statistical properties for its household consumption would be similar to electricity.

In estimating the sample size required, we assumed:

a) The standard deviation of the energy data sets was close to 50% of the mean values derived from the NatHERS star-rating scale, based on a related but not identical data set, the total household energy consumption for 800,000 houses in NSW.

b) The shape of the population distribution of heating and cooling energy samples during periods of winter or summer was the same as for total house energy consumption.

This was later found to be incorrect, and the distribution was found to be approximately exponential.

c) There is a thirty percent reduction in heating or cooling energy when moving from 3.5–4 stars to 5-star rating as determined in the NatHERS star-rating scale.

d) An analysis method was to be used in which the energy efficiencies corresponding to the star ratings were compared using a matched sample design. We were unable to obtain the necessary matched pair samples, and instead used a multiple regression analysis, with restrictions on the diversity of heating and cooling appliances so that sample size could be optimised.

Two assumptions were not correct and required us to make significant changes to the data analysis method. One was the assumption that energy consumption values would be distributed normally, and the other was that star ratings could be determined in advance, allowing an equal number of samples within the two star rating bands being tested. However, the sample numbers proved adequate to make comparisons using regression analysis by setting confidence levels at 95% and p-values at less than 0.05.

A.3.3 DETECTION THRESHOLDS AND CONFIDENCE INTERVALS

Table A-2 shows how we estimated, for each climate zone, the detection thresholds for discriminating thermal energy consumption differentials between 3.5–4 star and 5-star groups. The thresholds were derived by using model data for the mean of the energy consumption differentials, and comparing them with the total house energy consumption value to determine their normalising factors. The standard deviations of actual (not modelled) energy consumption differentials for each climate zone were then estimated by applying these normalising factors to the standard deviation for total energy consumption. These standard deviation values were then used to determine the relationship between sample size and the smallest detectable difference for energy consumption differentials in each climate zone. Table A-2 also shows an estimate of the confidence interval aimed for by combining data from all three climate zones. It uses assumptions based on the study described in Table A-1.

Table A - 2 Smallest detectable difference and confidence intervals for 3.5–4 vs. 5-star comparisons

Smallest detectable difference for house total energy consumption			Smallest detectable difference for 3.5–4 and 5-star groups			
Sample size per group	Proportion of standard deviation	(Assumes a total energy of 7396 kWh and standard deviation of 3600 kWh)	Melbourne thermal energy (kWh)	Adelaide thermal energy (kWh)	Brisbane thermal energy (kWh)	Heat pump (kWh) (Syd/Bris)
25	0.81	2911	1158	1211	373	124
50	0.57	2037	811	847	261	87
100	0.40	1433	570	596	184	61
200	0.28	1011	402	421	129	43
300	0.23	825	328	343	106	35
500	0.18	639	254	266	82	27

Estimate of confidence intervals for 3.5–4 star vs. 5-star model comparisons averaging across zones

	Model value of energy Δ kWh	Group sample no.	SD	Var	Estimated standard error of the mean difference	95% confidence interval is equal to ± the mean difference (kWh)
Melbourne	2943	40	1458	2125759	326	639
Adelaide	3077	40	1524	2323154	341	668
Brisbane	947	40	469	220202	105	206
Average	2012	120	997	993766	129	252

A.3.4 DATA CHARACTERISTICS – SAMPLING AND DISTRIBUTION

It was not possible to select houses for an even distribution of ratings between 3.5 and 5 stars. Houses were therefore selected by year of construction. The resulting distributions were approximately Gaussian. After the houses and ratings had been evaluated, a significant proportion of ratings were found to be higher than required by the standard in Adelaide and Melbourne. Consequently, the population of star ratings was shifted by about half a star towards higher values in the range from 4 to 6 stars (Figure A–4 and Figure A–5).

The energy consumption distribution was also non Gaussian. In Adelaide and Brisbane, the distribution of energy consumption data was skewed, with the number of energy users increasing as their energy use reduced (Figure A-8 and Figure A-9). This was observed in both heat pumps and evaporative coolers.

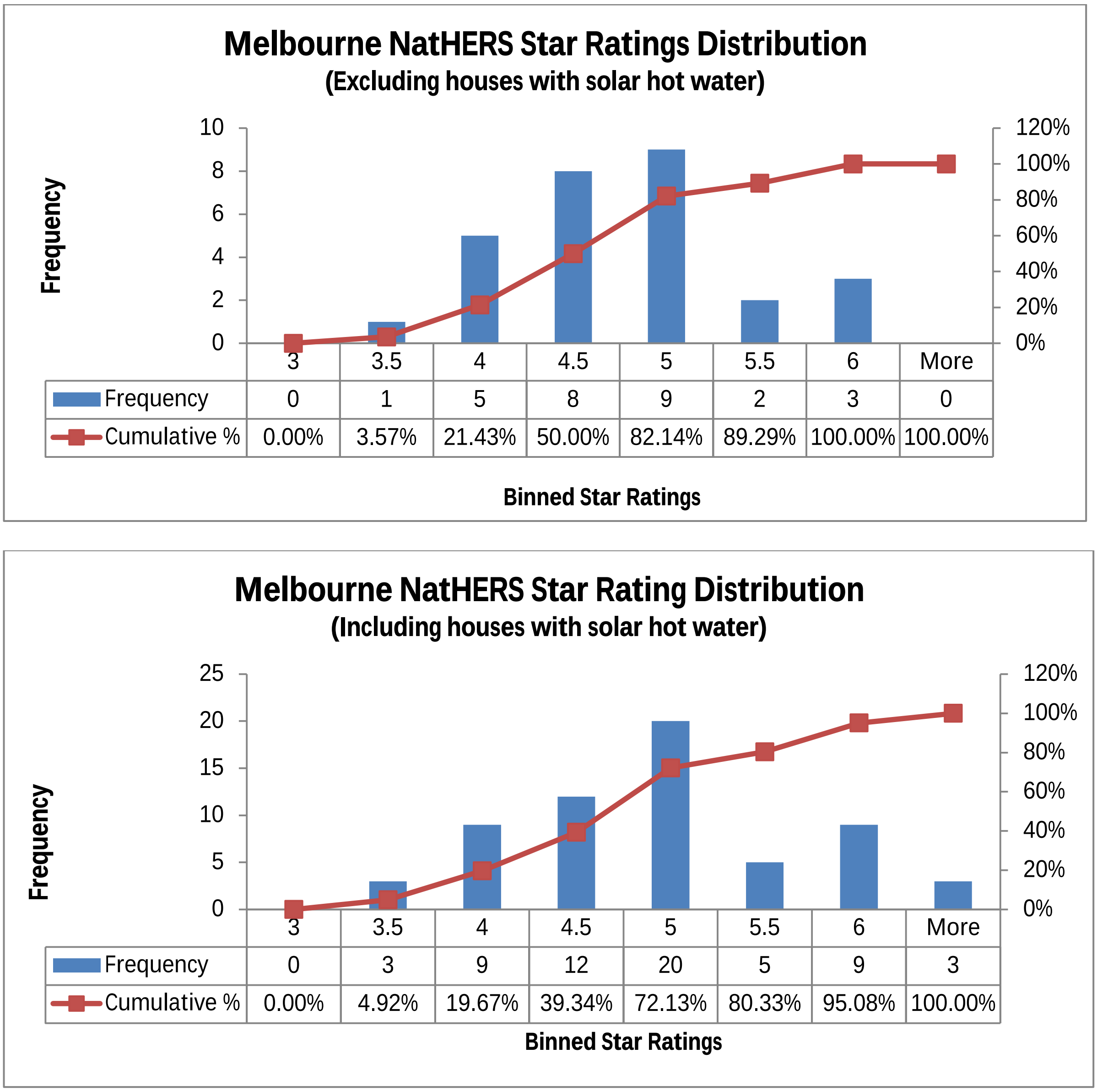
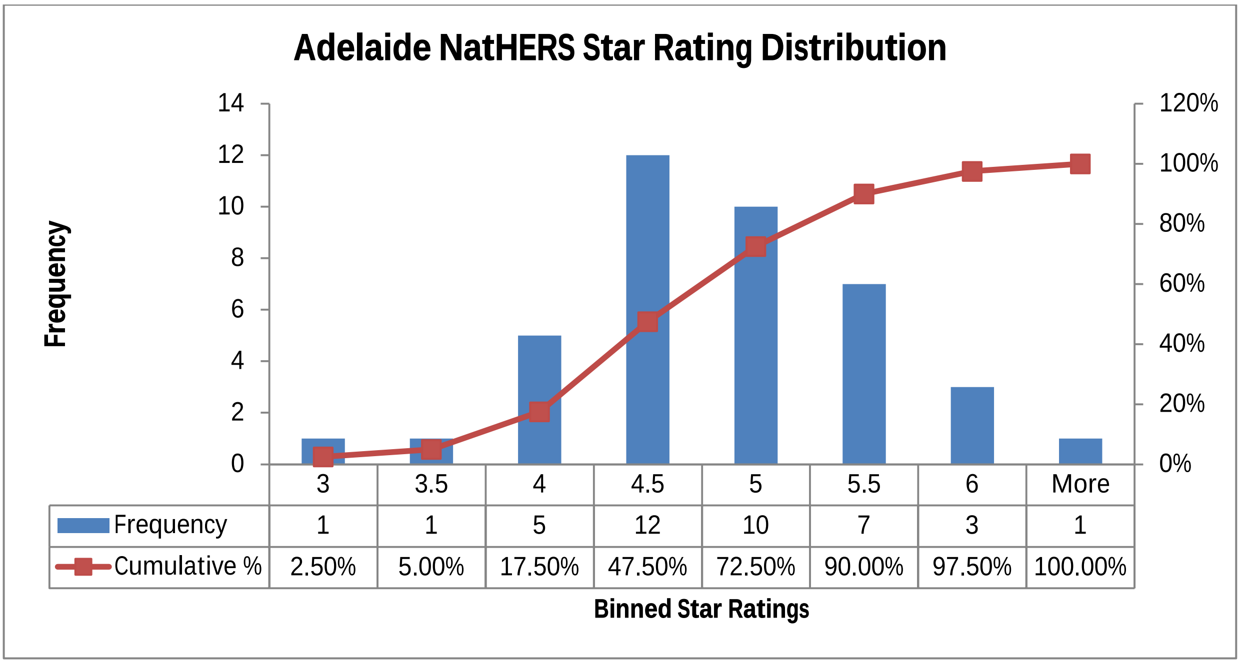
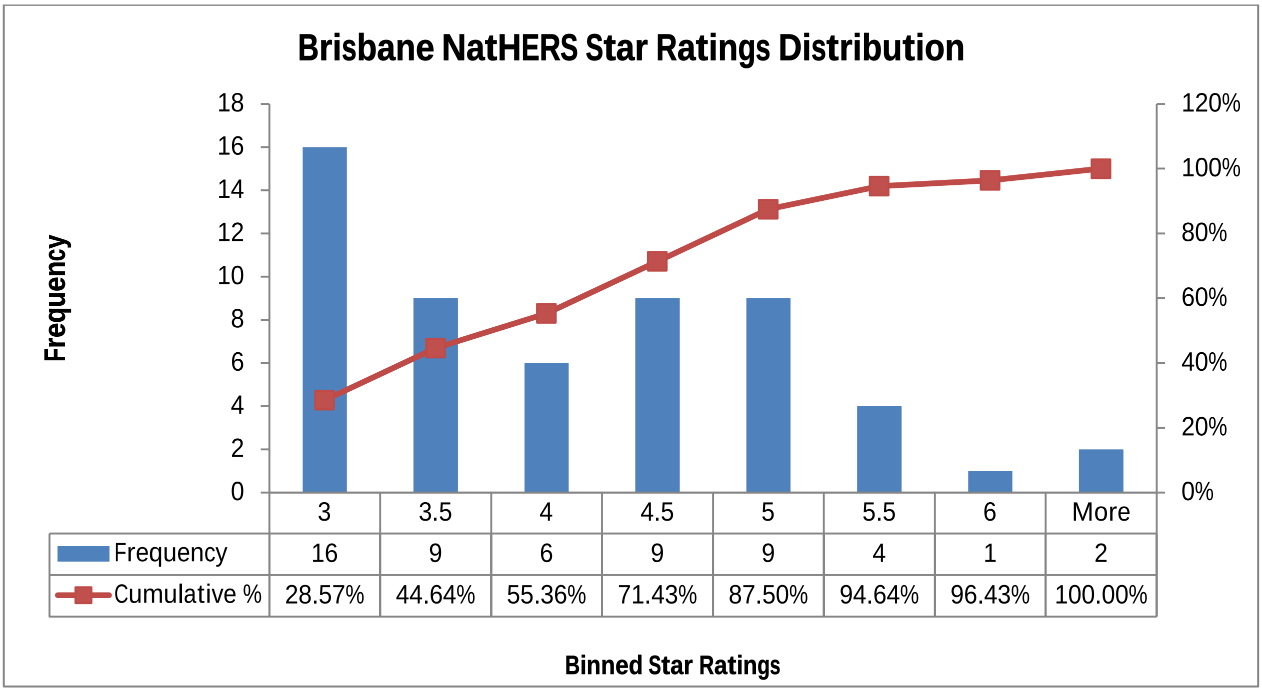


Figure A - 4 **Distribution of star ratings excluding and including solar hot water – Melbourne**



	3	3.5	4	4.5	5	5.5	6	More
Frequency	1	1	5	12	10	7	3	1
Cumulative %	2.50%	5.00%	17.50%	47.50%	72.50%	90.00%	97.50%	100.00%

Figure A - 5 **Distribution of star ratings – Adelaide**



	3	3.5	4	4.5	5	5.5	6	More
Frequency	16	9	6	9	9	4	1	2
Cumulative %	28.57%	44.64%	55.36%	71.43%	87.50%	94.64%	96.43%	100.00%

Figure A - 6 **Distribution of star ratings – Brisbane**

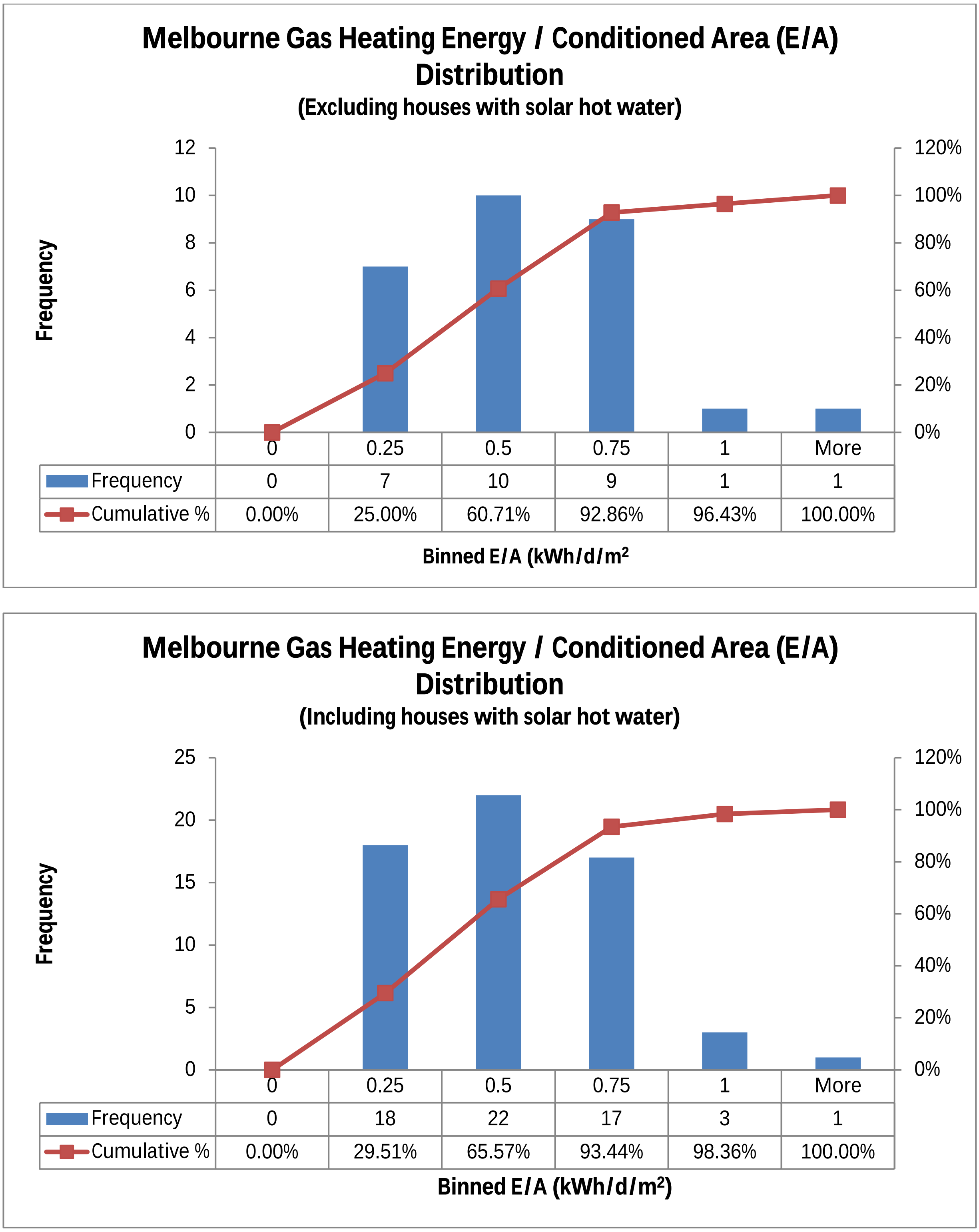
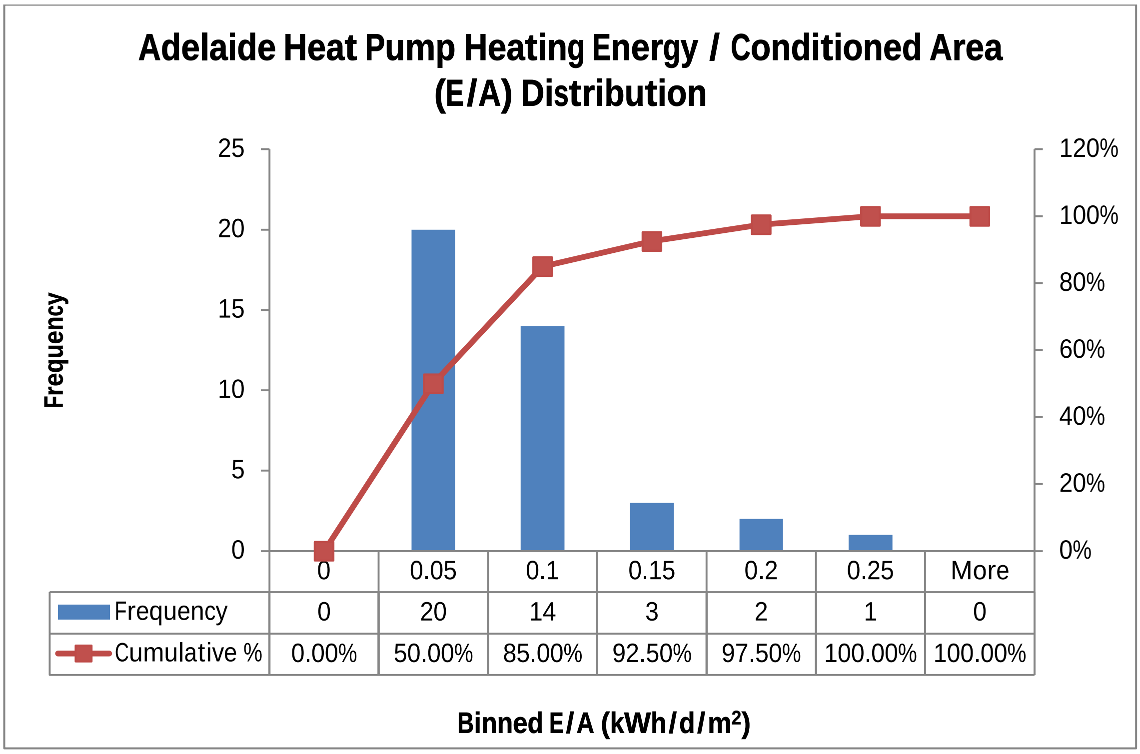
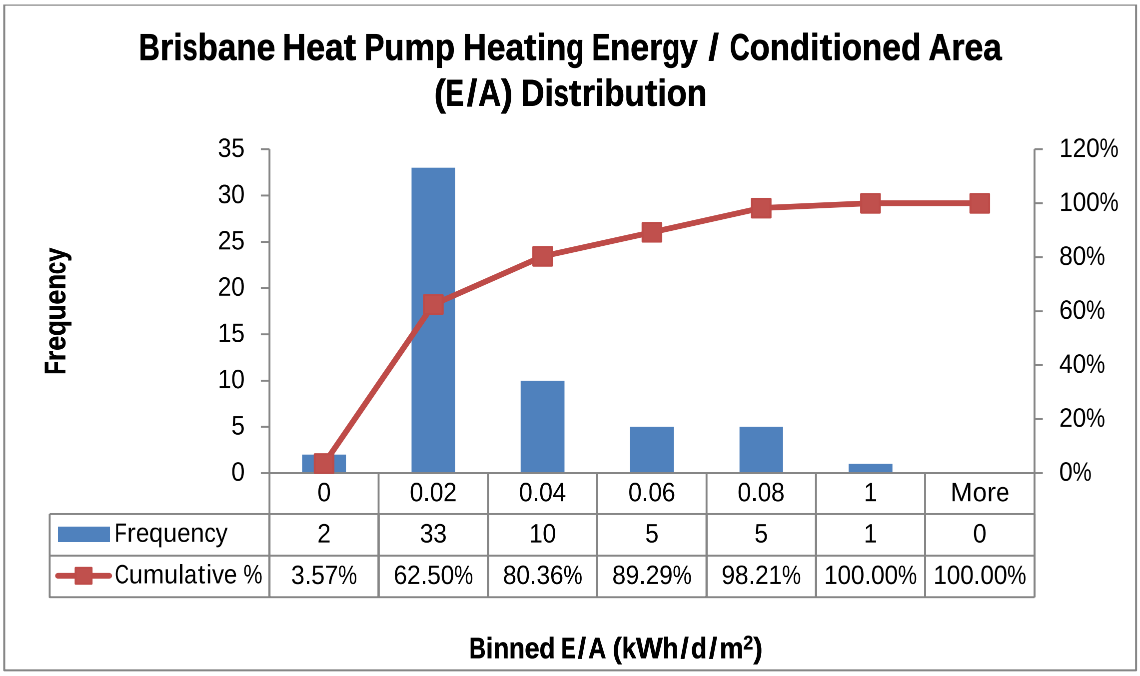


Figure A - 7 **Distribution of heating energy, excluding and including solar hot water – Melbourne**



	0	0.05	0.1	0.15	0.2	0.25	More
Frequency	0	20	14	3	2	1	0
Cumulative %	0.00%	50.00%	85.00%	92.50%	97.50%	100.00%	100.00%

Figure A - 8 **Distribution of heating energy – Adelaide**



	0	0.02	0.04	0.06	0.08	1	More
Frequency	2	33	10	5	5	1	0
Cumulative %	3.57%	62.50%	80.36%	89.29%	98.21%	100.00%	100.00%

Figure A - 9 **Distribution of heating energy – Brisbane**

A.3.5 STATISTICAL TESTING

Data groups

The data cohorts used in assessing impact of energy ratings on heating and cooling energy consumptions included measurements across:

- Adelaide, Brisbane and Melbourne
- the nine-month monitoring period from the beginning of June 2012 to the end of February 2013
- two seasons, summer and winter
- daily time intervals including 06:30 to 08:30, 15:00 to 17:00 and 19:00 to 21:00
- a limited range of appliances, including heat pump heating and cooling, gas heating, and evaporative cooling
- two forms of energy consumption data acquisition, including bills and direct measurement.

The principal explanatory variables included:

- star rating
- the temperature difference between the main living area and the nearest Bureau of Meteorology station.

The following factors were also considered, but did not have a significant effect:

- dewpoint
- quality of building construction
- householder self-reported energy efficiency behaviour
- floor area.

The influence of conditioned floor area was minimal. It is accounted for in the NatHERS standard. In addition, the range of floor areas was within a factor of two (Figure A - 10).

The lack of a significant effect for householder energy efficiency behaviour was a limitation in the sensitivity of our assessment. The influence of householder behaviour requires a much more detailed assessment than this study allowed and is currently the subject of a separate investigation.

Other factors that influenced energy consumption, but were not included in the star-rating system, were accounted for in the analysis, so that the specific influence of star rating could be isolated. Those included:

- standby energy in all appliances
- spurious additional loads, principally heater fans, for evaporative cooling circuits.

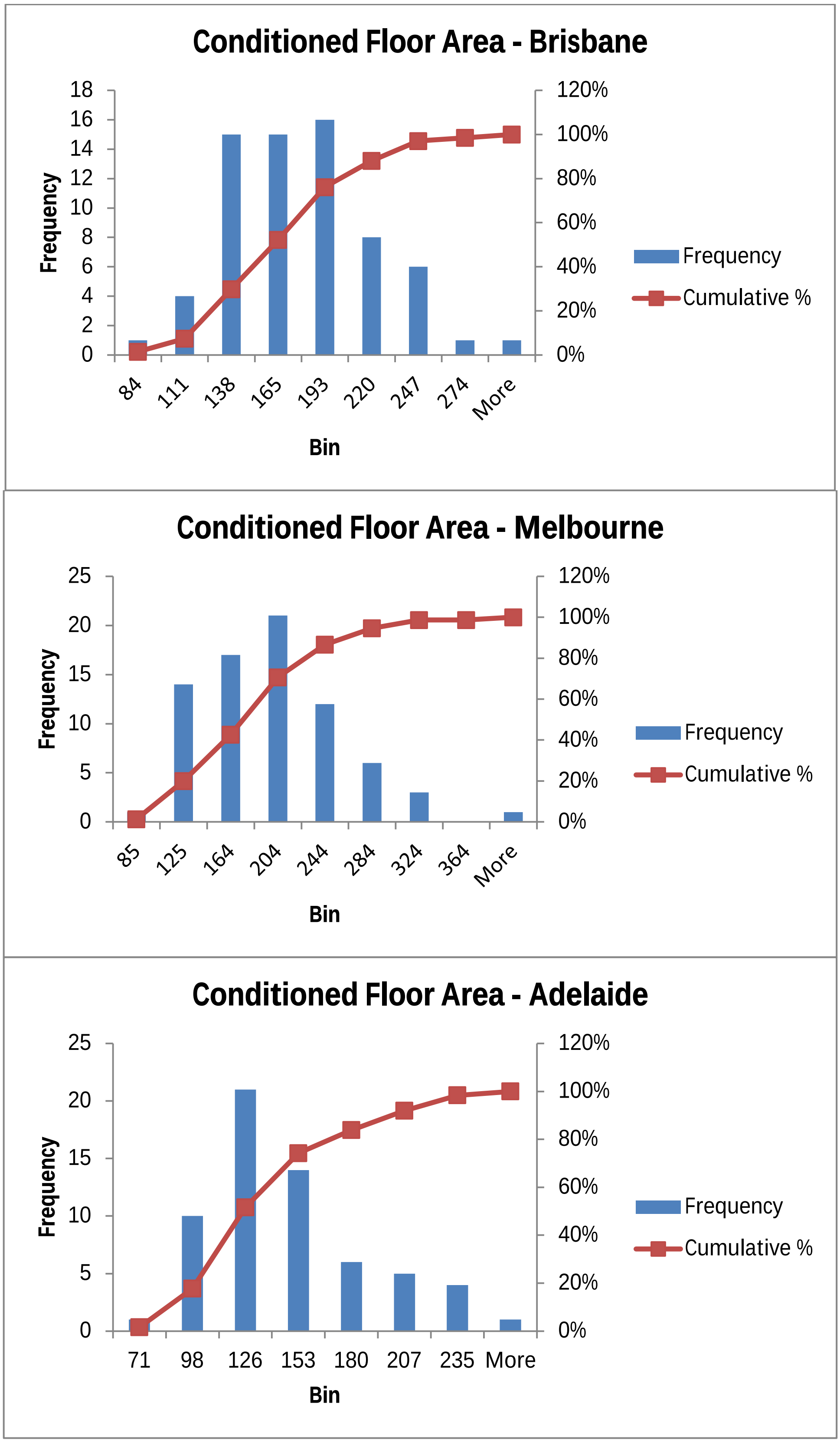


Figure A - 10 **Distribution of floor areas by city**

Selection of the statistical test

Regression analysis was used to fit a linear model of the energy dependence on star rating ($\Delta E/\Delta Star$). The results for each multiple regression analysis are presented in table form, together with a discussion. The data and regression predictions are presented graphically for illustration only. They may be useful to obtain a general idea of the data, but in using them one should be aware that the predicted values may be non-linearly distributed, because they describe the combined contribution of all explanatory variables, so that coefficients cannot be simply deduced from the graph. Likewise, a data point may seem to be an outlier in one component of the multiple regression prediction, but can be significant in another. For these reasons, our principal focus is on the table values.

The analysis is split into linear fits for each explanatory variable in the table. The key parameters reported are a set of coefficients, each indicating a linear 'association' or 'dependence' of the energy consumption or the temperature difference with an explanatory variable. For example, a linear relationship between energy consumption and star rating might be expressed as having a 'negative association with' or a 'negative dependence on' star rating, to describe the reduction of energy consumption as star rating increases. Each linear fit has a corresponding 'p' value. As p-values decrease, the probability that there is a significant association or dependence between the dependent and independent variable increases. In this study, where p-values are less than or equal to 0.05, we consider the association to be significant at a level of 95%. Where p-values were greater than 0.05, the association/dependence was not considered to be significant.

We used two models (equations 1 and 2) to describe the relationships between energy consumptions 'E', star ratings 'Star', and the temperature differences between the main living areas of the houses and their nearest Bureau of Meteorology weather stations 'ΔT'. We then used a multiple regression analysis to test the proposed relationships against our measured data. The two equations describing the energy E and temperature ΔT dependencies on star rating were:

Equation 1 $$E = k_a.Star + k_b.\Delta T + k_c$$

Equation 2 $$\Delta T = k_d.Star + k_e$$

Where:

E	heating or cooling energy
ΔT	temperature difference between main living area and nearest BoM weather station
Star	the NatHERS star rating
k_a	heating or cooling energy 'E' dependence on the NatHERS star rating (kWh d^{-1} m^{-2} $star^{-1}$)
k_b	describes how the heating or cooling energy 'E' depends on the temperature difference between the interior of the house and the nearest BoM weather station (kWh d^{-1} m^{-2} $^{o}C^{-1}$)
k_c	background heat in the house comprising both stored heat and sources of heat not related to either the NatHERS star rating or the heating and cooling appliances (kWh d^{-1} m^{-2})
k_d	the temperature 'ΔT' dependence on the NatHERS star rating (^{o}C $star^{-1}$)
k_e	the temperature 'ΔT' dependence on the heating and cooling energy (^{o}C kWh^{-1} d^{-1} m^{-2})
k_f	the background temperature difference associated with the background heat (^{o}C).

The multiple regression evaluated the best fit for the six coefficients k_a to k_f that described the proposed relationship. Each coefficient was associated with a p-value that assessed whether the coefficient was inconsistent with the proposed model. Each coefficient was reported as a mean value with 95% confidence intervals and a p-value. Provided their p-values were less than 0.05, the coefficient ka, kb and kd were used to estimate on average how much energy was saved or lost in houses rated at 5 stars compared with houses rated at 3.5–4 stars. The 95% confidence intervals give an indication of how much this energy saving would vary in the population from which the sample was drawn.

A.4 De-identification and key points for ethical consideration

The ‘Ex-Post Evaluation of Residential Building Energy Efficiency Standards’ required the cooperation of both householders and energy supply companies, by virtue of its emphasis on the need for experimental data rather than modelling. It was a key requirement, therefore, that all participants in this research project were aware of and adhered to the requirements of the ‘National Statement on Ethical Conduct in Human Research’, particularly regarding informed consent and the privacy of participant information. [2]

A.4.1 ENGAGEMENT WITH VOLUNTEERS

Householders were asked to make a number of commitments and allow a number of interventions for the purpose of measuring household energy consumption and house thermal efficiency. In return, they were offered advice, a nominal financial payment, and the opportunity to keep the energy-monitoring equipment. Data relating to the household and energy supply companies were de-identified in reports for the study, to preserve householder and energy company privacy.

A.4.2 HOUSEHOLD COMMITMENTS

Household commitments included:

- monitoring energy and gas usage in the house (via monitoring equipment or energy bills)
- monitoring the temperature inside the house (via small temperature sensors)
- undertaking a lifestyle survey on how the house usage affects energy consumption
- providing access to energy bills
- providing, or allowing access to, house plans and energy rating (as held by the local council).

A.4.3 HOUSEHOLD INTERVENTIONS

The activities directly involving the volunteer households included:

- Installation in the house switchboard of current clamps on the principal electrical circuits and a data logger linked to a secure web site. The web site holds household energy consumption data in a de-identified coded form.
- Supply to the householder of two envelopes, each containing a temperature data logger to be stored by the householder in the thermally conditioned space. These were exchanged three times during the study. The householder was paid a nominal amount for looking after these loggers.
- A morning or afternoon visit by two house sustainability assessors to measure key parameters associated with house thermal efficiency. These personnel had accreditation as required by ABSA, including appropriate police checks, public liability and professional insurance.
- A survey in the form of a preliminary telephone briefing, followed by filling in a form available either as paper or on the internet in the householders own time. The information gathered included stakeholders' descriptions of when they use home heating or cooling, socio-demographic detail relevant to the degree of consumption of energy, and suggestions the householder may have for energy saving. Participation was voluntary and written informed consent was obtained before

the interview. Interviewees were free to stop the interview, refuse to answer questions, and withdraw their data if so desired.

A.4.4 THE PROCESS OF ENGAGEMENT

Engagement with the householder involved:

1. Identifying regions of high growth.
2. Advertising the opportunity via local media and in collaboration with local councils and developers.
3. Providing access to an information sheet and an internet or paper registration Expression of Interest (EOI) form that included a number of questions addressing the necessary criteria for participation.
4. Screening for participants that meet the study's criteria for participation.
5. Sending out a detailed information sheet, application form and consent forms.
6. Acknowledging all EOI's and applications to participate.
7. Setting up appointments for monitoring equipment installation and providing a verbal telephone briefing.
8. Carrying out the installation and measurement.
9. Providing facilities for responding to the survey.
10. Making quarterly calls to discuss progress and any issues with the volunteers and to request an exchange of temperature sensors.
11. Providing a final debriefing at the end of the study.

A.4.5 HOUSEHOLD BENEFIT FOR PARTICIPATION

At the end of the study the householder received the following benefits:

1. A nominal payment to acknowledge the householder's care of temperature sensors.
2. A personalised report on ways the householder might be able to make further savings in house heating and cooling energy.
3. A discussion of whether the householder would like to take over the use of the energy monitoring equipment.
4. A discussion of whether the householder would be interested in further collaboration in new studies of energy consumption.

Throughout the study, the householder was able to contact nominated CSIRO project scientists to discuss questions relating to the study or relating to energy efficiency in the house.

A.4.6 CONFIDENTIALITY

No householder names will be cited in any reports or publications. CSIRO will de-identify individual household and energy provider data and maintain these datasets in a de-identified form to preserve householder and energy provider confidentiality. To this end:

- The results of compliance testing and house energy rating assessments generated in the performance of the Services will be de-identified and encoded and incorporated into the de-identified Contract Material and Generated Data Base.[3] It will not be possible for anyone, including CSIRO, to reconstitute individual house or energy supply company's identities from the contract material or Generated Data Base.
- A separate database in which individual household data is de-identified will be kept for holding research data for the benefit of the householder and future research programs. This will not include data on compliance testing and house energy rating assessments.
- CSIRO will keep the de-identified data bases and key for encoding and decoding the data on separate CSIRO-secured servers for a period of seven years to allow CSIRO to meet its obligation to provide householders with relevant information in return for their participation.

A.5 Additional Data

A.5.1 HOUSE ASSESSMENT

The assessor checked the location of two temperature sensors in the principal conditioned space of the house. A photograph was taken of their location.

Qualitatively assessing the house

A qualitative assessment of each house in the data set was made using the Android data logger as a prompt. It took into account such factors as quality of insulation, presence of window furnishings, additions such as pergolas, verandas and shading, trees, nearby buildings and the presence of pool or spa heating.

Thermography of walls and ceilings

The thermography test was aimed at providing a qualitative assessment of insulation; in particular, the presence of gaps in insulation in areas that were otherwise inaccessible, such as walls. Each image was automatically associated with a temperature calibration scale, a time and date stamp and an identifier reference, which were recorded on the interview log.

Measurement sequence

1. At the end of the first heating cycle (for the thermal step response test) the Testo 'thermograph' scanner was used to scan the external walls and ceiling, checking quality and consistency of insulation. Areas for particular attention included:
    - perimeter of the ceiling
    - where the roof frame changes direction (rooms that step in or out, corners and ground-floor roofs on double-storey dwellings)
    - rear projections or roof space with no manhole access, including cathedral ceilings
    - around penetrations (lights, fans, power points)
    - above or below windows/doors
    - walls where lower floor roof butts into the upper floor walls on double-storey or split-level dwellings.
2. Still shots/images were taken of the external ceiling and walls of conditioned spaces to assess the quality of insulation. Images were captured to:
    - show the overall quality of insulation (good or bad)
    - indicate weak points in the quality of insulation.
3. A description was selected and recorded into the android/netbook to indicate insulation quality (scale A to D).
    - Poor: Inconsistent insulation coverage – lots of gaps or large gaps
    - Average: Typical outcome, majority of coverage consistent – expect gaps/cold spots to ceiling perimeter, around downlights, under heater platforms and tight corners
    - Good: Majority of coverage consistent – only minimal
    - Excellent: No gaps/cold spots in coverage.
4. Images were downloaded from the SD card in the Testo thermal imaging device (TTID) to the Netbook, then deleted from the SD card, which was then returned to the TTID.
5. The naming protocol for images was: “RBEEsTherm_jobnumber_Room_Descrpt.BMT”.
6. Images were uploaded to selected secure CSIRO online location before leaving the site.
7. Batteries were recharged for the next visit.

A.6 Appliance auditing

The appliance audit included hot water, heating and cooling and other gas appliances only. Data was acquired and recorded using the Android data logger, including a photographic record of power rating and capacity notes from the rating plates for hot water tanks and heating and cooling services (air conditioners and central heating). The appliance audit specifically included the following gas and electric appliances, if they were present. Data was captured from multiple appliances if they were present:

1. Hot water
2. Ducted heating
3. Ducted cooling.

The following information was collected, where available, from the name plate of each appliance:

1. Brand name
2. Model
3. Input power (heating/cooling only)
4. Output power (heating/cooling only)
5. Capacity (hot water only)
6. Total hours usage/year entry, including the calculation formula inputs (Hrs/day x days/month x months/year)
7. Total power (if stated on name plate)
8. Star rating.

Best efforts were made to photograph the hot water system and heating system where details were otherwise unavailable.

A.7 References

1. DCCEE, *Request for Tender in relation to 'Ex-Post Evaluation of Residential Building Energy Efficiency Standards'*. 2011.
2. NHMRC, AVCC, and ARC, *National Statement on Ethical Conduct in Human Research (2007) incorporating all updates as at September 2009* 2007, National Health and Medical Research Council.
3. CSIRO and DCCEE, *Contract in relation to Ex-Post Evaluation of Residential Building Energy Efficiency Standards*. 2011, DCCEE.
4. ABCB, *Building Code of Australia (BCA) - Residential Construction*, A.B.C.B. (ABCB), Editor. 2009.
5. 'Space Heating and Cooling' Robert Foster, Energy Efficient Strategies, DCCEE REMP Workshop

Appendix B – AccuRate rating methodology

The following represents the methodology used to assess NatHERS star ratings. The documentation was prepared by Energy Makeovers, who were contracted to undertake the NatHERS assessments of all houses. The methodology was assessed and developed in conjunction with Association of Building Sustainability Assessors (ABSA).

B.1 Guidelines

- Energy Makeovers will conduct an “initial screening check” of the documentation provided by CSIRO for each household to determine whether there is sufficient information to enable Energy Makeovers to complete a new AccuRate assessment of the dwelling.
- If the initial screening check reveals that there is missing information, and this ABSA-approved rating protocol does not provide clear pre-determined guidelines to compensate for the missing data in a consistent manner, then Energy Makeovers shall not commence the rating until either the missing data is provide or the protocol is updated to allow consistent rating assumptions to be used. Note: In the event that CSIRO wishes to apply protocol changes to the rating methodology after an assessment has been completed, and CSIRO wish this work to be performed by Energy Makeovers, this will be a contract variation and Energy Makeovers will provide a quotation to CSIRO to perform such additional work.
- If there is insufficient information and this rating protocol does not provide protocols to compensate for the missing data, then the plans will be referred back to CSIRO.
- Where missing information is covered by this protocol and, therefore, appropriate consistent assumptions can be applied, then Energy Makeovers will accept the drawings, document the assumptions made and complete the assessment (intended to be in a single session)
    - for example, window material/configuration, floor coverings, wall insulation or ceiling insulation.
- Rating amendments to completed assessments utilising data collected during the on-site Additional Data Collection (ADC) assessments may be made by CSIRO at a later date if deemed necessary by CSIRO. Note: Should CSIRO wish this work to be performed by Energy Makeovers, this will be a contract variation and Energy Makeovers will provide a quotation to CSIRO to perform such additional work.

B.2 Data entry into EM QA Sheet

- The Assessor saves a copy of the EM QA spreadsheet template to job file. Name: “RBEEs AccuRate QA_<job number>.xls”.
- Save .PRO file following this naming protocol: “RBEE BaseCase <job number> initial YYMMDD.PRO” (e.g. RBEE BaseCase 3004001 RG 120411.PRO).
- In the EM QA sheet is a checklist, which exists to guide the Assessor in the Quality Assurance of the rating process.

- Ø Energy Makeovers AccuRate Assessor to use only a full set of working drawings to assess a house's energy rating in AccuRate. All relevant details for the rating are to be extracted from the working drawings ONLY and not from the energy rating report. The energy rating report is for CSIRO's reference only.
- Ø The Assessor extracts the following documentation from SharePoint, saves it to the secure EM "RBEEs only laptop" or USB drive and records the receipt of all documentation below in the AccuRate QA excel sheet (QA sheet):
  - Working drawings, including
    - general notes
    - site plan: for north orientation and shading from neighbours
    - floor plans: for dimensions and plan of house layout etc.
    - elevations: for dimensions and plan of house layout etc.
    - sections: for plan of house layout etc.
    - window schedule: may not always be available (see generic rules)
    - Electrical plan: often not available (see rules for down lights/exhaust fans)
    - Energy Rating/Deemed to Satisfy specifications: ON working drawings if available (especially for plans created after 2004)
  - Full Energy Rating Report (for CSIRO's use only).
- Ø Enter "Zone Names" into checklist on QA sheet, using names as per plans
  - Enter subfloor zone(s) first and
  - Then enter zones in a clockwise direction starting from the zone that contains the front door (i.e. the "entry zone"), unless this zone is a large open-plan space that extends into the centre of the house, in this case start from the room to the left of the front door
  - For second stories also start from the room above this first external door
  - Record each room as one zone
  - Enter roof zone(s) last.
- Ø Any rooms that share the same "air space" (e.g. open plan kitchen/living) should also be combined as a third zone (i.e. as Room 2 & 3) in checklist.
- Ø Enter, in checklist on QA sheet, the dimensions (in metres to 2 decimal points. i.e. 2.75) of each zone to calculate areas and volumes of each individual zone, using:
  - Width dimensions (up-down on landscape-page)
  - Length dimensions (left-right on landscape-page)
  - Height to ceiling, (if raked use average wall height).
- Ø Also record the following as required in the checklist to assist calculations and data entry (in metres to 2 decimal points. i.e. 2.75):
  - Floor height (from origin)
  - Internal wall heights (m)
  - Surface area of internal doors
  - Surface area of skylights and roof lights.
- Ø Checklist to be marked as "complete" and number of elements listed at various checkpoints as mentioned in AccuRate Data Entry section (below).

B.3 AccuRate Data Entry

- Ø Data entry is to strictly follow the following procedures; failure to do so will lead to errors and misinterpretation of data.

- Ø Zones are to be entered in the same order as the checklist, commencing with the subfloor or entry zone, whichever is first.
- Ø Sequence of data entry is to follow the tab sequence in AccuRate:
  - · Project details o Constructions o Zones
  - · Shading
  - · Elements
  - · Ventilation.
- Ø In the “Elements” tab, enter the construction and dimensions of each element, one at a time, in a clockwise direction starting from the wall to the left of the front door (viewed from the inside),following the order defined in the “Element type” drop down menu.
- Ø Mark each as "Complete" on checklist before moving on.
- Ø Save AccuRate data file regularly throughout creation process.

B.4 Project data

- Ø In the “Project Data” tab section of the AccuRate file:
  - · Enter the RBEEs Job Number in the project name field.
  - · NO reference to the actual house address or householder details is to be made other than:
    - o Postcode
    - o Climate zone
    - o Site exposure: RULE: Check that it has been correctly selected (mostly “Suburban” to be selected).
  - · DO NOT CHANGE GROUND REFLECTANCE, it MUST remain at 0.2.

1) **RULE**: if there are TWO **Climate zones** the first is always to be selected (OK by CSIRO 7/3/12).
2) **RULE: PROJECT TABLE NOTES**: ALWAYS record ALL notes related to .PRO file on project tab, that is;
   a. if ANY documentation is missing from working drawings; and
   b. Record ALL assumptions that are made when entering data.

B.5 Construction

- Ø Save AccuRate data file regularly throughout creation process.
- Ø In the “Constructions” tab enter “all Construction Materials” as per plans, using options defined on “Generics” tab in EM QA Sheet if item is not specified on plans (based on ABSA Protocol see: “ABSA Assessor Procedures: Residential Building Thermal Performance V0.7 1 May 2007” for more details).
- Ø Enter all construction data, following the order defined in the “Construction type” drop down menu:
  - · For ease of use, and to avoid confusion on materials and naming conventions, a standard set of construction materials in relevant libraries will be available for the RBEEs project.
  - · Additional library items will be available on request from ABSA; when this occurs, use the library with the most recent date at the end of the file name (YYMMDD).

Library files to use:

RBEES ceilings below a roof space YMMDD.FLR

RBEES External walls YYMMDD.WLE

RBEES flat and cathedral roofs YYMMDD.ROF

RBEES Standard roof YYMMDD.ROF

Roof custom YYMMDD.ROF

RBEES concrete floors and ceilings YYMMDD.FLR

RBEES doors YYMMDD.DOR

RBEES Internal walls YYMMDD.WLI

RBEES timber floors and ceilings YYMMDD.FLR

3) **RULE: INSULATION**: if R-value of insulation is greater than that which would normally fit within a wall (max R2.5) / floor /raked ceiling space, question consult with subject matter expert on the correct R-value to use.
4) **RULE: system values**: If R2.2, R1.3, R1.4 or another partial R-rating is used, then it is a system value. CHECK BCA 2005 photocopy for material composition of external wall or ceiling
5) **RULE: INSULATION**: if the insulation information is missing, refer to the table below for standard assumptions.

Victoria	**Before July 2004**	**July 2004–April 2011**	**May 2011 onwards**
External Walls	Single-sided foil	R1.5 bulk insulation	R2.0 bulk insulation
Ceiling	R2.5 bulk insulation	R3.5 bulk insulation	R4.0 bulk insulation

South Australia	**Before July 2004**	**July 2004–April 2010**	**May 2010 onwards**
External Walls	Single-sided foil	R1.5 bulk insulation	R2.0 bulk insulation
Ceiling	R2.5 bulk insulation	R3.0 bulk insulation	R3.5 bulk insulation

Queensland	**Before April 2009**	**May 2009 onwards**
External Walls	Single-sided foil	Double-sided antiglare foil
Ceiling	R1.5 bulk insulation	R2.5 bulk insulation to tiled roofs
Roof	NA	55 mm Anticon blanket to metal roofs

B.6 Zones

- Save AccuRate data file regularly throughout creation process.
- In the “Zone” page, enter zone names and dimensions from EM QA Sheet into AccuRate file strictly in the same order as the checklist (combined zones should be entered as one zone only).
- Don’t get creative; strictly follow the supplied zoning methodology and procedures.
- Care must be taken to complete all zone/elements etc. See “Common properties”.

Common properties

a) All fields must be entered.
b) Zone name.
c) Type.

d) Volume X Rule: IF ceiling is RAKED: Use average ceiling height of ZONE, for volume calculations, NOT average raked ceiling for whole floor.
e) Floor height, above ground level for the ground floor.
f) Maximum ceiling height.
g) For multi-level houses, for each subsequent level, the floor height must equal the total of the lower floor height and max ceiling height.
h) Both heating and cooling are to be checked in conditioned zones.
i) Default conditioned zone, the fields are shaded, and cannot be changed.
j) Unconditioned zone, then neither is checked.
k) Reflective roof space: Check this field if reflective sarking or a reflective surface on a composite insulation product is directly under the roof and the reflective surface is facing down.
l) Infiltration: Enter quantity into relevant fields.
m) Ceiling fans: Enter quantity and type.
n) Mark as "Complete" on checklist before moving on.

6) **RULE: Kitchen**: In the zone that has the kitchen, the kitchen must be labelled first (i.e. living, dining, kitchen = Kitchen/living/dining).

7) **RULE: Floor Height** includes thickness of slab, assume 250 mm from RFL (unless noted on plans use FL and RL numbers. Freeboard = Nominal height above ground.

8) **RULE: Air Infiltration: Downlights**: Do not include any downlights.

9) **RULE: Air Infiltration: Ceiling fans**: Do not include unless noted on plans.

10) **RULE: Air Infiltration: Exhaust Fans**:

    - 1 per ensuite
    - 1 per bathroom
    - 1 per WC ONLY if zone has no windows/vented skylight
    - 1 per laundry ONLY if zone has no windows/vented skylight.

11) **RULE: Air infiltration: Exhaust fans:**

    - VIC/QLD 2005 onwards all exhaust fans sealed (unsealed prior)
    - SA 2006 onwards all exhaust fans sealed (unsealed prior)
    - ALL kitchens have a SEALED exhaust fan
    - If exhaust fans exist on windows ALWAYS mark as UNSEALED.

12) **RULE: Conditioning: Ensuite:**

    - Conditioned if it does not have a door to the bedroom
    - Conditioned if it has a door but there is no external openable window
    - Unconditioned if there is a door and a external openable window.

13) **RULE: Conditioning: for heating/cooling selections:**

    - If a zone has no doors between itself and another zone, which is conditioned - then select both heat/cool
    - If a zone is a hallway, surrounded by closable doors and primarily conditioned spaces - select heat/cool
    - If a zone is an entry and has closable doors to all other areas and is unconditioned - do not select heat/cool
    - Always select both heat/cool.

14) **RULE: Zone selection: Living:** Maximum 2 living zones are allowed, largest zones take precedence.

15) **Rule: Zone selection:** Small rooms such as a pantry or linen cupboard, which has a hollow core door, it should always be recorded as part of the zone that it is adjacent to.

16) **RULE: Zone selection:** Bed/study rooms are always bedroom.

17) **RULE: Zone selection: Ensuite:** always other night time zone.

18) **RULE: Zone selection: Ensuites:** create a permanent opening if no door between bedroom/ensuite, ALWAYS create two separate zones (i.e. for ensuite and attached bedroom).

19) **RULE: Zone Selection: WIR:** Walk in robes should be separate zones.

20) **RULE: Zone selection: Bathroom**

    - § Other daytime unconditioned
    - § Unless the plans show there is a heating/cooling outlet, then Other daytime conditioned or,
    - § If there is no external openable windows then it is Other night time conditioned zone.

21) **RULE: Anticon** – if it exists, select sarking AND reflective in roof space ZONES.

22) **RULE: Subfloor:** Best to overestimate than underestimate subfloor space ONLY. Subfloor area to include perimeter of walls.

23) **RULE: Subfloor:**

    - § Enclosed: if it has barge boards – is there a wall cavity allowing unobstructed air flow between the subfloor? Mark YES only for cavity brick, not weather board or FC or double brick
    - § Open: subfloor but cannot walk under
    - § Very open: for elevated houses.

B.7 Shading

- Ø Save AccuRate data file regularly throughout creation process.
- Ø In the "Shading" tab, strictly follow the naming protocol.

Common properties

a) Enter separate shading schemes for each shading device, covered pergolas, verandahs, alfresco roofs or eaves attached to or directly above an external wall.
b) If a shading device only shades a window, then enter that as a separate item.
c) If a fixed shade scheme or multiple shading schemes shade part of the width of a window, then the parent wall and window are split appropriately.
d) Shading scheme names must be descriptive and have the relevant data shown
    a. i.e. Eave 450/-260, which means an eave with a 450 mm projection and offset down 260 mm from the top of the wall

24) **RULE: Shading/Eave devices:**

a) For normal eaves (450mm or 600mm) create shading element only for wall directly below it
b) For larger shading devices (i.e. Balcony), no matter which side of house it appears on, create shading device for ALL walls below that shading device

c) TASK: Once shading schemes have been entered into AccuRate, mark on the floor plans each section of external wall that will need to be entered (i.e. External wall segments to be entered for each different external shading scheme).

B.8 Elements

- Ø Save AccuRate data file regularly throughout creation process.
- Ø In the "Elements" tab, strictly follow the order shown in the Zone and construction type drop down menus.

B.9 External Walls

- Ø Save AccuRate data file regularly throughout creation process.

Common properties

a) Select the first zone, then add a new wall for each external wall in the zone detailing the following in a clockwise direction.
b) The construction type.
c) For each wall enter the length and height dimensions.
d) Azimuth: in degrees of the selected wall.
e) Fixed shade: select from drop down menu.
f) Opening: Leave at 0.00.
g) Insect screens: Uncheck.
h) Wing walls: If present, they must be entered accurately
    a. In both projection and offset
    b. And if the wing wall forms part of a courtyard
        i. i.e. has both left and right wing walls
        ii. If the wall is part of courtyard, the courtyard check box is checked
        iii. If not, ensure that it is not checked.
i) External screens (external building/large fence etc).

25) **RULE: Wing walls:** Only those walls that are attached to the house are wing walls. Walls attached to neighbouring buildings are not recorded as wing walls. Wing walls must be opaque walls (solid walls) only.

26) **RULE:** shading applied to ALL adjacent wall(s) perpendicular to that wing wall (limit to 10 m for single story buildings, 16 m for double story buildings).

27) **RULE:** exclude lattice privacy screens that are perpendicular to parent wall.

28) **RULE: External Screen:** Horizontal offset for external screens = measured from the right-hand side of the OUTSIDE of wall, from right hand to the outside of the screen.

29) **RULE: External Screen:** Vertical offset for external screens = apply the vertical offset as per the AccuRate help instructions.

30) **RULE: External Screen:** Apply to ALL parallel wall(s) to that external screen, (for example: neighbours) if they are:

a. A single-storey building within 10 m
b. A double-storey building within 16 m.

31) **RULE:** lattice screens in front of window/wall etc. – state % shading, if present they must be entered accurately**:**

  a. Height, width, distance, projection and offset
    i. Blocking factor (%).

32) **RULE: External Subfloor wall**: REMEMBER to include shading for subfloor walls.

33) **RULE: External Wall for Garage**: Input extra external wall section in garage that goes to external soil 86 mm X 100 mm (or as shown by elevation/plans), due to higher ceiling height in garage

34) **RULE: External wall**: Two bricks or more above a verandah will mean that Energy Makeovers need to separate the external wall; one will be shaded by the verandah, the other by the eave overhead.

35) **RULE: External Garage Wall**: all external garage walls are UNINSULATED, unless specifically noted.

36) **RULE: External Wall Splitting for Different Construction Materials**: External walls should be split horizontally where a different construction material is shown. For example: a brick veneer base (400 mm approx.) with weatherboard cladding above:

- If there are standard eaves 450 no shading is required for the lower portion of the wall
- Don't forget that you still need to include the overall wall height a 2400 ceiling height with 400 BV leaves 2000 WB (even with a negative eave offset).

For each "external wall" also create the following element (if present).

B.10 Windows in external wall(s)

Ø Save AccuRate data file regularly throughout creation process.

Common Properties

a) Windows are to be labelled in a clockwise direction from the left of the ground floor main entrance door (viewed from the inside).

b) Windows, fully glazed doors, sliding doors: it is important to locate these "windows" accurately in the wall both in window head height and window offset from the RH side of the wall
   i. Name of window (or fully glazed door) i.e. W01
   ii. Type
   iii. Construction
   iv. Height
   v. Width
   vi. Window head height (from floor level)
   vii. Offset : Rule: measure from RH side of internal section of wall looking out – state even if there is not wing wall present
   viii. Weather-stripped : not checked
   ix. Insect screens: not checked
   x. If there is a separate window shading scheme it must be entered in the window "fixed shade" field
   xi. Outdoor coverings (External blinds)
   xii. Indoor covering must be Holland blind (for both conditioned and unconditioned spaces, irrespective of statement on plans)
   xiii. Openable % of window, remember that AccuRate automatically applies a restriction or shielding factor to awning openings.

37) **RULE: Window frame,** derivation method, priority order

  a. Derive from working drawings, if not noted
  b. Assume the generic (prior to 2005, timber frame, and 2005 onwards, aluminium frame)
  c. Then RECORD assumption on project tab.

38) **RULE**: **Window type,** derivation method, priority order

  a. Derive from working drawings, if not noted
  b. Assume the generic (single glazed)
  c. Then RECORD assumptions on project tab.

39) **RULE: Gaps and weather sealing**, derivation method, priority order

a) Derive from working drawings, if not noted
b) Assume:
  i. If manufacturer is known: sealed
  ii. If double-glazed windows: sealed
  iii. If fixed window or sliding door: sealed
  iv. Remainder: small gaps
c) Then RECORD assumptions on project tab.

40) **RULE: half light doors**: enter as half window + half-sized solid door; label the window portion with the door number so it is clear that they are one unit/door.

41) **RULE: Door/window combinations**: sidelight and highlight windows have the same frame as the door (assume timber if not noted on plans/window schedule).

Openability Guide:

Doors:	90% (Rule: always one opening for external doors even if it is a double door unit)
Window Guide:	*****openability = portion of window that moves over total*****
Casement/Awning	1 panel 90%, 1 of 2 panels 45%, 1 of 3 panels 30%, 2 of 3 panels 60%
Sliding:	1 of 2 panels 45%, 2 of 3 panels 29%
Louvre:	80%
Fixed:	0% and weather sealed

- **ALWAYS** Refer to elevations to confirm configuration

For each “external wall” also create the following element (if present).

B.11 Doors in external wall(s)

Ø Save AccuRate data file regularly throughout creation process.

Common Properties

a) Ensure all common properties are entered
  i. Name: i.e. D1 clockwise from ground floor main entrance door viewed from inside
  ii. Construction, select from drop down list
  iii. Height and width i.e. 2040 x 820

   iv. Horizontal offset: **Rule**: measure from RH side of internal section of wall looking out – state even if there is not wing wall present
   v. Weather-stripped: not checked (if not stated otherwise)
   vi. Openable, 90%
   vii. Insect screens: **Rule**: NEVER INCLUDE (even if stated that they exist on plans)
   viii. Gap size: **Rule**: medium (if not stated otherwise).

b) Ensure all external wall/s in all zones including roof zone, if a gable is present, are entered.
c) Assessor to highlight element-segments on hardcopy plans as data is entered into AccuRate for QA as per colour legend in EM QA Sheet.
d) Mark as "Complete" on checklist before moving onto the next Element type.

42) **RULE: External Door**: For double doors always enter in AccuRate as a SINGLE door.

B.12 Internal Walls

Ø Save AccuRate data file regularly throughout creation process.
Ø Internal walls are vertical divisions between zones.

Common Properties

a) Save AccuRate data file regularly throughout creation process.
b) An internal wall can also be shared with an attic zone or sub floor zone, such as:
   i. Shaft walls for a skylight
   ii. Walls formed by a split level house in which the wall faces a roof zone or subfloor.
c) Enter each internal wall for each zone as a discreet item and include associated Controlled (door) or Permanent (fixed) opening.
d) Enter each wall length individually within each zone:
   i. Construction type, Select from drop down menu
   ii. Forward and reverse are only applicable if there is a wall present that has different construction properties on each side
   iii. i.e. a internal Brick Veneer wall, then you need to check forward if the Brick faces the zone that it is first entered
   iv. Or reverse if the plasterboard faces the zone in which it is first entered
   v. Length (in metres, to 2 decimal places)
   vi. Height (in metres, to 2 decimal places)
   vii. Adjacent zone
   viii. Opening in m2 and if Controlled (door) or Permanent (fixed)
   ix. Internal walls, including openings
   x. Assessor to highlight element-segments on hardcopy plans as data is entered into AccuRate for QA as per colour legend in EM QA Sheet. Mark as "Complete" on checklist before moving onto the next Element type.

43) **RULE: Internal Garage/House Wall**: Internal garage wall UNINSULATED unless otherwise noted.

B.13 Floors

Ø Save AccuRate data file regularly throughout creation process.

- Floors are horizontal surfaces dividing zones such as a conventional floor, a floor to an alfresco area, or verandah in which the floor area forms part of the roof /attic space.
- A ceiling is also a floor to the attic space.

Common Properties

a) Construction: Select from drop down menu.
b) Area: m^2 to 2 decimal places.
c) Under the floor: Select from drop down menu.
d) Openings: Such as void areas or stairwells (m^2 to 2 decimal places).

44) **RULE: Horizontal openings**: Always place horizontal permanent openings (for stairs/voids etc.) in floor element (openings will automatically be placed in ceiling).

45) **RULE: Floor finishes:**

a) Derive from working drawings, if not noted.
b) Living/Bedroom zones: carpet.
c) Bathroom/laundry/kitchen: tiles.
d) Garage: bare.
e) Then RECORD assumptions in project tab.

46) **RULE: Roof floor:**

a) All roof floors to open air are uninsulated.
b) All eaves, porch, alfresco, verandah etc. areas that are lined and attached to the roof space must be included.

B.14 Ceilings

- Save AccuRate data file regularly throughout creation process.
- Ceilings are horizontal surfaces dividing zones, such as a conventional ceiling under an attic/roof space; it is also the floor to the attic/roof space.

Common Properties

a) Construction: Select from drop down menu.
b) Area: m^2 to 2 decimal places.
c) Above the ceiling: Select from drop down menu.
d) Openings: i.e. such as void areas or stairwells. You cannot have an opening to an attic space/roof zone.

47) **RULE: Garage Ceiling**: ceiling insulation EXCLUDED in Garage unless specifically noted on plans as included.

B.15 Roof

- Save AccuRate data file regularly throughout creation process.
- Roofs can be a conventional roof (above a attic/roof space), or a combined roof/ceiling, such as a flat or skillion roof.

Common properties

a) Construction: Select from drop down menu.
b) Area: m^2 to 2 decimal places.
c) Azimuth: In degrees.
d) Pitch: In degrees.
e) Exposure: Select from drop down menu. It would be unusual to select anything other than "normal".
f) Record the roof area.

48) RULE: Roof Calculation: Use the current version of the RBEES_AccuRateQA_TEMP.xlsx spreadsheet to work out roof area and volume, because the following calculations have been incorporated on to the checklist tab.

Use Sin or Cos where appropriate for roof area and roof volume calculations:

- Actual Roof Surface Area (m^2) = Sum (horizontal roof areas, including eaves in m^2)/COS(roof pitch) Actual Roof Volume (in m^3, at an azimuth of "0") = Sum (horizontal roof areas, including eaves in m^2) x SIN (roof pitch)*(Horizontal distance to ridge m) x volume factor.

Volume factor = 0.333 for hip and valley, 0.5 for gable/skillion.

49) Rule: Roof Construction: if a roof has a small volume, the construction material selected should be a flat roof construction.

- For example, where a lower floor roof butts into the upper floor walls. If the highest point is 400 mm or less, select a flat roof construction. Due to the floor joist, this would leave approximately 100 mm of the wall that goes to the "Roof Space"; this small section of "internal wall" should be included as external wall.

B.16 Skylights

Ø Save AccuRate data file regularly throughout creation process.
Ø Skylights are entered into the relevant roof area, which has the same azimuth and pitch, although the pitch can be set at 0d for dome skylights that do not follow the regular roof pitch.
Ø They are also fixed, with no ventilation openings, and have shaft walls.

Common properties

a) Name: i.e. bath sky light.
b) Type: Skylight with shaft.
c) Construction: Select from drop down menu.
d) Area: m^2 to 2 decimal places.
e) Azimuth: In degrees.
f) Pitch: In degrees.
g) Zone lit: from drop down menu.
h) Outdoor shading: Select from drop down menu.
i) Shaft length; in meters to 2 decimal places. Measured from roof element to ceiling.
j) Shaft reflectance: Normally 0.05, 00 if not known.
k) Diffuser: Check if diffuser fitted at ceiling height.

B.17 Roof Windows

- Ø Save AccuRate data file regularly throughout creation process.
- Ø Roof windows are entered into a roof attached to a specific zone, other than attic/roof zone. They can be operable and do not require shaft walls if fitted to a flat or skillion roof.

Common properties

a) Name: i.e. Family room.
b) Type: Roof window.
c) Construction: Select from drop down menu.
d) Area: m^2 to 2 decimal places.
e) Azimuth: in degrees.
f) Pitch: In degrees.
g) Openable: Fixed 0.00 or Openable percentage i.e. roof window similar to a Velux roof window.
h) Indoor shading: Select from drop down menu.
i) Outdoor shading: Select from drop down menu.

50) **RULE: Window frame**, derivation method, priority order:

a. Derive from working drawings, if not noted
b. Assume the generic (prior to 2005, timber frame, and 2005 onwards, aluminium frame)
c. Then RECORD assumption on project tab.

51) **RULE: Window type**, derivation method, priority order:

a. Derive from working drawings, if not noted
b. Assume the generic (single glazed)
c. Then RECORD assumption on project tab.

B.18 Review data entry

- Ø Save AccuRate data file regularly throughout creation process.
- Ø Check that all data had been entered correctly.
- Ø Review data quantities in various elements of construction page.
- Ø “Check” file and amend any issues raised as “errors” or “warnings” and then finally, finish the ventilation tab.

B.19 Ventilation

- Ø Save AccuRate data file regularly throughout creation process.

Common properties

a) Set north arrow.
b) Set footprint of building by entering the overall length and width.

52) **RULE: Azimuth:**

a) USE BOUNDARY ANGLE on SITE PLAN if available
b) Otherwise use North Angle

   c) Finally use angle from Google maps.

B.20 Run simulation

- Ø Once satisfied – Run the model.

Output files

- Ø Save both the Summary report (aka “Rave report”) and the Building Data Report as PDFs
  - a) Summary report (rave report): Job number_Accurate Cert_YYMMDD.PDF
  - b) Building Data Report: Job number_Accurate Report_YYMMDD.PDF.

File management

- Ø EM RBEES Project Manager to approve AccuRate files for submission to CSIRO.
- Ø Upload to SmartSheet:
  - a) AccuRate Data “.PRO” file
  - b) Summary report (aka “Rave report”) as a PDF
  - c) Building Data Report as a PDF.
- Ø Mark AccuRate Status on SmartSheet as “Base Case Complete”.
- Ø Add comments to the start of the comments cell (newest comments at the start):
  - a) Initials
  - b) Date
  - c) Copy of any comments or assumptions from the Project Tab.

Internal audit

- Ø Periodically, the AccuRate ratings will be audited internally by the Energy Makeovers subject matter expert, to ensure assessments are of high quality.

External audit

- Ø A randomly selected fixed amount of assessments will be externally audited to ensure compliance has been achieved and maintained.

B.21 EM’s AccuRate rating : generic construction materials table

Element	**Description**
All colours	Medium
External walls	
Brick veneer external walls	Brick / vertical air gap >90 mm / 10 mm plasterboard
Cavity brick external walls	Brick / vertical air gap >90 mm / Brick
Wall insulation	Refer to insulation assumptions tables
Light weight external walls	9 mm fibre cement board / vertical air gap 60L90mm / 10mm plasterboard
Garage external walls	Uninsulated unless otherwise noted
External openings	
Entry door: side lights & transom/highlight windows	Clear single-glazed with timber frame if not detailed on plans or window schedule
Window	Clear single-glazed and timber or aluminum as per plan (if not shown on plan refer to window in wall section of current EM AccuRate rating methodology document) with 2100 head height unless noted otherwise
Window coverings	Holland blinds
Window shading	None
Insect screens	None
Window openabilities	**Check elevations for window configuration: % of window that moves should be applied as openability %
External doors	Solid core
Shading (vegetation)	None unless heritage listed tree (as per plan)
Other external	
Roof material	As per plan, if not shown use Google street view
Eaves	Should always be on plan

Internal elements	
Internal walls	10 mm plasterboard / vertical air gap 60-90 mm / 10 mm plasterboard - no exceptions for wet areas
Internal doors	Hollow core 2040 high unless noted otherwise width 720, 820 etc. as per plan
Ceiling	10 mm plasterboard / horizontal air gap >90mm
Garage ceiling	Exclude insulation unless otherwise noted
Insulation (ceiling/floor/wall)	If R value given but type not specified use: glass fibre batts
Ceiling insulation	Refer to insulation assumptions tables on
Floor insulation	None
Floor coverings: wet areas & kitchen	Tiles
Floor coverings: living rooms/hallways	Carpet
Floor coverings: bedrooms	Carpet
Floor coverings: garage	Bare
Weather sealing	NONE doors, windows, wall vents, chimney
Downlights	DO NOT INCLUDE
Insect screens	Not present
Ventilation	Bathroom x 1 unsealed exhaust fan Ensuite x 1 unsealed exhaust fan WC x 1 unsealed exhaust fan ONLY if there is no window (if there is a window no exhaust fan is required) Kitchen x 1 sealed exhaust fan Laundry x 1 unsealed exhaust fan ONLY if there is no window (if there is a window no exhaust fan is required)

Appendix C – Heating and cooling energy consumption

C.1 Heating Totals

C.1.1 BY BOM ZONE

Climate zone	BoM station	Total electricity for heating (kWh) (By BoM zone)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	40958	1208.45	423.08	81.66	20.51	61.24
2	40913	1118.03	321.19	36.64	23.29	40.52
2	40211	1082.33	259.81	36.95	13.92	42.74
2	40004	431.91	38.46	2.99	3.29	3.91
5	23090	1492.21	602.59	70.31	28.50	126.74
5	23083	1644.65	530.21	47.76	23.63	86.66
6	87031	1461.69	532.79	43.22	42.15	82.40
6	86282	1021.06	441.75	49.00	34.69	61.19
6	86077	1477.84	653.01	75.09	36.57	108.22
6	86104	1237.57	445.56	53.75	36.77	69.44
6	23842	2102.07	1288.68	112.53	93.35	268.89

C.1.2 BY BOM ZONE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	BoM station	Total electricity for heating (kWh) (By BoM zone and adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	40958	689.40	314.20	96.39	9.84	65.84
2	40913	590.78	161.01	25.20	11.77	28.21
2	40211	760.44	163.19	38.96	7.16	37.95
2	40004	330.08	2.13	0.00	0.00	0.06
5	23090	1197.94	501.98	74.52	20.35	128.90
5	23083	1626.17	504.51	40.12	30.17	88.54
6	87031	714.92	319.19	26.20	26.33	60.72
6	86282	548.79	304.52	56.50	24.39	71.91
6	86077	755.36	415.25	53.06	18.36	83.57
6	86104	763.91	310.79	47.83	31.18	62.57
6	23842	1717.80	1146.68	103.11	81.70	256.15
5 and 6	23885	655.68	283.98	36.45	23.92	82.50

C.1.3 BY HEATING MODE

Climate zone	Heating mode *(gas, electric reverse cycle)*	Total electricity for heating (kWh) (By heating mode)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	Reverse cycle	1102.48	303.38	42.99	18.32	43.67
5	Reverse cycle	1655.46	706.50	73.20	36.93	144.17
6	Reverse cycle	1361.81	554.68	54.98	41.91	90.83
5	Gas	–	168.17	19.30	7.99	22.30
6	Gas	–	473.05	51.48	34.85	68.83

C.1.4 BY HEATING MODE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Heating mode *(gas, electric reverse cycle)*	Total electricity for heating (kWh) (By heating mode and adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	Reverse cycle	669.42	177.32	39.39	9.12	36.19
5	Reverse cycle	1314.34	598.64	74.39	30.69	147.13
6	Reverse cycle	983.79	551.62	72.50	51.98	118.72
5	Gas	–	98.55	12.78	4.40	18.56
6	Gas	–	221.84	30.90	14.32	43.27

C.1.5 BY CLIMATE ZONE AND STAR RATING

Climate zone	Star rating	Total electricity for heating (kWh) (By climate zone and star rating)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	< 5 Stars	1056.43	294.78	43.52	18.27	42.75
5	< 5 Stars	1716.39	746.32	79.45	36.77	146.43
6	< 5 Stars	1187.41	470.45	51.50	34.77	71.11
2	5 Stars +	1350.51	339.20	37.77	16.75	47.79
5	5 Stars +	1132.26	423.98	40.45	26.13	93.09
6	5 Stars +	1478.59	576.46	54.70	43.54	89.96

C.1.6 BY CLIMATE ZONE & STAR RATING & ADJUSTED FOR STANDBY ENERGY

Climate Zone	Star Rating	Total Electricity for Heating (kWh) (By climate zone & star rating & adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	< 5 Stars	660.36	181.28	43.31	10.29	37.59
5	< 5 Stars	1507.37	661.26	83.02	34.56	150.13
6	< 5 Stars	623.18	304.63	42.46	22.61	62.48
2	5 Stars +	803.80	173.09	24.20	3.51	32.65
5	5 Stars +	879.99	338.83	36.69	21.55	96.92
6	5 Stars +	826.09	398.20	49.63	31.41	80.54

C.2 Cooling Electricity Totals

C.2.1 BY BOM ZONE

Climate zone	BoM station	Total electricity for cooling (kWh) (By BoM zone)				
		Metered period	Summer Dec-Jan-Feb	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	40958	1208.45	503.94	28.69	72.83	50.68
2	40913	1118.03	539.70	29.04	79.05	47.96
2	40211	1082.33	642.09	26.57	103.58	63.44
2	40004	431.91	298.27	19.21	41.14	26.87
5	23090	1492.21	637.73	20.56	104.21	77.43
5	23083	1644.65	806.99	33.11	133.34	91.13
6	87031	1461.69	527.31	25.81	76.37	54.60
6	86282	1021.06	316.12	16.55	50.59	36.30
6	86077	1477.84	464.97	21.99	57.68	55.80
6	86104	1237.57	515.96	17.44	82.20	66.47
6	23842	2102.07	559.31	14.79	107.28	63.73
5 and 6	23885	858.42	300.81	8.45	53.60	37.59

C.2.2 BY BOM ZONE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	BoM station	Total electricity for cooling (kWh) (By BoM zone and adjusted for standby energy)				
		Metered period	Summer Dec-Jan-Feb	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	40958	689.40	342.00	16.55	65.74	46.83
2	40913	590.78	363.02	17.27	69.82	35.78
2	40211	760.44	545.49	18.60	101.90	60.64
2	40004	330.08	291.24	16.43	48.56	26.42
5	23090	1197.94	530.55	13.86	98.97	72.94
5	23083	1626.17	792.36	37.91	139.90	71.55
6	87031	714.92	276.33	7.62	52.85	30.08
6	86282	548.79	172.69	6.32	45.13	24.18
6	86077	755.36	219.01	2.58	37.35	33.06
6	86104	763.91	361.70	5.06	68.79	50.79
6	23842	1717.80	479.18	7.63	109.54	61.26
5 and 6	23885	655.68	236.96	4.57	47.36	34.81

C.2.3 BY COOLING MODE

Climate zone	Cooling mode *(evaporative reverse cycle)*	Total electricity for cooling (kWh) (By cooling mode)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	Reverse cycle	1102.48	573.89	27.94	87.78	54.64
5	Reverse cycle	1655.46	672.74	22.77	111.48	80.81
6	Reverse cycle	1361.81	526.94	16.41	95.72	57.84
5	Evaporative	–	303.48	9.94	57.34	30.13
6	Evaporative	–	396.16	23.06	47.42	47.32

C.2.4 BY COOLING MODE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Cooling mode *(evaporative reverse cycle)*	Total electricity for cooling (kWh) (By cooling mode and adjusted for standby energy)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	Reverse cycle	669.42	432.00	17.70	81.94	47.44
5	Reverse cycle	1314.34	556.03	15.52	105.03	74.17
6	Reverse cycle	983.79	391.08	7.30	91.43	45.85
5	Evaporative	–	242.28	5.59	52.20	23.73
6	Evaporative	–	160.44	5.12	26.95	24.52

C.2.5 BY CLIMATE ZONE AND STAR RATING

Climate zone	Star rating	Total electricity for cooling (kWh) (By climate zone and star rating)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	< 5 Stars	1056.43	542.23	25.81	82.99	53.33
5	< 5 Stars	1716.39	691.91	24.25	111.15	88.84
6	< 5 Stars	1187.41	411.99	20.00	62.23	46.40
2	5 Stars +	1350.51	776.87	41.70	118.83	62.92
5	5 Stars +	1132.26	490.75	15.04	89.60	47.50
6	5 Stars +	1478.59	534.63	20.57	78.01	63.67

C.2.6 BY CLIMATE ZONE AND STAR RATING AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Star rating	Total electricity for cooling (kWh) (By climate zone and star rating and adjusted for standby energy)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	< 5 Stars	660.36	418.60	16.71	80.19	48.80
5	< 5 Stars	1507.37	618.26	23.23	109.00	80.04
6	< 5 Stars	623.18	224.03	5.68	46.45	29.28
2	5 Stars +	803.80	566.99	25.30	101.80	45.39
5	5 Stars +	879.99	415.63	9.37	88.19	43.55
6	5 Stars +	826.09	327.74	6.19	69.40	43.14

C.3 Heating Average

C.3.1 BY BOM ZONE

Climate zone	BoM station	Average hourly electricity for heating (kWh) (By BoM zone)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	40958	0.09	0.10	0.22	0.06	0.17
2	40913	0.09	0.07	0.10	0.06	0.11
2	40211	0.09	0.06	0.10	0.04	0.12
2	40004	0.03	0.01	0.01	0.01	0.01
5	23090	0.12	0.14	0.19	0.08	0.35
5	23083	0.13	0.12	0.13	0.06	0.24
6	87031	0.11	0.12	0.12	0.11	0.22
6	86282	0.08	0.10	0.13	0.09	0.17
6	86077	0.11	0.15	0.20	0.10	0.29
6	86104	0.09	0.10	0.15	0.10	0.19
6	23842	0.16	0.29	0.31	0.25	0.73
5 and 6	23885	0.07	0.09	0.10	0.06	0.22

C.3.2 BY BOM ZONE AND STANDBY ENERGY REMOVED

Climate zone	BoM station	Average hourly electricity for heating (kWh) (By BoM zone and standby energy removed)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	40958	0.02	0.02	0.15	0.00	0.09
2	40913	0.03	0.02	0.05	0.01	0.06
2	40211	0.04	0.01	0.05	0.00	0.07
2	40004	0.00	0.00	0.00	0.00	0.00
5	23090	0.03	0.06	0.11	0.00	0.27
5	23083	0.06	0.06	0.07	0.01	0.16
6	87031	0.03	0.04	0.04	0.03	0.14
6	86282	0.01	0.04	0.07	0.03	0.10
6	86077	0.04	0.08	0.13	0.03	0.22
6	86104	0.05	0.05	0.10	0.05	0.14
6	23842	0.05	0.18	0.19	0.14	0.62
5 and 6	23885	0.01	0.03	0.04	0.00	0.16

C.3.3 BY BOM ZONE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	BoM station	Average hourly electricity for heating (kWh) (By BoM zone& adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	40958	0.81	0.95	1.16	0.85	0.76
2	40913	0.98	1.05	0.92	2.61	0.80
2	40211	1.09	0.84	1.00	0.54	0.76
2	40004	0.74	0.24	0.00	0.00	0.06
5	23090	0.90	0.83	0.93	0.76	0.88
5	23083	0.87	0.59	0.40	0.36	0.59
6	87031	0.48	0.37	0.32	0.36	0.36
6	86282	0.48	0.30	0.30	0.29	0.25
6	86077	0.61	0.53	0.43	0.49	0.51
6	86104	0.72	0.30	0.37	0.26	0.30
6	23842	1.40	1.35	1.39	1.15	1.37
5 and 6	23885	0.43	0.33	0.43	0.30	0.41

C.3.4 BY HEATING MODE

Climate zone	Heating mode *(gas, electric reverse cycle)*	Average hourly electricity for heating (kWh) (By heating mode)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	Reverse cycle	0.09	0.07	0.12	0.05	0.12
5	Reverse cycle	0.13	0.16	0.20	0.10	0.40
6	Reverse cycle	0.10	0.13	0.15	0.11	0.25
5	Gas	–	0.04	0.05	0.02	0.06
6	Gas	–	0.11	0.14	0.09	0.19

C.3.5 BY HEATING MODE AND STANDBY ENERGY REMOVED

Climate zone	Heating mode *(gas, electric reverse cycle)*	Average hourly electricity for heating (kWh) (By heating mode and standby energy removed)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	Reverse cycle	0.03	0.08	0.06	0.00	0.06
5	Reverse cycle	0.05	0.08	0.12	0.02	0.32
6	Reverse cycle	0.06	0.08	0.11	0.07	0.20
5	Gas	–	0.05	0.03	0.00	0.04
6	Gas	–	0.01	0.06	0.01	0.11

C.3.6 BY HEATING MODE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Heating mode *(gas, electric reverse cycle)*	Average hourly electricity for heating (kWh) (By heating mode and adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	Reverse cycle	0.99	0.92	0.95	1.42	0.75
5	Reverse cycle	0.96	0.87	0.92	0.76	0.91
6	Reverse cycle	0.97	0.59	0.60	0.64	0.62
5	Gas	–	0.08	0.09	0.09	0.09
6	Gas	–	0.24	0.25	0.22	0.23

C.3.7 BY CLIMATE ZONE AND STAR RATING

Climate zone	Star rating	Average hourly electricity for heating (kWh) (By climate zone and star rating)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	< 5 Stars	0.08	0.067	0.118	0.050	0.116
5	< 5 Stars	0.13	0.172	0.217	0.101	0.407
6	< 5 Stars	0.09	0.107	0.140	0.094	0.193
2	5 Stars +	0.11	0.077	0.103	0.046	0.130
5	5 Stars +	0.09	0.096	0.110	0.071	0.253
6	5 Stars +	0.11	0.131	0.149	0.118	0.244
(<5 star) – (≥5 star)	ΔE2	–0.028	–0.010	0.014	0.004	–0.014
	ΔE5	0.047	0.076	0.107	0.030	0.154
	ΔE6	–0.023	–0.024	–0.009	-0.024	–0.051

C.3.8 BY CLIMATE ZONE AND STAR RATING AND STANDBY ENERGY REMOVED

Climate zone	Star rating	Average hourly electricity for heating (kWh) (By climate zone and star rating and standby energy removed)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	< 5 Stars	0.03	0.078	0.068	0.001	0.066
5	< 5 Stars	0.04	0.079	0.126	0.012	0.310
6	< 5 Stars	0.03	0.080	0.075	0.029	0.128
2	5 Stars +	0.02	0.046	0.011	0.000	0.038
5	5 Stars +	0.03	0.011	0.051	0.012	0.194
6	5 Stars +	0.05	0.000	0.081	0.051	0.177
(<5 star) – (≥5 star)	ΔE2	0.016	0.032	0.057	0.001	0.029
	ΔE5	0.016	0.068	0.074	0.000	0.115
	ΔE6	–0.020	0.080	–0.006	–0.022	–0.049

C.3.9 BY CLIMATE ZONE AND STAR RATING AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Star rating	Average energy consumed when heating (kWh) (By climate zone and star rating and adjusted for standby energy)				
		Metered period	Winter (June-July-August)	Winter 06:30-08:30	Winter 15:00-17:00	Winter 19:00-21:00
2	< 5 Stars	0.97	0.93	0.94	1.60	0.79
5	< 5 Stars	1.00	0.88	0.81	0.72	0.93
6	< 5 Stars	0.52	0.35	0.34	0.34	0.33
2	5 Stars +	1.25	0.94	1.12	0.53	0.61
5	5 Stars +	0.67	0.57	0.76	0.58	0.63
6	5 Stars +	0.65	0.43	0.45	0.40	0.43
(<5 star) – (≥5 star)	ΔE2	–0.280	–0.008	–0.180	1.074	0.173
	ΔE5	0.337	0.306	0.053	0.137	0.296
	ΔE6	–0.131	–0.081	–0.107	–0.061	–0.098

C.4 Cooling Electricity Average

C.4.1 BY BOM ZONE

Climate zone	BoM station	Average hourly electricity for cooling (kWh) (By BoM zone)				
		Metered period	Summer Dec-Jan-Feb	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	40958	0.09	0.12	0.09	0.20	0.14
2	40913	0.09	0.13	0.08	0.22	0.13
2	40211	0.09	0.15	0.07	0.29	0.18
2	40004	0.03	0.07	0.05	0.11	0.07
5	23090	0.12	0.15	0.06	0.29	0.22
5	23083	0.13	0.19	0.09	0.37	0.25
6	87031	0.11	0.12	0.07	0.22	0.15
6	86282	0.08	0.07	0.05	0.14	0.10
6	86077	0.11	0.11	0.06	0.16	0.16
6	86104	0.09	0.12	0.05	0.23	0.18
6	23842	0.16	0.13	0.04	0.30	0.18
5 and 6	23885	0.07	0.07	0.02	0.15	0.11

C.4.2 BY BOM ZONE AND STANDBY ENERGY REMOVED

Climate zone	BoM station	Average hourly electricity for cooling (kWh) (By BoM zone and standby energy removed)				
		Metered period	Summer Dec-Jan-Feb	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	40958	0.02	0.05	0.01	0.13	0.07
2	40913	0.03	0.07	0.03	0.16	0.08
2	40211	0.04	0.10	0.02	0.24	0.13
2	40004	0.00	0.03	0.01	0.07	0.03
5	23090	0.03	0.07	0.00	0.21	0.14
5	23083	0.06	0.12	0.03	0.29	0.18
6	87031	0.03	0.04	0.00	0.13	0.07
6	86282	0.01	0.01	0.00	0.08	0.04
6	86077	0.04	0.04	0.00	0.09	0.08
6	86104	0.05	0.07	0.00	0.18	0.14
6	23842	0.05	0.01	0.00	0.18	0.06
5 and 6	23885	0.01	0.01	0.00	0.09	0.05

C.4.3 BY BOM ZONE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	BoM station	Average hourly electricity for cooling (kWh) (By BoM zone& adjusted for standby energy)				
		Metered period	Summer Dec-Jan-Feb	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	40958	0.81	0.83	0.87	1.02	0.76
2	40913	0.98	1.84	0.59	0.92	0.76
2	40211	1.09	1.19	0.83	1.41	1.05
2	40004	0.74	0.71	0.35	0.91	0.41
5	23090	0.90	0.99	0.56	1.31	0.92
5	23083	0.87	0.87	0.52	0.95	0.67
6	87031	0.48	0.55	0.38	0.60	0.52
6	86282	0.48	0.53	2.33	0.56	0.42
6	86077	0.61	0.67	0.30	0.72	0.64
6	86104	0.72	0.79	0.26	0.80	0.60
6	23842	1.40	1.76	0.47	2.26	1.40
5 and 6	23885	0.43	0.58	0.28	0.67	0.46

C.4.4 BY COOLING MODE

Climate zone	Cooling mode *(evaporative reverse cycle)*	Average hourly electricity for cooling (kWh) (By cooling mode)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	Reverse cycle	0.09	0.13	0.08	0.24	0.15
5	Reverse cycle	0.13	0.16	0.06	0.31	0.23
6	Reverse cycle	0.10	0.12	0.05	0.27	0.16
5	Evaporative	–	0.07	0.03	0.16	0.08
6	Evaporative	–	0.09	0.06	0.13	0.13

C.4.5 BY COOLING MODE AND STANDBY ENERGY REMOVED

Climate zone	Cooling mode *(evaporative reverse cycle)*	Average hourly electricity for cooling (kWh) (By cooling mode and standby energy removed)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	Reverse cycle	0.03	0.08	0.02	0.19	0.10
5	Reverse cycle	0.05	0.08	–0.01	0.23	0.15
6	Reverse cycle	0.06	0.08	0.00	0.22	0.12
5	Evaporative	–	0.05	0.00	0.14	0.06
6	Evaporative	–	0.01	–0.02	0.05	0.05

C.4.6 BY COOLING MODE AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Cooling mode *(evaporative reverse cycle)*	Average hourly electricity for cooling (kWh) (By cooling mode and adjusted for standby energy)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	Reverse cycle	0.99	1.37	0.73	1.14	0.87
5	Reverse cycle	0.96	1.06	0.55	1.35	0.93
6	Reverse cycle	0.97	1.07	2.19	1.14	0.85
5	Evaporative	–	0.48	0.23	0.50	0.35
6	Evaporative	–	0.32	0.22	0.36	0.31

C.4.7 BY CLIMATE ZONE AND STAR RATING

Climate zone	Star rating	Average hourly electricity for cooling (kWh) (By climate zone and star rating)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	< 5 Stars	0.08	0.127	0.073	0.232	0.153
5	< 5 Stars	0.13	0.162	0.068	0.313	0.226
6	< 5 Stars	0.09	0.096	0.056	0.173	0.161
2	5 Stars +	0.11	0.180	0.116	0.330	0.084
5	5 Stars +	0.09	0.114	0.042	0.249	0.133
6	5 Stars +	0.11	0.126	0.058	0.221	0.000
(<5 star) – (≥5 star)	ΔE2	–0.028	–0.053	–0.043	–0.098	0.069
	ΔE5	0.047	0.048	0.026	0.064	0.093
	ΔE6	–0.023	–0.030	–0.002	–0.048	0.161

C.4.8 BY CLIMATE ZONE AND STAR RATING AND STANDBY ENERGY REMOVED

Climate zone	Star rating	Average hourly electricity for cooling (kWh) (By climate zone and star rating and standby energy removed)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	< 5 Stars	0.03	0.077	0.024	0.180	0.099
5	< 5 Stars	0.04	0.071	0.000	0.218	0.156
6	< 5 Stars	0.03	0.031	0.000	0.108	0.064
2	5 Stars +	0.02	0.088	0.024	0.238	0.083
5	5 Stars +	0.03	0.055	0.000	0.190	0.073
6	5 Stars +	0.05	0.059	0.000	0.154	0.112
(<5 star) – (≥5 star)	ΔE2	0.016	–0.010	0.001	–0.058	0.016
	ΔE5	0.016	0.016	0.000	0.028	0.082
	ΔE6	–0.020	–0.028	0.000	–0.045	–0.048

C.4.9 BY CLIMATE ZONE AND STAR RATING AND ADJUSTED FOR STANDBY ENERGY

Climate zone	Star rating	Average in use electricity for cooling (kWh) (By climate zone and star rating and adjusted for standby energy)				
		Metered period	Summer (Dec-Jan-Feb)	Summer 06:30-08:30	Summer 15:00-17:00	Summer 19:00-21:00
2	< 5 Stars	0.97	1.407	0.724	1.112	0.843
5	< 5 Stars	1.00	1.079	0.495	1.353	0.957
6	< 5 Stars	0.52	0.605	1.104	0.625	0.498
2	5 Stars +	1.25	1.265	0.804	1.417	1.076
5	5 Stars +	0.67	0.774	0.512	0.967	0.636
6	5 Stars +	0.65	0.677	0.420	0.796	0.635
(<5 star) - (≥5 star)	ΔE2	–0.280	0.142	–0.080	–0.305	–0.233
	ΔE5	0.337	0.305	–0.017	0.385	0.320
	ΔE6	–0.131	–0.073	0.684	–0.171	–0.137

Appendix D – Whole House Totals

D.1 By BoM Station

BoM station	Total electricity use (kWh)		
	Metered period	Winter	Summer
40958	5050	1818	1699
40913	5419	1949	1891
40211	5124	1714	1999
40004	6105	2004	2153
23090	4291	1512	1585
23083	5353	1800	2105
87031	4397	1548	1434
86282	3618	1398	1059
86077	4512	1797	1371
86104	6602	2118	2406
23842	6725	3169	1991
23885	3488	1322	1192

D.2 By Climate Zone and Star Rating

Star rating	Climate zone	Total electricity use (kWh)		
		Metered period	Winter	Summer
< 5 Stars	2	5319	1889	1845
< 5 Stars	5	4670	1745	1642
< 5 Stars	6	4076	1509	1265
5 Stars +	2	5176	1690	2140
5 Stars +	5	4491	1574	1692
5 Stars +	6	4752	1700	1561

D.3 Whole House Averages

D.3.1 BY BOM STATION

BoM station	Average hourly electricity use (kWh)		
	Metered period	Winter	Summer
40958	0.77	0.81	0.78
40913	0.86	0.88	0.91
40211	0.81	0.78	0.94
40004	0.95	0.93	1.01
23090	0.68	0.71	0.74
23083	0.83	0.82	0.98
87031	0.68	0.70	0.67
86282	0.55	0.63	0.50
86077	0.69	0.81	0.64
86104	1.01	0.96	1.12
23842	1.08	1.44	0.94
23885	0.56	0.64	0.57

D.3.2 BY CLIMATE ZONE AND STAR RATING

Climate zone	Star rating	Average hourly electricity use (kWh) (By climate zone and star rating)		
		Metered period	Winter	Summer
2	< 5 Stars	0.82	0.85	0.88
5	< 5 Stars	0.74	0.81	0.77
6	< 5 Stars	0.63	0.68	0.59
2	5 Stars +	0.84	0.77	1.00
5	5 Stars +	0.71	0.74	0.79
6	5 Stars +	0.73	0.77	0.73

Appendix E – Other data

E.1 Solar energy

Free energy from the sun commonly has two main uses in residential houses. The first is for solar hot water systems, and the second is for electricity generation via a solar photovoltaic (PV) array. In addition, for houses that have swimming pools, many use solar heating to warm the pool water: see Table A - 3.

Table A - 3 Solar energy systems in houses (%) by city

Solar energy system	City		
	Melbourne	**Brisbane**	**Adelaide**
Solar hot water (gas boost)	47.3	4.3	12.0
Solar hot water (electric boost)	0.9	23.7	7.2
Solar PV	28.2	28.8	41.6
Solar pool heating	5.5	4.3	3.6

E.1.1 SOLAR HOT WATER

Solar hot water systems are becoming increasingly popular in new houses. In Melbourne in particular, gas-boosted solar hot water systems are installed in almost half the houses in the study. Much of this will be due to additional Melbourne government requirements that new houses have either a solar hot water system or a rainwater tank connected to toilets. The solar hot water option appears to be the more popular choice, because it is the lower cost item and all houses require a hot water system of some type.

A preliminary study was undertaken of houses in Melbourne with gas hot water systems (both solar and standard gas storage) to determine how effective they have been. Gas billing data was used and houses split into their star-rating cohorts and the type of hot water system that was installed based on the survey data obtained from the house assessment that was undertaken, see Table A - 4. The analysis assumes that gas consumption for cooking is the same in both star-rating cohorts and the gas consumption for winter heating should be less in the higher-rated houses due to their improved thermal performance.

Table A - 4 Hot water systems in Melbourne

Hot water system	Less than 5 stars	5 Stars or more
Electric storage	1 (3%)	1 (1.5%)
Gas storage	22 (59%)	32 (44%)
Solar (gas boost)	14 (38%)	38 (53%)
Solar (electric boost)	0	1 (1.5%)
Total	**37**	**72**

Table A - 5 shows the results of the analysis. The lower-rated houses show results in line with those expected, with the houses with solar hot water systems having lower gas consumption in both the winter and summer season. Indeed, the houses with the solar hot water systems use 42% less gas in summer and a surprising 44% less in winter. Winter savings were expected to be less than the summer savings, due to the reduced solar input. The higher-rated houses display a much more surprising result. Although summer gas consumption is lower in the houses that have solar hot water, it is not as pronounced as in the lower-rated houses. Gas consumption in houses with solar hot water is down 18%, but is higher than the average summer gas consumption for the lower-rated houses by 23%. Most surprising of all is that during winter, higher-rated houses with solar hot water are using 12% more gas than the higher-rated houses with standard gas storage hot water, and a significant 57% more than the lower-rated houses with solar hot water.

Table A - 5 Gas consumption (MJ) in Melbourne by star rating and hot water system

Hot water system	Less than 5 stars		5 stars or more	
	Summer	Winter	Summer	Winter
Gas storage	30.42	274.68	26.56	206.03
Solar (gas boost)	17.58	147.09	21.66	230.86

The precise reasons why these differences occur are not known. However, possible reasons might include:

- smaller solar hot systems on the higher-rated houses, thus giving lower solar benefits
- higher consumption of gas for other appliances in higher-rated houses, e.g. due to greater use of gas-ducted heating
- poorly installed or less efficient hot water systems on the higher-rated houses
- different hot water usage patterns.

We recommend further investigation into the performance of solar hot water systems to determine if they are performing as expected and that compliance is being achieved.

E.1.2 SOLAR PV

A high percentage of the volunteer households had solar PV installed: 28% of houses in Melbourne and Brisbane, and 45% of houses in Adelaide. This is significantly higher than the national average, which is 16% of households.[4] The majority of the PV systems installed were between 1 and 2 kW, see Figure A - 11. However, there were a significant number of large arrays, with more than 20% larger than 4 kW, resulting in an average array size of 2.6 kW. In energy-efficient houses, such an array may be sufficient to provide all electrical energy requirements.

Within each of the star-rating cohorts, the percentage of houses with solar PV was around the same, as was the average size of the PV array.

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[4] Climate Spectator, Australia usurps the solar throne, 21 August 2012, www.climatespectator.com.au/commentary/australia-usurps-solar-throne

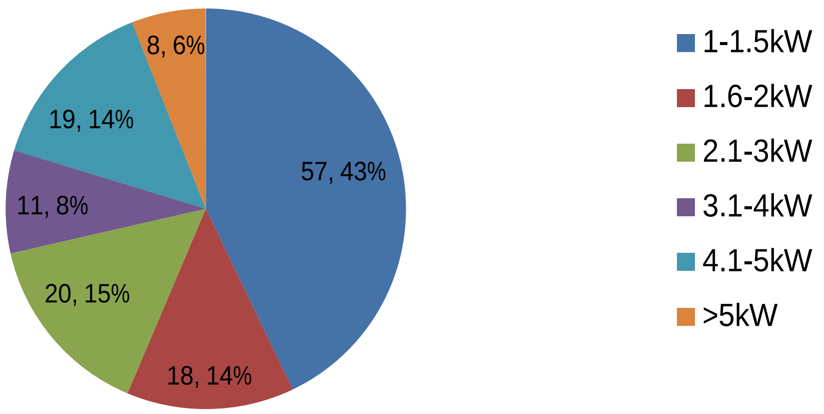

Figure A - 11 **Size of solar photovoltaic array**

The high percentage of solar PV may be due to the nature of the volunteers that were attracted to this study being households that are interested in energy efficiency, who have taken action to reduce their consumption and/or their energy costs. Table A - 6 shows the average daily consumption for houses with and without PV arrays. It reveals that, on average, houses in Adelaide and Melbourne with PV arrays use significantly less electricity (15 kWh) than houses without (21 kWh). However, in Brisbane, houses with PV systems use 4% more electricity than houses without a PV system.

Houses with PV in Adelaide use 34% less electricity, regardless of the season. This would indicate that households that have installed a PV system are energy-saving households as well.

Table A - 6 **Average daily electricity consumption for houses with PV arrays by city**

City	PV array	Daily average (kWh)		
		Yearly	Winter	Summer
Brisbane	Yes	20.4	19.9	22.9
Adelaide	Yes	13.9	14.9	15.1
Melbourne	Yes	14.5	15.9	13.7
Brisbane	No	19.6	19.9	20.9
Adelaide	No	20.9	22.3	22.8
Melbourne	No	18.0	19.7	17.8

Appendix F – Cost data

Costs (per m^2)	Rawlinson 2011			Rawlinson 2008			% Increase/year		
	Melbourne	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide	Melbourne	Brisbane	Adelaide
Windows									
Single-glazed fixed	$244.00	$195.00	$240.00	$226.00	$153.00	$220.00	2.5%	7.2%	2.8%
Single-glazed awning	$327.00	$305.00	$325.00	$304.00	$260.00	$300.00	2.3%	4.9%	2.6%
Double-glazed fixed	$378.00	$380.00	$395.00	$334.00	$301.00	$365.00	3.9%	6.9%	2.5%
Double-glazed awning	$461.00	$490.00	$480.00	$412.00	$408.00	$445.00	3.5%	5.6%	2.4%
Walls									
BV face brick	$113.37	$100.04	$120.40	$112.89	$100.53	$112.64	0.1%	-0.2%	2.1%
Stud wall 100x38mm 450mm centres	$33.30	$39.20	$36.10	$33.30	$35.00	$34.00	0.0%	3.6%	1.9%
Plasterboard 10mm	$24.90	$23.40	$33.30	$21.50	$21.30	$26.00	4.6%	3.0%	7.3%
Paint acrylic	$8.60	$8.10	$11.25	$7.90	$8.10	$9.55	2.7%	0.0%	5.0%
Wall insulation (glasswool batts)									
R1.0	$9.25	$9.15	$8.80	$8.10	$7.95	$7.55	4.1%	4.4%	4.7%
R1.5	$9.25	$9.15	$8.80	$8.10	$7.95	$7.55	4.1%	4.4%	4.7%
R2.0	$9.60	$9.50	$9.15	$8.70	$8.50	$8.15	3.1%	3.5%	3.6%
R2.5	$10.15	$10.10	$9.75	$8.85	$8.70	$8.35	4.3%	4.6%	4.8%

Ceiling insulation (glasswool batts)									
R1.0	$9.25	$9.15	$8.80	$8.10	$7.95	$7.55	4.1%	4.4%	4.7%
R1.5	$9.25	$9.15	$8.80	$8.10	$7.95	$7.55	4.1%	4.4%	4.7%
R2.0	$9.60	$9.50	$9.15	$8.70	$8.50	$8.15	3.1%	3.5%	3.6%
R2.5	$10.15	$10.10	$9.75	$8.85	$8.70	$8.35	4.3%	4.6%	4.8%
R3.0	$11.90	$11.80	$11.45	$10.45	$10.30	$9.95	4.1%	4.2%	4.4%
R3.5	$12.80	$12.75	$12.40	$11.30	$11.15	$10.75	3.9%	4.2%	4.4%
R4.0	$13.55	$13.45	$13.10	$11.90	$11.75	$11.35	4.1%	4.2%	4.5%
R5.0	$17.00	$16.90	$16.55	$14.90	$14.75	$14.30	4.1%	4.2%	4.5%

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