Energy consumption of 100 Australian residential air conditioners

Seasonal operating and stand-by energy consumption of air conditioners across Melbourne, Adelaide and Brisbane

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1. INTRODUCTION

1.1 Residential air conditioner energy use

This study describes the heating and cooling energy consumption of air conditioners in 100 houses distributed across Melbourne, Adelaide and Brisbane, with a particular focus on air conditioner stand-by energy consumption. It is based on results obtained from a project funded by the Department of Climate Change and Energy Efficiency, and the CSIRO, which investigated the relationship between the NatHERS rating and residential heating and cooling energy consumption [1].

Household energy consumption, including transport and residential, accounts for 25 per cent of Australia's energy use [2]. In 2005 in the residential sector alone, there were about six million air conditioners distributed amongst 7.5 million households [3]. The conventional wisdom for the past 15 years has been that households consume about 40 per cent of their residential energy in space heating and cooling. The best available estimates suggest that 33 per cent of this is for heating and 12 per cent for cooling [3, 4]. However, this data is old, based on end-use measurements conducted by Pacific Power on 290 houses in NSW and the ACT in 1993 [5], and model estimates from baseline studies carried out in 1999 [6] and 2008 [4]. The 2008 study cautioned that there was "a paucity of end-use data for residential energy use in Australia" and warned that some of the energy consumption estimates relied on 15-year-old research. The study reported here is the first of a series of papers that will provide more up-to-date measurements and identify ways of improving the efficiency of residential energy use.

1.2 Assumptions embedded in NatHERS for AC usage

NatHERS is a scheme used to rate the impact of a building's design on the heating and cooling energy required to achieve a realistic degree of comfort under common (standardised) assumptions. The benefits may include greenhouse gas reduction, reduced air conditioner running costs, and reduction in electricity network peak demand.

The scheme is not intended to take account of perturbing influences such as: occupant air conditioning usage/thermal preferences; household appliance efficiency, age and maintenance; and differences in occupant controlled heat loads and lifestyle factors. These factors are known to have a potentially overwhelming impact on the achieved benefits that would be obtained from the design of a thermally efficient house [7]. A high-star-rating house does not compensate for a profligate use of energy-consuming appliances.

The report that follows examines one such perturbing influence. It investigates the performance of air conditioning appliances in 100 houses in three cities – Melbourne, Adelaide and Brisbane – and in particular, the consumption of energy by these heat pumps while in stand-by mode.

2. MEASUREMENTS AND METHODS

2.1 Household and air conditioner selection

Households were recruited from Melbourne, Adelaide and Brisbane to represent major population centres in climate zones 2, 5 and 6 as determined by the BCA. 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.

The houses selected were constructed between 2005 and 2011, had NatHERS ratings in a range from 3.5 to 6 star, and used heat pumps for space heating or cooling. Forty houses in Adelaide and 39 in Brisbane were available for measurements in both heating and cooling modes, and 17 houses in Melbourne used heat pumps only for cooling.

While the study from which this paper was derived included many configurations of air conditioner, in this paper we have focused on houses with only one air conditioner. This allowed us to determine the impact of high stand-by energy use. Peak power was assessed from the air conditioner rating plate where accessible, and by measuring peak power consumption from half-hourly measurements taken over nine months.

2.2 Data collection

The heat pump electricity consumption and house internal temperatures were measured at half-hourly intervals. Bureau of Meteorology (BoM) data was also recorded from the nearest weather station. This was carried out from June 2012 to February 2013.

The electricity consumption was monitored using up to 10 current clamps on sub-circuits connected to the main switchboard. The measurement range was 10 milliamps to 80 Amps. Voltage and power factor were measured at the main circuit and power factor estimates were made for the air-conditioner sub-circuits. A data logger in the switchboard stored measurements at half hourly intervals. Figure 2.1 shows a typical installation with a data logger, Wi-Fi router and a 3G modem to allow centralised data collection and ongoing maintenance checks.

We downloaded the coded data twice a day to a secure central computer, using internet technology, while also maintaining the data in the data logger. The data was checked twice a day. Communication failures were usually addressed within a week and the rare data logger failures within 24 hours, except where storms, cyclones or power and telecom infrastructure failures made this impossible.

Central computer back-ups were carried out daily, and the system of back-ups shared between the data logger and the central computer proved to be absolutely essential.

The data logger displayed all the switchboard circuit electricity consumptions as a single bar (Figure 2.1). Individual circuits were colour coded and could be selected or removed from the bar. During the study period the display and the associated data could be accessed by researchers, but not by the householder. This allowed rapid surveys of energy-use patterns for periods of a day, month or year, which enabled us to characterise signals from heating, ventilation and cooling (HVAC) appliance power circuits and to rapidly correct system failures.

The temperature inside each house was measured in a reasonably well-ventilated area of the main living room, 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 (Figure 2.2).

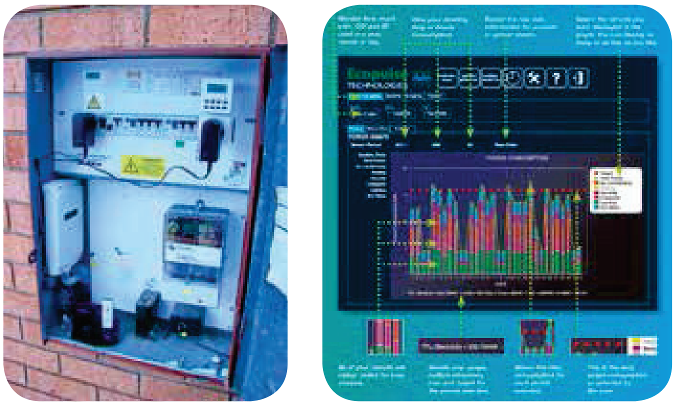


Figure 2.1: Data logger installation with timer, Wi-Fi router and 3G modem and internet webpage display.

Figure 2.2: Typical temperature sensor installed in the home's main living area.

2.3 Analysis of energy consumption

We first compared the measured and modelled heating and cooling energy consumptions to assess the degree to which factors other than house design might influence energy use. We also determined the temperatures and times at which heat pumps were switched on and off, and the energy consumed within the run and stand-by periods.

There were a few days when measurements in some houses were not possible, for example during the cyclone season in Brisbane because of storm damage, or other power or telecommunications shut-downs. Days with missing data were checked and discriminated from normal air conditioner cycling by measuring all house circuits and excluding days in which no data was present on any circuit. Where data was missing, daily or monthly averages for the affected house were substituted. A record was kept of all such lost days, and the associated standard errors were adjusted accordingly.

3. RESULTS

3.1 Average air conditioner energy usage by day

Figure 3.1 is typical of the results we obtained from a visual survey of the data logger measurements. The graph shows the scatter of measured energy consumption data across half-hourly intervals for a typical air conditioner in the sample. It rises to a peak of between 1.5kWh and 2.5kWh over a half-hour interval. Notably there is a very dense line (i.e. frequent occurrence) of energy-consumption measurements at a level of about 0.15kWh. This is the stand-by energy component, and it is apparent that stand-by power is being consumed for very long periods when the heat pump is essentially unused.

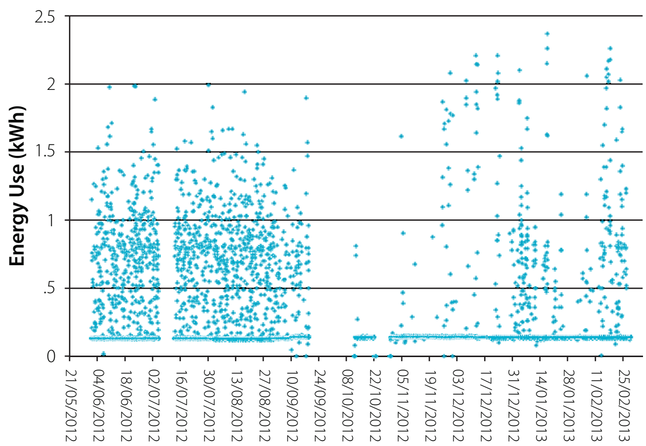


Figure 3 1: Daily operation of an air conditioner over three seasons in Adelaide houses.

3.2 Comparison of heat pump run and stand-by times

Further analysis was carried out to compare run and stand-by periods. Figure 3.2 shows the monthly hours of operation in heating or cooling mode (run time) for air conditioners in Melbourne, Adelaide and Brisbane. The Melbourne sample shows no usage in winter because the houses are heated by gas.

The run time is then compared in Figure 3.3, with periods of operation in stand-by indicating that stand-by periods range from typically three to a hundred times as long as the run times. This is particularly evident in the spring months and is

Melbourne n=17

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
Running						38 ± 14	73 ± 25	145 ± 47	209 ± 65	**465**
Standby						42 ± 13	43 ± 13	40 ± 12	34 ± 11	**159**

Adelaide n=41

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
Running	209 ± 43	221 ± 46	196 ± 42	50 ± 9	37 ± 13	101 ± 37	133 ± 39	242 ± 72	244 ± 73	**1433**
Standby	24 ± 6	24 ± 6	21 ± 5	31 ± 7	31 ± 8	32 ± 8	30 ± 8	26 ± 8	23 ± 6	**241**

Brisbane n=37

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Total
Running	70 ± 23	104 ± 38	69 ± 24	17 ± 9	24 ± 9	71 ± 24	270 ± 79	316 ± 93	83 ± 26	**1025**
Standby	38 ± 8	38 ± 8	38 ± 7	46 ± 9	47 ± 10	44 ± 10	42 ± 10	39 ± 10	35 ± 8	**367**

Table 3.1: Average ± standard error for heat pump energy consumptions (kWh) when running or in stand-by.

most evident in Brisbane. These charts suggest a potential for significant wastage of energy through unnecessary stand-by operation despite the relatively low power levels of the stand-by controllers.

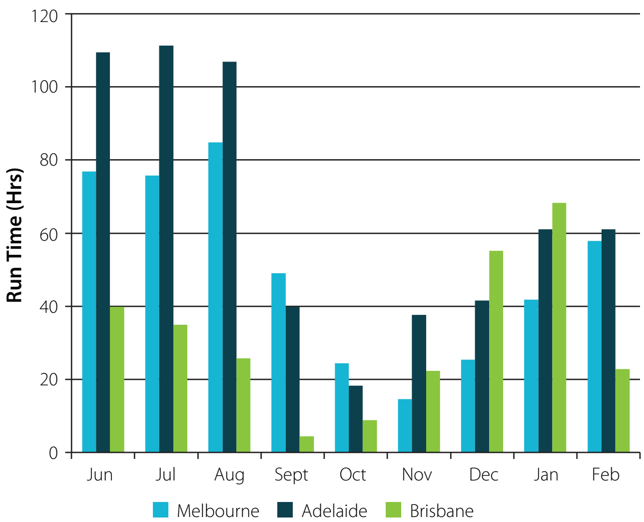


Figure 3.2: Monthly average heat pump run times in each city.

3.3 Comparison of air conditioner energy use in stand-by and when running

Figure 3.4 compares monthly energy consumptions for Brisbane heat pumps when running or in stand-by. Adelaide has a similar profile but with a larger peak in winter, and Melbourne shows the same trend during summer; however, no data is available for winter when most heating in Melbourne changes over to gas.

The monthly and total run and stand-by energies for all three cities are given in Table 3.1. The data confirms that significant amounts of energy are being consumed in stand-by operation, particularly during spring time. Over nine months the air

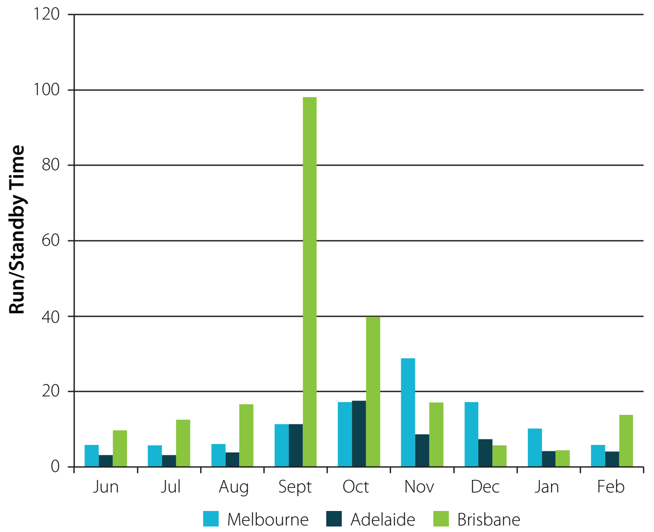


Figure 3.3: Ratios of heat pump stand-by time to running time (monthly averages over houses in each city).

conditioner stand-by energy consumption was about 25 per cent of the total air conditioner consumption in Melbourne and Brisbane, and 14 per cent in Adelaide. If the figures are extrapolated to a year by adding estimated values for autumn, which are similar to the spring season, then these rise to 17 per cent for Adelaide and 31 per cent for Brisbane.

3.4 Air conditioner power use in stand-by and when running

The average power consumption levels when air conditioners were running were similar across all houses in all three cities. The Melbourne cohort of air-conditioners averaged 1.8kW in summer, the Adelaide cohort averaged 1.9kW in winter and summer, and the Brisbane cohort averaged 1.6kW in winter and 2.2kW in summer. Figure 3.5 shows the distribution of run

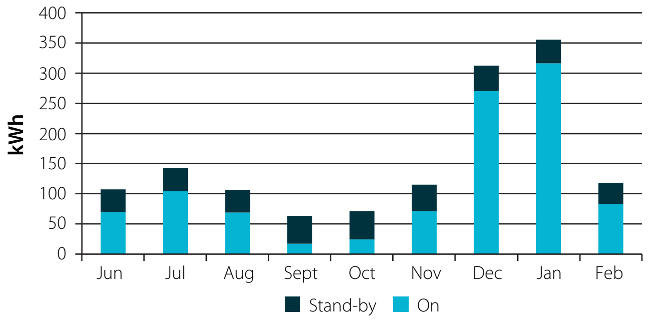


Figure 3.4: Heat pump run and stand-by monthly energy consumptions – Brisbane.

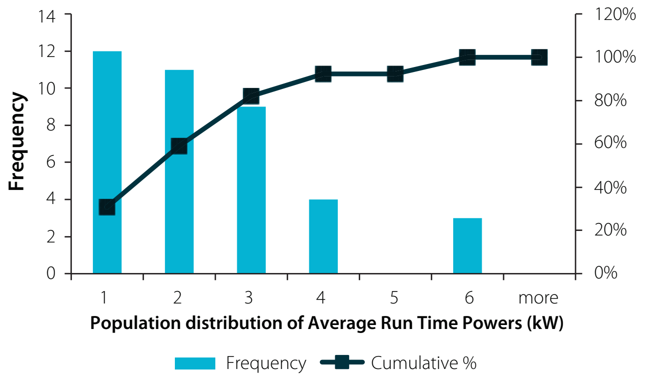


Figure 3.5: Adelaide – peak summer power distribution for heat pumps when running.

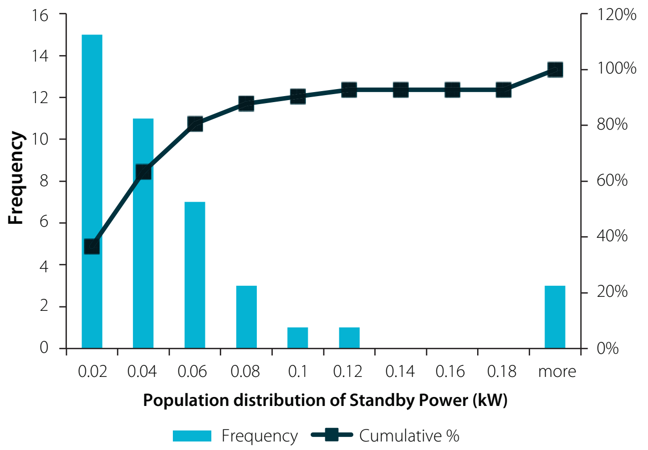


Figure 3.6: Adelaide – summer power distribution for heat pumps in stand-by.

time power consumption across the Adelaide house sample in summer; while the average is 1.8kW there is substantial variation across houses, with three houses having an average run time demand of 6kW of electricity.

The power consumption in stand-by is shown in Figure 3.6. The power used by the air conditioners in stand-by typically ranged from less than 10W up to 150W in all three cities. This is low compared to run- time power, nevertheless it is important because of the long periods of time when stand-by power is used. While the power consumption of stand-by energy control does not contribute significantly to peak power demand, the typical value of 60W is still high for the purpose of electronic control. Reducing both the power and the period of operation in stand-by would each independently provide significant reductions in energy consumption.

3.5 Heat pump operating temperatures

The average temperatures at which the heat pumps were switched on and off during the nine-month monitoring period are shown in Figure 3.7. The range of temperatures, from 17°C to 21°C in winter and from 24°C to 28°C in summer, is not excessive by contemporary standards. Heating and cooling "switch on" temperatures, for example, are well inside the levels used in NatHERS rating calculations.

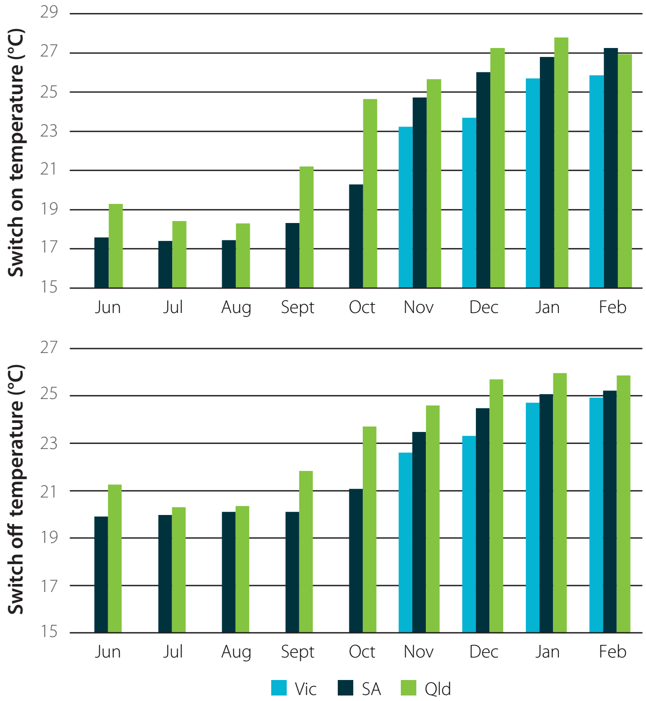


Figure 3.7: Heat pump temperatures when switching on and off.

The change of temperature between the heat pump switching on then off is given in Figure 3.8. The switch from positive to negative values during September, October and November is because in spring time some reverse-cycle heat pumps are in cooling mode while others are heating. This creates an averaging affect that does not necessarily reflect how individual occupants are using their air conditioners in these months.

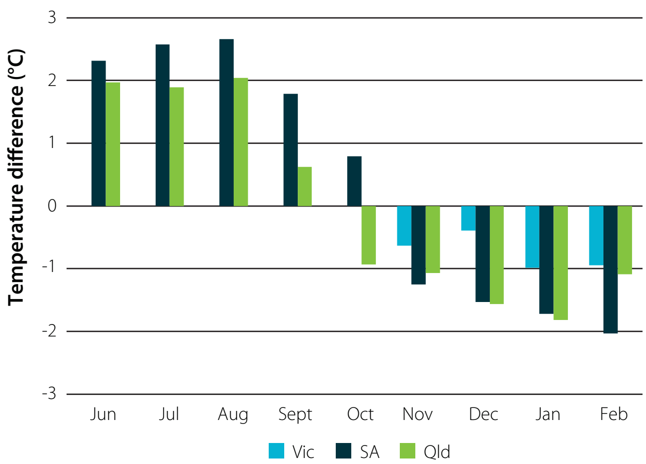
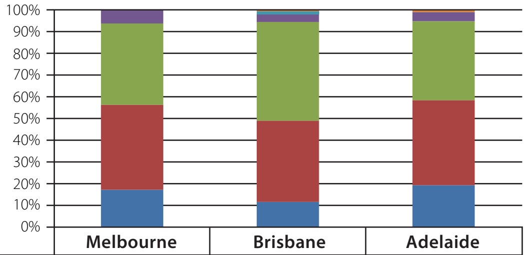


Figure 3.8: Variation in the internal house temperature while the heat pump is running.

The range of temperatures is slightly less, and is more variable from month to month, in summer than in winter. This variability is also seen in the heat pump run times for summer, which are generally shorter and more erratic than in winter. This variability may be associated with the much greater temperature difference between external and internal house temperatures in winter.



	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 3.9: Household awareness of energy use.

3.6 Householder attitudes to energy consumption

We were also interested to know if householders were concerned about energy consumption and, by inference, whether they would be likely to change how they use their air conditioner if given appropriate advice. We carried out a survey of self-reported household attitudes to energy use, the results of which are shown in Figure 3.9.

This indicated that more than 50 per cent of our volunteers considered themselves "very mindful" or "extremely mindful" of energy consumption. While this is by no means a formal market survey, it does suggest that the redesign of air conditioning controllers, to reduce stand-by consumption and to enable air conditioners to be switched off completely, would be well accepted by a majority of well-informed householders.

4. CONCLUSIONS

There are many factors that influence residential heating and cooling energy consumption [7], including inter alia (i) the house thermal efficiency, (ii) householder air conditioner usage/thermal preferences, (iii) householder occupancy and (iv) the efficiency of heating and cooling appliances.

In order to reduce heating and cooling energy consumption we investigated stand-by energy consumption in air conditioners. We found that the energy consumed, simply by leaving an air conditioner to switch on and off automatically, can account for 17 per cent of a home's heating and cooling energy in Adelaide, 25 per cent in Melbourne and 31 per cent in Queensland.

One reason for this is because many controllers run at power levels ranging from less than 10W and up to 150W, which is quite large for a household appliance controller. More importantly, the controllers can run for 10 to 100 times as long as the heat pump, so that even a low power consumption of 10W becomes significant. Three key areas to reduce controller energy consumption might include:

- Reducing the power levels required by the controller electronics possibly through the minimum energy performance standards (MEPS) scheme.
- Development of straightforward control interfaces, to (i) enable householders to manually achieve fully off status and/or (ii) for daily scheduling of air conditioner operation, and/or (iii) a display that includes the hourly energy consumption and cost.
- Older air conditioner controllers use a warm-up phase in stand-by to reduce refrigerant migration when the heat pump is not running, so as to avoid excessive loads when the heat pump starts up. Strategies are needed to minimise or to remove the need for this warming phase.

We hope that this paper may stimulate discussion on how air conditioning systems are star rated, as well as a direct-action approach by air conditioner manufacturers to design enhanced efficiency controllers. The benefits are significant; our measurements suggest that if the stand-by energy consumption was at least halved across Australia it would save 4000GWh of electricity per year, equivalent to about 3.9 million tonnes of CO_2-e/yr of greenhouse gas. It could be highly cost-effective, and the vast majority of potential customers could be very interested in such benefits. ▮

5. ACKNOWLEDGMENTS

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- Association of Building Sustainability Assessors (quality control of the energy re-rating process).

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