STUDY REPORT

SR 329 (2015)

Heat pumps in New Zealand

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Andrew Pollard

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The participation and cooperation of the large number of house occupiers involved in this study is appreciated. This project was in progress during the Canterbury earthquakes and despite that, many households were able and wished to continue with this study. We thank them, as well as those that were unable to continue with the monitored.

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Contents Page

Figures Page

Tables Page

1. EXECUTIVE SUMMARY

There has been a dramatic increase in the use of heat pumps in New Zealand homes over the last 15 years. Their visibility has grown from poorly known, specialised products to widely advertised products with high word of mouth recognition. Heat pumps appear to have bridged the chasm between early adopters and the wider population to become an accepted technology in New Zealand homes.

Despite this popularity, householder’s expectations can sometimes be askew with regard to energy use, delivered comfort, installation issues or maintenance requirements. This study examined a random sample of 160 New Zealand households with heat pumps. This study included site inspections, surveys with the householders and a year of data collection of heat pump energy use as well as the achieved indoor temperature and humidity conditions.

Overall there was a very high degree of satisfaction within the householders. Over 94% of them would recommend a heat pump to their friends or family. Over three quarters of them found them convenient and easy to use. The survey also found 42% described the heating performance as excellent. However only 15% described the running costs as excellent.

Energy efficiency

The high energy efficiency of a heat pump is a strong influencing factor for people purchasing heat pumps. There are two components of energy efficiency that are important to new purchasers. One is to assist in ranking comparable heat pumps on the market. The other is to help to assess what the running costs of the heat pump will be like. There is generally a poor understanding of how energy efficient heat pumps are, as well as what sort of running costs they will incur.

There is widespread use of the Coefficient of Performance (*COP*) as a performance measure both as a ranking method and as an indirect measure of running costs. The *COP* is an experimental result under test conditions of heat output to electrical heat input at a particular set point (typically 7°C). Owing to the dynamic nature of temperatures, the *COP* does not effectively summarise the performance of a heat pump in actual practice. Advice that purchasing a heat pump with a *COP* of greater than 3, gives the false impression that these systems produce more than 3 times the heat output to electrical input over the complete winter heating period. The actual performance is generally lower as the outdoor temperature when the heat pumps are operating are usually much colder than 7°C.

The actual output of a heat pump over a heating season will depend on the climate the heat pump is used in, as well as when and how the heat pump is used. **Typically a heat pump will provide 1.5 to 3 times the heat output to electrical input over the heating season**. Performance measures can be constructed from *COP* measurements at multiple temperature set points (Heating Season Performance Factor; *HSPF*) or from estimating the heat output provided by the heat pump (Measured Heating Performance Factor; *MSPF)*.

There needs to be clearer guidance for consumers about what the actual operating costs will be for a particular heat pump. There is an overuse of the *COP* as a performance measure, that this study has indicated, tends to overstate performance.

Installation

For households which had heating appliances prior to having a heat pump installed, there was an even split between those that were looking to substitute an existing heating system and those looking to supplement an existing heating system.

There was a clear belief amongst householders that a heat pump would have a heating impact through the house. Only 20% of the households had their primary heat pump heating just one room.

Householders provided comments, based on their experience of having a heat pump installed, as to what other people need to consider when installing a heat pump. Many of these householders' comments related to ensuring that the heat pump is appropriately sized for the space that it is intended to service. There was also comment that care needs to be taken with positioning of the indoor units to avoid draughts and there performance in cold weather.

There is need for need for more information about how heat pumps should be setup and what sort of indoor environment they will achieve for each particular household.

As part of the check of the installations some items were encountered. Many of the outdoor units were not well located, with regard to noise disturbance, or clearance from the ground. Condensation drains were sometimes difficult to see or incorrectly discharged onto paths. Around one third of the householders reported that they had no information, or found it too difficult to understand, how to maintain or operate their heat pump.

How they are used

New Zealand homes have traditionally been under heated during winter. One of the promises of heat pumps is that with their greater heating capacity and level of control, householders will be able to maintain relatively stable temperatures in their homes. However over a third of households in this study reported that they were not always warm in winter.

There are indications that heat pumps are being used in different ways from other heating types. Potentially the ease of operation has seen heat pumps being operated more frequently in the mornings and overnight than was the case seen with other types of heating from the Household Energy End-use Project (HEEP; see Isaacs, et al. 2010).

Most householders reported using just one temperature set point. The use of multiple set points such as reduced overnight temperature or different temperature for different times of the day were infrequently used. From the monitored data, the heated room in the houses were seen to be, on average, 2.2°C below the set point temperature during winter evenings. There are multiple reasons for these differences with no common cause. However, the presence of insulation is important. The study found for those houses that were poorly insulated their chances of being less than 18°C were increased.

Heat pumps do not replace the need for insulation in order to achieve appropriate temperature control.

Electrical network impacts

There is a potential that the large scale uptake of heat pumps will place greater demands on the electrical supply network. The convenience of heat pumps over non-electrical heaters, such as woodburners, could potentially drive up the overall demand for electrical heating at peak times.

The changing heating behaviours seen in households with heat pumps could also be important. The more frequent use of heat pumps in the mornings and overnight could have an impact on the electricity network.

The ability of heat pumps to cool also introduces a potential new load that has not previously existed. Around 58% of the participants in this study reported using their heat pump for cooling. However the monitored use of the heat pumps over the summer period shows only a few households where this resulted in the heat pump being on for extended periods of time.

2. INTRODUCTION

How New Zealand homes are heated has attracted the attention of health, environmental, energy and welfare policy makers for at least 30 years. The use of open fires, particularly in airsheds vulnerable to poor air quality because of inversion, prompted a raft of legislative constraints and programmes. These programmes directed the use of clean heat appliances as far back as the 1980s. In combination with the desire to increase energy efficiency, particularly electricity, the impacts of cold and damp dwellings on health, mortality and productivity have driven insulation programmes since the 1990s.

Over that time, heating appliances in New Zealand dwellings have changed and diversified. Until the immediate post-war period, almost all dwellings were heated primarily by open fires, often using coal and coke. The latter part of the 20th century saw some built without any installed heating appliances, with the expectation that plug-in heating appliances would be used. Therefore radiant electric heaters, fan and oil column heaters would be the main source of heating. Gas fires, mostly unflued, have been a feature of many lower-income homes and in areas outside living rooms. Enclosed wood burners, pellet burners and heat pumps are heating appliance options that are not fuelled primarily by electricity but add to the choices for homes.

In the context of the diversification of heating appliances, heat pumps have been presented to the market as energy-efficient, convenient and cost-effective. They will not only allow New Zealanders to space heat but to space cool. They are like other electrical heating appliances that are, in general, acceptable in vulnerable airsheds. The potential technical efficiency and thermostatic control appear to provide a heating appliance that will improve indoor dwelling temperatures, with the associated health benefits. This is whilst delivering affordable heat and reducing the consumption of high-grade electricity.

This report explores the extent to which heat pumps are transforming New Zealand's residential heating. It considers the impact of heat pumps on households' heating practices. This includes the extent to which heat pumps are delivering the heating amenity, energy efficiency and affordability expectations that many associate with them. Finally, it provides guidelines around the installation and operation of heat pumps to improve their performance.

2.1 Study method

This study is directed to establishing how people use their heat pumps, heat pump performance and the determinants of that performance. The study uses a multi-method approach to data collection consisting of:

- on-site observation and assessment of heat pump type, model, output and installation
- on-site monitoring of:
  - energy use
  - temperature and relative humidity in the room being heated or cooled by a heat pump
- a house audit recording physical insulation levels, window size, orientation, type and openable area, roof colour, position of heat pump(s) and other heater locations
- in-depth, telephone-based interviews through structured conversational interviewing techniques.

The use of multiple, complementary data sources improves the robustness of the data platform by allowing triangulation of findings across data sets. The data has been collected from a nationally representative sample of New Zealand dwellings with heat pumps installed.

The project was designed to be nationally representative of houses with air-source heat pumps for space heating. Ground and water-source heat pumps for space heating were not excluded from the study. However the uptake of ground and water-source heat pumps in New Zealand is not large, so predictably, none have been captured in the sample.

2.1.1 Sample frame, recruitment and sample

A sample size of approximately 170 houses is required to give a national picture of heat pump energy use to within 10% with 90% confidence.

To capture the regional and climatic variation necessary to explore heat pump use and performance, sample targets were established for each of the 16 regions in New Zealand. These were based on population (Statistics New Zealand, 2009) and estimated proportions of houses with heat pumps in the region (Page, 2009).

Households were recruited from all councils where it was estimated that there may be heat pumps in more than 1,000 dwellings. The number of households was determined as proportional to heat pump distribution among dwellings in each local or unitary authority area. Recruitment was undertaken in a stepwise process, in the first instance, using an independent company to undertake a brief survey of randomly selected telephone numbers in each region. This screening survey simply involved asking householders whether they had a heat pump and, if they did, whether they were interested in participating. This process involved telephone contact with 2,189 householders. Of those, 683 households (31%) confirmed they had a heat pump and 44% of households with a heat pump expressed interest in participating in the monitoring project. Interest in participation varied regionally, with the lowest being 18% and the highest 83%.

Where householders expressed willingness to participate and were also owner occupiers, formal consent for the installation of monitoring equipment was sought directly from them. Where occupants were tenants, consent was sought from them that their landlord or property manager could be approached for their agreement to install monitoring equipment. Therefore, for tenanted houses, recruitment was dependent on both householder and owner (or their agent) consenting.

A total of 168 dwellings were recruited. Of those, three dwellings had a change of occupants during the course of monitoring to date. In the case of two of those dwellings, the original occupants agreed to be surveyed in addition to the current occupants. This made the total population available for interviewing to 160 householders.

There are some pronounced differences between the study participants and the New Zealand population both in terms of household characteristics and dwelling characteristics. These are set out in section 3. These differences may reflect some degree of sample bias arising from the recruitment method but also reflect the pattern of heat pump demand. Figure 1 sets out the national distribution of participants in the heat pump study.

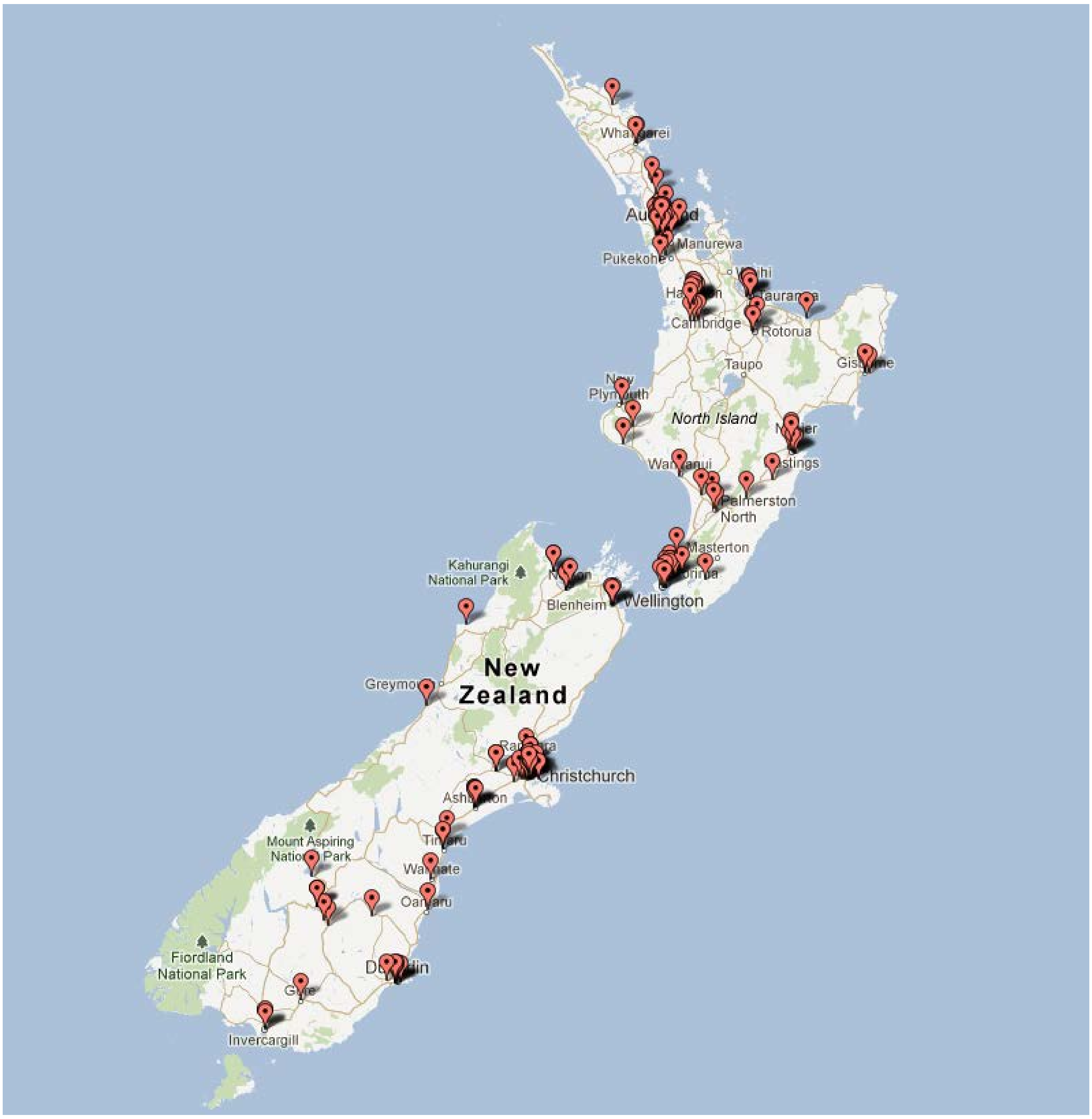


Figure 1 Distribution of participants in the heat pump study

2.1.2 Data collection

Data collection was undertaken using a variety of methods. These including direct monitoring of energy use, auditing of heat pump installation, dwelling surveying and in-depth interviewing of householders.

Each of these data collection activities is detailed in Table 1.

Table 1 Data collection

Monitoring	For each heat pump, the real and reactive electrical energy was monitored at 5-minute intervals by VM smart meters (Energy Intellect, 2010). Each VM smart meter sent data by way of an inbuilt modem to the cellphone network daily. This system resulted in high-quality data with minimal losses. Where possible, houses also had other electricity uses monitored using the same equipment. This was possible only when the heat pump was wired back to the meter or switchboard. Additionally enough space was available on the switchboard for the VM smart meter to be temporarily installed. In all houses, the temperature and relative humidity was monitored in the room with the heat pump at 10-minute intervals by a Hobo logger (Onset, 2010). Temperature and relative humidity loggers were downloaded by a regional download officer every 3 months over the monitoring period. Any material changes in household composition or occupation were updated during those visits.
Audits of installation quality	Installation quality was checked using the checklists produced by the Energy Efficiency and Conservation Authority (EECA). In particular, section 10.6 of the good practice guide for installing heat pumps (Energy Efficiency and Conservation Authority, 2009). That section is presented in Appendix B.
Building audits	Each dwelling was subject to a building audit that collected information regarding the placement of meters as well as a wide variety of other data. This is presented in Appendix C. Completed by the BRANZ staff installing the monitoring equipment. The building audit captured data related to the age and physical characteristics of the dwelling, orientation and wind exposure, heat pump location and installation. It also included a set of preliminary questions with the occupants about the heat pump and a form for the completion of EECA's installation quality checklist.
Householder interviews	Data was collected from householders participating in the study through telephone interviews. The interviews used a semi-structured conversational questionnaire of 46 questions, which included a mix of pre-coded, close-ended categories and open-ended commentary. The questionnaire was developed by the Centre for Research, Evaluation and Social Assessment (CRESA) and includes questions around installation, operation, maintenance and satisfaction with heat pumps. Telephone interviewing commenced in late September 2010 and continued until late August 2011. Interviewing was undertaken in two tranches two allow monitoring recruitment.

2.1.3 Analysis

All energy, temperature and relative humidity data was quality checked, processed and stored at BRANZ, with analysis done in S-Plus. Interview data was recorded by hand and anonymised. The pre-coded data was entered and analysed in the Statistical Package for the Social Sciences (SPSS). For the purpose of this paper, quantitative data has been subject to univariate and bivariate analysis. Thematic analysis has been made of open-ended commentary entered and stored in text form. Data from the BRANZ building audit along with summary variables from the monitoring data has also been incorporated into SPSS and matched to anonymise the household telephone interview data.

2.2 Report structure

The report is structured as follows:

- Section 2 provides an overview of heat pump technology and its supply and take-up in New Zealand.
- Section 3 describes the household and dwelling characteristics of participants in the heat pump study.
- Section 4 presents data on the study participants' heating practices and heat pump use and looks at the indoor environment prevailing in the study dwellings.
- Section 5 focuses on the energy performance of heat pumps, the implications for national energy use and the affordability of heat pumps to households.
- Section 6 deals with installation and maintenance of heat pumps in the study dwellings.
- Section 7 comments on householders' take-up of and satisfaction levels with heat pumps. It also summarises the key issues around heat pump installation, maintenance, use and performance.

3. HEAT PUMPS

This section provides a brief overview of heat pump technology and how the efficiency of heat pumps is measured for the market. It then presents evidence around heat pump supply in New Zealand. A picture of heat pump take-up is presented in the context of broader trends in heating fuels, appliances and practices in New Zealand homes. That data set the context for the heat pump study.

3.1 What are heat pumps and how do they work?

The most common types of heat pump installed in New Zealand homes are air-to-air reverse-cycle single-split systems. These consist of an outdoor unit (compressor) and an indoor unit. These two components are most efficient when placed in close proximity to each other. Back-to-back outdoor and indoor units generally involve the lowest installation costs.

Other types of air-to-air heat pumps include multi-split systems and central systems. Multi-split systems have one outdoor unit and two or more indoor units connected to it. Central systems have a compressor sometimes outside or sometimes in a roof space with ducting to different rooms. Other types of heat pumps include water-to-air, ground-to-air, ground-to-water and air-to-water. These are uncommon in New Zealand in residential buildings and are outside the scope of this study.

Extracting solar heat embodied in the air and raising it to the level where it can provide heating provides an efficient way of utilising energy from the surroundings (Figure 2). When this process is reversed, internal spaces can be cooled.

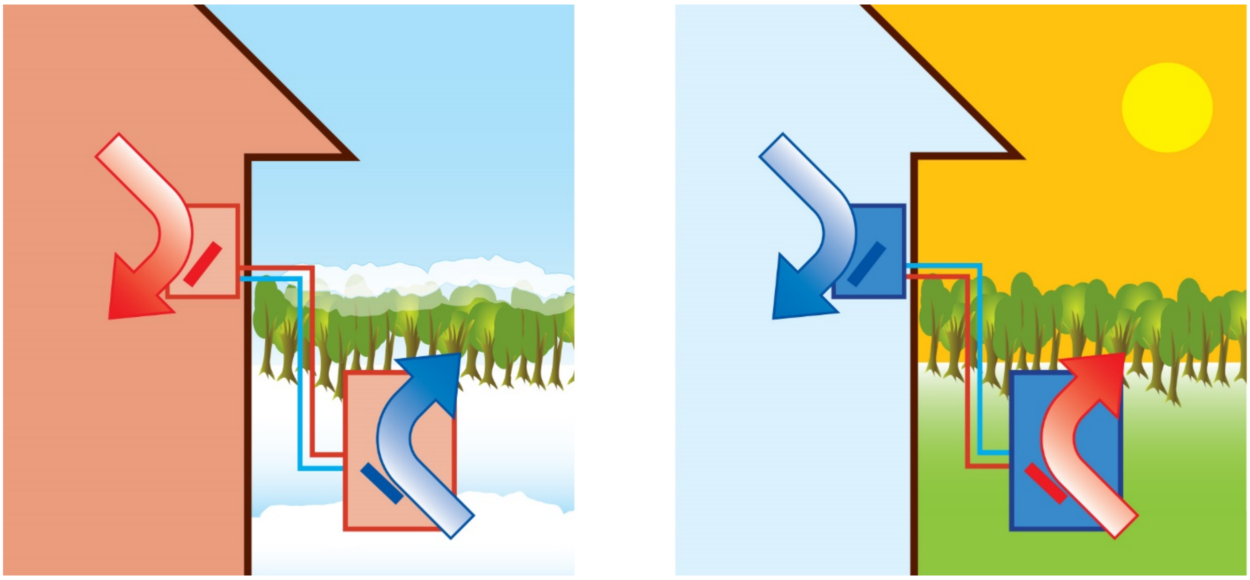


Figure 2 How a heat pump works

There are some technical issues that arise for heat pumps when dealing with very cold environments. In particular, as the outdoor-indoor temperature differential increases, the ratio of heating delivered to the effective energy input of the heat pump will approach 1.0. When this point is reached, heat transfer no longer occurs. The temperature at which this will occur can range from -10°C to -20°C. At around 0–4°C (7°C in high humidity), any water vapour in the air will start to condense and freeze onto the evaporator (outdoor heat exchanger) coils. This disrupts the heat flow, and coils must be defrosted for heating to continue.

To remove ice build-up on the coils, most heat pumps have a defrost cycle where the system switches into cooling mode (taking heat from inside). While this is occurring, no heat is supplied to indoors, and if the indoor fan does not shut down, cold air may be blown inside. The defrost frequency and performance are critical to heat pump efficiency. Undersized heat pumps will need to defrost frequently in low ambient temperatures, reducing the system's ability to reach and maintain set point. If the defrost cycle operates too frequently or if it does not operate often enough, it will not provide sufficient heating. This results in the heat pump's heating performance being compromised.

The defrost cycle control can be one of two types. Time-temperature defrost, starts and stops at pre-set times. On-demand defrost, operates only when frost build-up is detected on the outdoor coil. Systems that include a dry-coil defrost cycle briefly run the outdoor fan at maximum speed before the system starts to remove any water still on the coil fins that could refreeze.

Before the heat output of a heat pump matches the electricity input energy, there will be a point where the heating capacity cannot provide enough heat to keep the space warm enough. This is described as the balance point. Below the balance point, additional heating will needed to keep the indoor spaces comfortable. The balance point will vary according to ambient outdoor temperature, insulation levels of the building and/or heat loss through ventilation.

3.2 The promise of efficiency

The efficiency of a heat pump is the ratio of the heating or cooling delivered to the total energy required to operate the system. If 4.5 kWh of heating is provided by a heat pump which requires 1.5 kWh to operate, then the efficiency is 300%. The efficiency for heating and cooling for a particular heat pump generally have different values and consequently different terms for each are used. The efficiency of a heat pump for heating is called the **Coefficient of Performance (COP)** and the efficiency for a heat pump to cool is known as the **Energy Efficiency Ratio (EER)**.

COP and EER values vary with the temperature differential between the source and supply heat. As the temperature difference increases, the COP or EER of a heat pump decreases. The decrease in COP or EER occurs as the requirements for either indoor heating or cooling increases. For heating, as the outdoor temperature falls, increasing outdoor and indoor temperature difference, the COP of a heat pump decreases (see Figure 3). For cooling, as the outdoor temperature rises, increasing the difference between the outdoor and indoor temperatures, the EER of a heat pump also decreases. Irrespective of the measure used, a higher COP or EER indicates a higher-efficiency heating or cooling system.

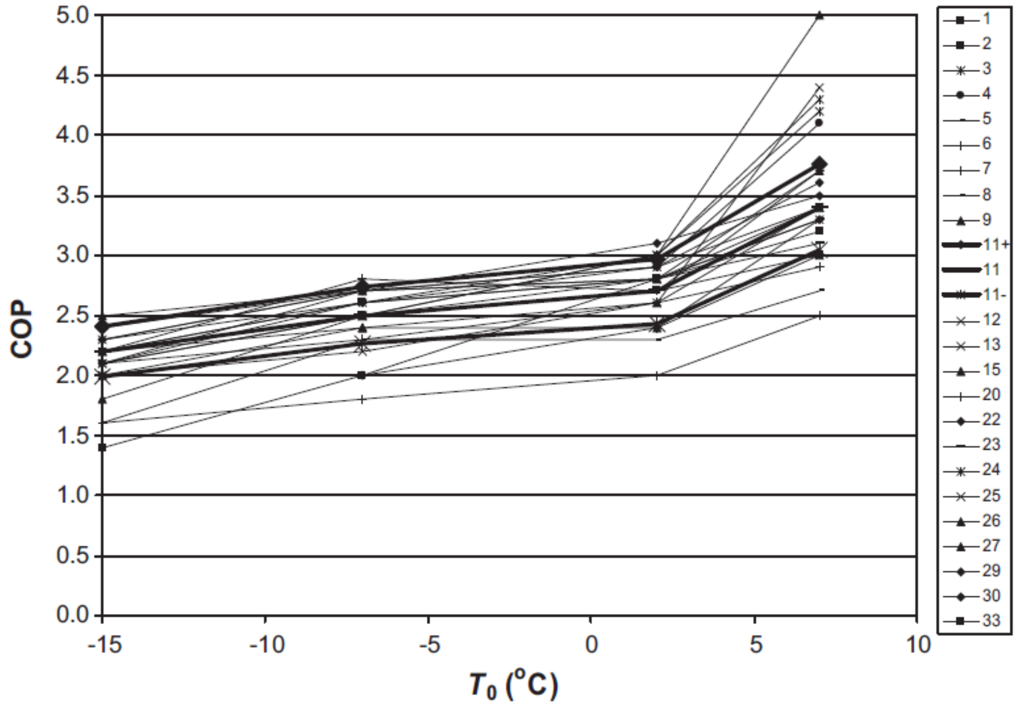


Figure 3 The COP for 23 air-source heat pumps with varying ambient temperature (reproduced from Ertesvåg, 2011)

Because the COP depends on the differential between supply and source temperatures, heat pump outputs are rated at specific temperatures. Heat pumps in New Zealand must be rated in test conditions at a 7°C ambient outdoor temperature test condition (known as H1). This is according to AS/NZS 3823.1.1:2012 *Performance of electrical appliances – Airconditioners and heat pumps – Part 1.1: Non-ducted airconditioners and heat pumps – Testing and rating for performance*. However, test conditions are not necessarily replicated in the conditions of in situ dwelling use. The COP generally does not take into consideration the actual mid-winter temperatures at which heat pumps may operate. The test method in AS/NZS 3823.1.1:2012 does provide for testing at lower temperatures (2°C for H2 and -7°C for H3). However, these are not used in the Minimum Energy Performance Standards (MEPS) requirements under the Energy Efficiency (Energy Using Products) Regulations 2002. Nor are they used for the energy star rating label requirements under AS/NZS 3823.2:2013 *Performance of electrical appliances – Air conditioners and heat pumps – Part 2: Energy labelling and minimum energy performance standards (MEPS) requirements*. However EECA's higher energy performance standard, Energy Star®, has requirements for energy performance at H2 (2°C) conditions (EECA, 2015).

Ranking heat pumps based on their performance solely at 7°C presents a difficulty in that their ranking is not necessarily the same when operated at other temperatures. For example, for the 23 heat pumps shown in Figure 3, the heat pump with the second-highest COP at 7°C becomes mid-ranked when the test conditions are changed to 2°C.

In some other countries, such as the USA (Department of Energy, 2015), product declaration information includes performance measures that combine performance estimates for a number of different temperatures. The weightings for the performance of the heat pump at each temperature level need to be set depending on the conditions the heat pump is likely to be exposed to. In the USA, the **Heating Season Performance Factor (HSPF)** for heating and a **Seasonal Energy Efficiency Ratio (SEER)** for cooling are used. These factors are not directly relevant for New Zealand because they include American customary units (BTU) and consider different temperature conditions. The advantage of the HSPF (and SEER) over the COP (and

EER) is that it more accurately account for the operation of the heat pump in different temperature conditions

In an actual house (non-test conditions), the actual efficiency of a heat pump may be influenced by:

- climate
- heating and cooling demands
- the time of day the heat pump is used
- source and supply temperatures
- auxiliary energy consumption (pumps, fans)
- operating characteristics.

The performance of a heat pump in actual use over a complete heating season taking account of the outdoor temperatures when the heat pump is operating can be summarised by the **Measured Heating Performance Factor (MHPF).** The MHPF is the ratio of heating delivered over the heating season to the total energy input, including defrost cycles.

The MHPF is a dynamic measure of the performance of the heat pump and gives a value similar to the COP and the HSPF but is what the heat pump actually achieves in practice.

The same model of heat pump (which has a particular COP) used the same way in identical houses will have a different HSPF (and MHPF) when it is located in Auckland as to when it is located in Queenstown. Two identical heat pumps used in two differently operated Queenstown houses will have the same COP and HSPF but are unlikely to have the same MHPF. This is summarised in Table 2.

Table 2 Changes of the various performance measures when the climate and the operation of the heat pump is changed

Measure	Number of temperature set points	Impact on measure by changing	
		Climate	Climate and Use
COP	1	None	None
HSPF	2-4	Different	None
MHPF	Actual range	Different	Different

3.3 Heat pump supply in New Zealand

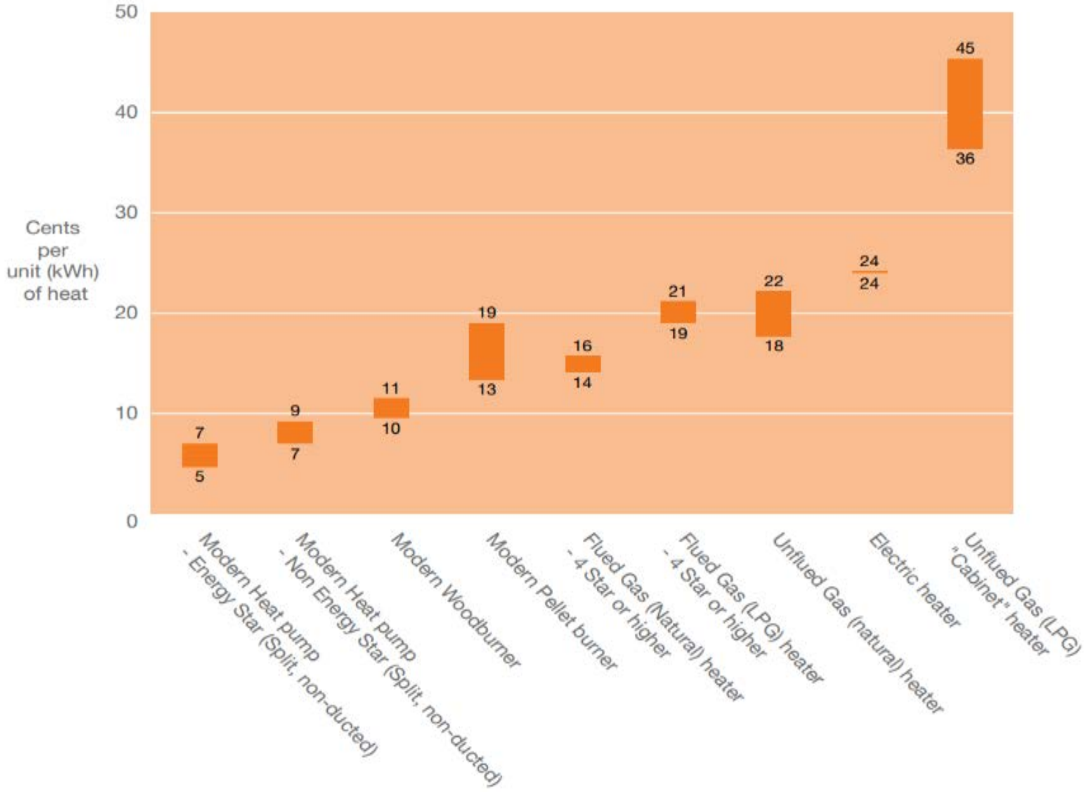
There is a wide variety of heat pumps available in New Zealand with a diversity of brands, designs and specifications. They are available from specialist installers as well as building product retailers, heating appliance retailers and some electrical appliance retailers. Despite piercing the building envelope, heat pumps can be installed in New Zealand dwellings without a building consent. In this regard, heat pumps contrast with enclosed wood burners, flued gas heaters and pellet burners and are more akin to plug-in electrical appliances.

The COP rating system is widely used by consumers to compare heat pump models. In the absence of other information, heat pump COPs are also used to assess relative performance, heat output and cost effectiveness compared with other types of heating.

There are, of course, other measures of appliance performance. These include absolute heat output, purchase and installation cost, compliance requirements, appliance longevity, operating costs and payback periods. Table 3 provides an indicative comparison of different appliance groups in relation to acquisition price, heat output and compliance requirements. EECA provides operating cost estimates for different heating appliances, as does Consumer NZ. There are some differences in their costing information as can be seen in Figure 3 and Figure 4 respectively. Operating cost information is sensitive to variations in fuel prices.

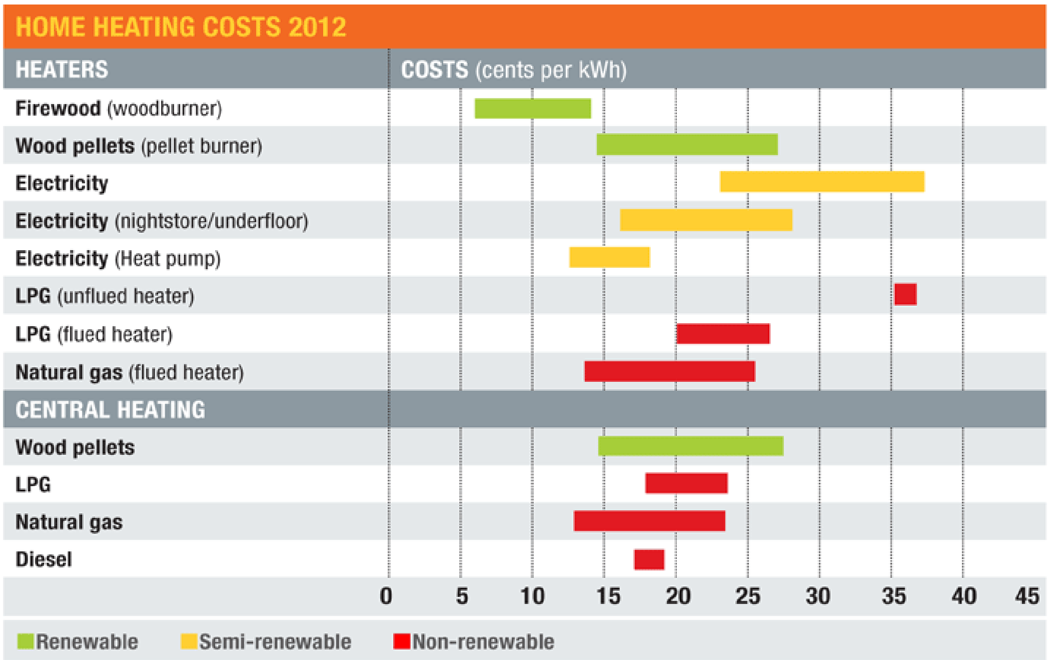
Table 3 Comparison of different heating appliances

	Heat pump	Pellet burner	Wood burner	Flued gas heater	Electric plug-in heater
Purchase and installation cost	$2,500–4,500	$4,000–5,000	$3,000–5,000	$2,500–7,000	$50–200
Typical output (test conditions)	2–10 kW	2–11 kW	Up to 27 kW	Up to 8 kW	1–2.4 kW
Council consent required	No	Yes	Yes	Yes	No



Based on typical highest and lowest heater efficiencies. Does not include purchase/installation and maintenance costs. Fuel cost assumptions: Electricity 24 c/kWh; Wood pellets $0.62/kg; Firewood $75/m3; Natural gas 12.4c/kWh; LPG (45kg bottle) $2.30/kg plus $120 annual rental charge (18.5c/kWh including bottle rental assuming a total annual gas consumption of 7000 kWh) ; LPG (9kg bottle) $3.50/kg. For unflued gas heaters 30% of the heat produced is assumed to be lost due to the requirement to leave a window open. Note that fuel costs can vary greatly depending on location, retailer and plan.
*Natural gas price includes a portion of fixed charges assuming a total annual gas consumption of 7000 kWh. Actual cost depends on your tariff and actual total gas consumption.

Figure 4 Estimated operating costs for a range of home heating options (EECA, 2010)



Costs are calculated on the basis of providing 1 kilowatt of heat for 1 hour. Firewood is pine, and its costs are from our November 2011 survey of prices. Electricity and natural gas costs are from PowerSwitch. Other costs are from pricing data collected during March 2012. GST is included.

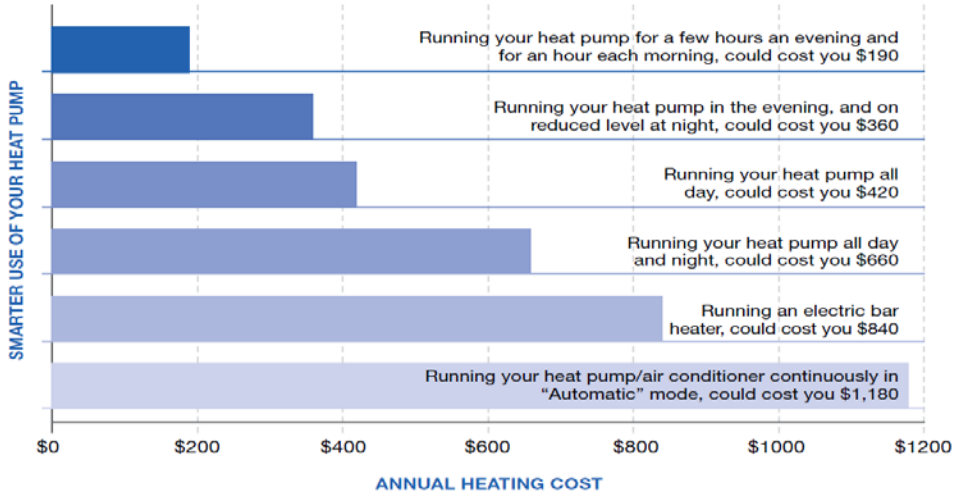
Figure 5 Consumer NZ's fuel price comparison[1]

Price information is directly available to consumers where a heat pump or other heating appliance is being retrofitted. It may or may not be itemised in new build construction prices. Purchasers of speculatively built dwellings or dwellings off plans are unlikely to be aware of price information on the heat pump itself. Information on typical operating costs under different operating conditions for heat pumps is becoming available to consumers.

EECA has released a good practice guide for consumers indicating how heating appliance use patterns may impact on annual heating expenditure. As Figure 6 shows, however, this type of information embeds a number of assumptions, the implications of which may not always be clear to householders.

[1] See: www.consumer.org.nz/reports/heating-options/fuel-prices-compared (accessed 7/9/12)

Figure 10.0 Annual heat pump running costs



Note: These figures are for information only. The values used are based on a number of assumptions (such as size of heat pump, ambient room and outside air temperature, levels of home insulation etc). Actual running costs will vary significantly depending on these assumptions as well as each particular product's characteristics and the individual installation.

Figure 6 Annual heat pump running costs from EECA good practice guide

Information on the life or operational longevity of heat pumps is not widely available to consumers, in part, because this data is less likely to be generated by laboratory testing. In addition, the relatively short history of heat pump use means that experiential information is limited. However, most estimates suggest that heat pump longevity ranges from 12–15 years, although warranties on the compressor and parts are typically 5 years or less. Corrosive environments may see longevity significantly reduced. Longevity combines with acquisition, installation and operating costs to determine the payback period for heating appliances.

Table 4 sets out the payback period of different heating appliances against a baseline of an electric plug-in heater. It shows that, compared to other appliances, heat pumps have a slightly quicker payback period than a wood burner where living room spot heating is the predominant form of use. Where a more whole-house heating approach is undertaken, wood burners can be expected to have shorter payback periods. Notably, both pellet burners and flued gas heaters have significantly longer payback periods. Unflued gas heaters have not been included in this analysis because they are associated with a wide range of negative health and indoor air-quality problems that make their use inadvisable (Pilotto et al., 2004).

Table 4 Operating costs, payback periods and operational life

	Heat pump	Pellet burner	Wood burner	Flued gas heater	Electric plug-in heater
Payback – living room heating only	6–9 years	10–16 years	6–10 years	13–37 years	N/A – electric heater is the payback baseline
Payback – heating 80% of house	5–8 years	5–8 years	3–5 years	9–28 years	N/A – electric heater is the payback baseline
Expected lifetime	12–15 years (less in corrosive environments)	15–20 years	20–30 years	20 years	2–10 years
Typical warranty period	5 years on compressor, 3 years on parts	5 years on firebox, 1 year on parts	Up to 15 years on firebox, 1 year on parts	Up to 15 years on firebox, 3 years on parts	1–2 years

3.4 Home heating and heat pumps in New Zealand

Heat pump use in New Zealand dwellings is relatively recent and is part of a broader diversification of heating appliances in New Zealand homes since the 1960s. It also reflects the long-term tendency for reticulated electricity to be adopted as the primary fuel source for both water and space heating in New Zealand.

3.4.1 Changing heating fuels

The increased availability of reticulated electricity and distributed gas in the second half of the 20th century resulted in a shift away from reliance on solid fuel. Table 5 and Table 6 demonstrate a trend away those fuels from to reticulated electricity.[2] Table 3 shows a jump of 28% in the proportion of houses using electricity from 1961 to 1966. The proportion of houses using mainly solid fuel (coal, coke or wood) fell by 34% between 1961 and 1966.

Table 5 Main heating fuel – 1961 to 1971 Censuses and HEEP

Main fuel used for heating	1961 Census	1966 Census	1971 Census
Electricity	10%	38%	42%
Gas	2%	1%	1%
LPG*	2%	3%	6%
Solid fuel^	83%	49%	50%
Other	2%	6%	0%
Not specified or no heating	1%	3%	1%

* Assuming 'kerosene' in 1961, 1966 and 1971 Censuses is functionally equivalent to an LPG heater.
^ Assuming 'space heater' in 1961 and 1966 Censuses is an enclosed solid-fuel burner.

Table 6 demonstrates the importance of electricity in space heating. It also shows that households have persisted with solid fuels for heating, although this became increasingly mixed with the use of electrical heating appliances.

[2] For the purposes of this analysis, the reported fuel 'kerosene' has been taken as functionally equivalent to LPG – both are used in the main for portable space heating.

Table 6 Heating fuels – 1971/72 Electricity Survey, Censuses and HEEP

<table>
<tr><th>Fuel type used to heat dwelling</th><th>1971/72 Household Electricity Survey</th><th>1976 Census</th><th>1981 Census</th><th>1986 Census</th><th>1991 Census</th><th>1996 Census</th><th>2001 Census</th><th>HEEP</th></tr>
<tr><td>Electricity</td><td>92%</td><td>81%</td><td>72%</td><td>79%</td><td>77%</td><td>77%</td><td>72%</td><td>75%</td></tr>
<tr><td>Reticulated gas</td><td>5%</td><td>4%</td><td>5%</td><td rowspan="2">9%</td><td rowspan="2">16%</td><td>12%</td><td>13%</td><td>13%</td></tr>
<tr><td>LPG (or kerosene or oil)</td><td>15%</td><td>10%</td><td>7%</td><td>22%</td><td>28%</td><td>34%</td></tr>
<tr><td>Solid fuel</td><td>59%</td><td>49%</td><td>51%</td><td>67%</td><td>60%</td><td>62%</td><td>54%</td><td>52%</td></tr>
<tr><td>Other</td><td>1%</td><td>7%</td><td>4%</td><td>3%</td><td>2%</td><td>2%</td><td>2%</td><td></td></tr>
<tr><td>No fuels used</td><td></td><td>1%</td><td>3%</td><td>1%</td><td>1%</td><td>2%</td><td>3%</td><td></td></tr>
<tr><td>Average fuels per house</td><td>1.73</td><td>1.51</td><td>1.40</td><td>1.57</td><td>1.56</td><td>1.75</td><td>1.70</td><td>1.74</td></tr>
</table>

Assuming 'kerosene' reported in the 1971/72 Survey, 1976 and 1981 Censuses is functionally equivalent to an LPG heater. Reticulated gas and LPG were not separately reported in 1986 and 1991.

Despite the slow decline of solid fuel heating, the 2006 Census shows that 40.9% of households report using wood. A further 7.0% of households report using coal to heat their home (Statistics New Zealand, 2007). The Household Energy End-use Study (HEEP) confirmed that distribution of fuel type uses in the residential building stock.

3.4.2 Take-up of heat pumps

The prevalence of heat pumps in New Zealand households is by no means easy to establish. A survey of households in 2009 suggested that 21% of dwellings had heat pumps in their dwellings. However, this data may understate the prevalence of heat pumps. Heat pumps are more likely to be taken up by higher-income dwellings, and the profile of participants in that survey showed a bias towards lower-income households (Page, 2009). A 2010/11 survey of Community Service Card householders in the Rotorua airshed with non-compliant heating found that around 17.5% also had heat pumps (Saville-Smith et al., 2011). Of those, however, only around half used their heat pump as their main heating device. Among this group, there was a strong tendency to use heat pumps as ancillary heaters situated in parts of the dwelling other than the living area. Surveying in Rotorua among homeowners with non-compliant appliances found that wood burners remain a strong preference. 40.3% of households expressed a preference for this heating method. That preference was also evident in the Bay of Plenty Regional Council's clean heat scheme. 62% of the clean heat installations approved under the Regional Council's loan scheme had been for upgrading with low-emission wood burners.

However, there is evidence that higher-income households have been adopting heat pumps and have a preference for them. A longitudinal study into household renovation practices found that, while 30% of householders preferred an enclosed wood burner in their living room, a quarter (25%) of householders reported a heat pump preference. Moreover, out of 162 households undertaking renovations, 15.2% installed heat pumps but only 4.8% installed enclosed wood burners (Saville-Smith et al., 2010).

BRANZ's 2010 House Condition Survey provides the most recent, comprehensive and representative data on space heating in New Zealand. It shows 72% of dwellings used electrical heating, while 47% of dwellings used solid fuels. The take-up of heat pumps varied across climate zones but was persistently less than 40% of dwellings. In Franklin and Thames-Coromandel, heat pumps were found in less than 20% of dwellings. Nevertheless, they were the third most common heating system after wood burners and portable, convection plug-in electric heating systems (Buckett et al., 2011).

3.4.3 Impacts on heating practice

Completed in 2007, HEEP provided for the first time a systematic understanding of temperature management in New Zealand dwellings. Those practices were characterised by the tendency to under heat, spot heat, evening heat and heating but not cooling. Since HEEP, both fuel and appliance diversification has been marked. This raises two critical questions. Firstly, whether changes in heating appliance are impacting on New Zealanders' traditional heating practices. Secondly, whether the heating amenity experienced by those using heat pumps increases the likelihood of warm homes.

3.4.4 Implications of heat pumps for national energy consumption

One of the drivers of replacing solid-fuel burners with heat pumps is the clean air regulations (Ministry for the Environment, 2008). These were expected to be enforced by regional and unitary authorities in New Zealand. In response, the Ministry for the Environment, EECA and a number of territorial authorities have been involved in clean heat programmes that encourage heat pump take-up through subsidies. Two issues arise from this approach. The first is whether New Zealand has the capacity to meet any additional demand for electricity through low-emission forms of power generation. The second is whether New Zealand's generation and distributional infrastructure can cope with increased demand, particularly peak demand.

The substitution of non-electrical energy for heating by reticulated energy and changes in heating patterns, particularly increased heating or cooling, may have implications for national energy consumption. This substitution may also impact the consumption of reticulated electricity. Therefore changes associated with heat pump use may be considered a tool in minimising energy use or may pose a future challenge around the provision of electricity. There is potential for a shift from other energy forms to electricity to place additional loads on the electricity network. Peak loads and transmission issues due to heat pumps during peak heating times have already caused concern for many electricity supply companies.

Certainly, there is the potential for heat pumps to affect the energy network. In 2007, approximately 160 MW worth of heat pumps were installed into residential homes. The growth in heat pumps was considered in scenarios used for demand forecasts by the Electricity Commission in 2008. These indicated a new electrical generation plant will be required just for the growth in electrical heating. That, in turn, was expected to place pressure on transmission and distribution infrastructure and may fast forward the need for upgrades in some areas.

The pressure on the electricity network would be exacerbated if electrical heating demand is concentrated at the time of existing peak electricity load demands. To date, New Zealand's peak demand occurs in the winter and is driven mainly by electric space heating in houses. This pattern has matched reasonably well with the seasonal availability of renewable hydro power. Currently, approximately 55% of all electricity is from hydro (Dang et al., 2007). Replacing solid-fuel burners with heat pumps means there is potential for an approximate average increase of 60% in the winter peak load demands, if New Zealanders continue their tendency to evening heat. Heat pumps also present the challenge of a profound shift in domestic electricity use. Unlike electrical heaters of the past, heat pumps can be used for summer cooling. If this becomes a household practice, new electricity demand will require generation from New Zealand's hydro dams at a time of year this is traditionally low. Supply problems because of summer demand are already being experienced in some parts of New Zealand associated with commercial building air-conditioning and farm irrigation. Potentially, the flow-on effect of increased domestic summer cooling could place extra demands on the electricity network. This demand is both for electricity supply and transmission and, in dry years, could contribute to electricity shortages.

4. HOUSEHOLDS AND HOUSES IN THE HEAT PUMP STUDY

The heat pump study was initiated because it was clear that the incidence of heat pump take-up was increasing, with potential issues both for householders and the nation as a whole. For householders, there were issues about ensuring an adequate understanding of heat pump performance, installation and operation so that the potential benefits of heat pump use could be realised. Nationally, there were issues around the extent to which heat pump take-up might substitute non-electrical heating and impact on the nation's overall energy consumption and demand. Given the importance of those issues, it was recognised that the fragmentary evidential base was inadequate.

It is the potential for heat pumps to trigger change in heating patterns, the possibility of heat pumps being used for cooling and the challenges presented in optimising installation and operation that have prompted this study. This study allows us to consider systematically the prevalence of heat pumps in New Zealand, the characteristics of the owner-occupier households using heat pumps, the manner in which heat pumps are used and the installation and operating performance of heat pumps.

This section presents data on the more than 160 households participating in the heat pump study and their dwellings. It should be noted that 160 households had their heat pump use monitored and participated in the interviewing. In total, 168 dwellings were monitored, but eight householders did not participate in the householder interviews.

Canterbury houses were monitored in the second year of the study. This was also when a large number of damaging earthquakes occurred in Christchurch and the surrounding area. Most of the participants in the study suffered limited damage from the earthquakes. Three houses were 'red stickered', and monitoring equipment was removed from those houses. The remaining houses were lived in during the study. The use of energy in these houses was likely to have been affected owing to power outages. Therefore, the results for Christchurch should be treated with caution and possibly as atypical.

4.1 Household characteristics

The households participating in the heat pump study have a very particular set of characteristics. In part, this reflects the dominance in the study of owner-occupier dwellings. Compared with households nationally, the study households are more likely to consist of a couple but are less likely to accommodate a single person (Table 7).

They also tend to be older – 28.8% of heat pump householders are aged 50 years or more. Over a quarter (27.5%) of the heat pump householders are 65 years or more (Table 8). However nationally, according to the 2006 Census, only 20.1% of households have a reference person aged 65 years or more.

Table 7 Household size for heat pump study participants

Household size	% heat pump study households	% NZ households – 2006 Census
1 person	14.4%	22.6%
2 people	40.0%	34.0%
3 people	15.6%	16.5%
4 people	17.5%	15.2%
5 or more people	12.5%	11.7%
Total	*100.0%*	*100.0%*

Table 8 Householder age for heat pump study participants

Householder age	Heat pump study households	
	Number	Percent
20–29 years	4	2.5%
30–39 years	26	16.3%
40–49 years	40	25.0%
50–64 years	46	28.8%
65 years or over	44	27.5%
Total	*160*	*100%*

The median income for heat pump households is similar to the median income for New Zealand households of $64,272 annually at the June quarter 2010. However, the distribution of household income for study participants shows participants are over-represented in the over $100,000 household income group. Also, there is an under-representation in the under $21,000 household income group. Nationally, 26.4% of households have a household income of more than $100,000, and 9.9% of households have incomes of less than $21,000 per annum (Table 9).[3]

Table 9 Household income for heat pump study participants

Household income	Heat pump study households	
	Number	Percent
$20,000 or less	3	1.9%
$21,000–30,000	23	14.4%
$30,001–50,000	13	8.1%
$50,001–70,000	30	18.8%
$70,001–100,000	33	20.6%
More than $100,000	46	28.8%
Unsure	3	1.9%
Refused to answer	9	5.6%
Total	*160*	*100.0%*

The vast majority (85%) of the heat pump study householders are New Zealand Pakeha, while Maori householders make up only 3.8% of the heat pump households. Householders from Asian ethnic groups make up 2.5% of the heat pump householders with a similar proportion who fall into the 'Other' category. The 'Other' category is constituted by Europeans, North and South Americans and Africans. No Pacific households were among the heat pump households. Compared to the national population structure, this means that all non-Pakeha ethnic groups are under-represented.

4.2 Dwelling tenure and occupancy

The participants in the heat pump study were predominantly owner occupiers. Only five of the monitored dwellings were occupied by tenants. This underpins the tendency for the heat pump study householders to have slightly longer duration of occupancy in their dwellings than householders nationally. On average, the heat pump householders have resided a little over 9 years in their current dwelling. This compares to the national average in the 2006 Census of 3.7 years duration at usual residence. However, while the considerable difference between the study participants' occupancy patterns and national occupancy patterns is largely attributable to the low numbers of tenants among the study participants, this should not be overstated. This may reflect the slightly older demographic profile of the study participants. It may simply be a

[3] Customised data table from Statistics New Zealand using data from the Household Economic Survey year ended 30 June 2009.

skew resulting from the recruitment method or it may be that people with heat pumps tend to stay longer in a dwelling. The latter appears to be the least likely explanation.

4.3 Dwelling characteristics

The dwellings in which the heat pump study participants reside are dominated by three and four-bedroom homes. This is typical of the New Zealand housing stock. However, the participants' stock profile does tend to be more strongly biased to dwellings with more bedrooms than the national stock profile (Table 10). The skew to dwellings with slightly more bedrooms than the national stock is reflected in the overall size of the dwellings. The median dwelling size of the heat pump dwellings is 133 m^2. This profile of bigger dwellings reflects the limited number of rental dwellings in the study and the age of the study dwellings.

Table 10 Dwelling size for heat pump study participants

Dwelling size	% heat pump study households	% NZ households – 2006 Census
1 bedroom	0.6%	5.8%
2 bedrooms	6.9%	19.8%
3 bedrooms	47.5%	46.3%
4 bedrooms	35.6%	21.6%
5 bedrooms	7.5%	5.0%
More than 5 bedrooms	1.3%	1.5%
Missing	0.6%	0.0%
Total	*100.0%*	*100.0%*

Dwelling age data is available for 156 of the 160 dwellings of interview participants. Around 46% were built from 1980 onwards. Figure 7 compares the age of New Zealand's dwelling stock with the age profile of the study dwellings. The heat pump study dwellings show a considerable cluster of dwellings built in and after the 1990s compared to the dwellings in the national stock.

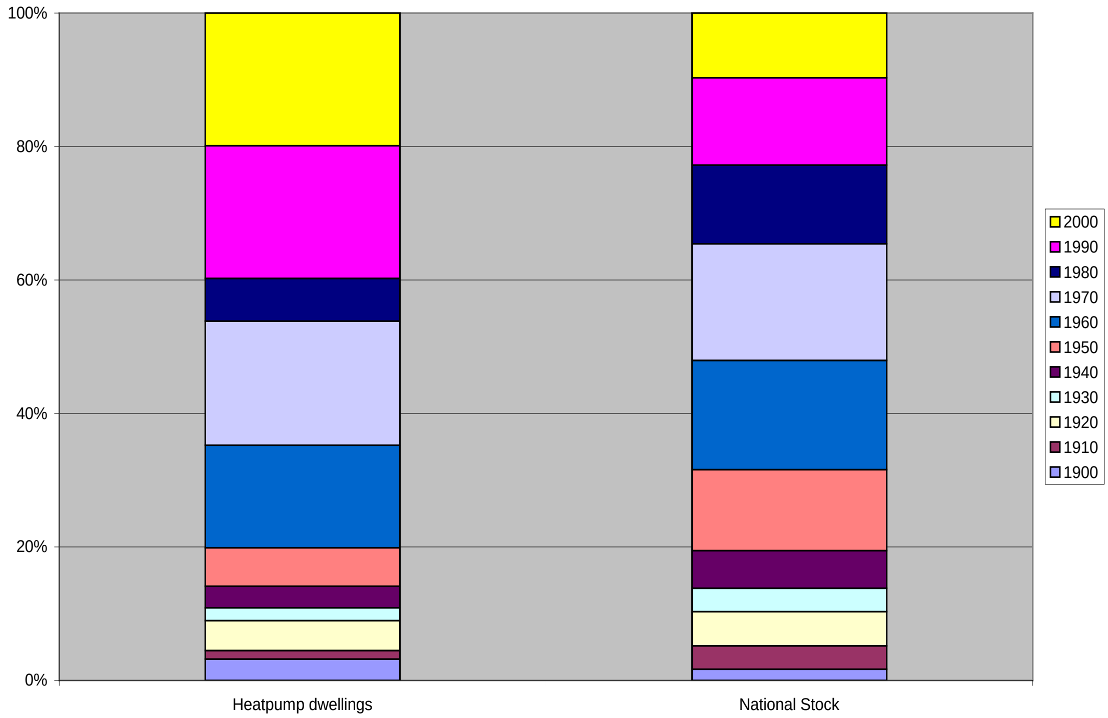


Figure 7 Age of New Zealand's dwelling stock compared to age of study dwellings

4.4 Dwelling performance indicators

The performance of New Zealand's dwellings has been the focus of considerable concern over the last three decades. It is well established that some dwellings have been affected by leaky home syndrome. Dwellings also tend to be cold and damp in New Zealand owing to poor levels of insulation, under heating and spot heating, poor maintenance, design and orientation. All of these factors are likely to impact on heat pump performance and delivery of thermal amenity.

4.4.1 Age of house

Figure 8 shows that about half the dwellings in the heat pump sample are built prior to the 1978 requirements on insulation. In addition, the 2010 House Condition Survey has found that dwellings of that age are more likely to have unmet repairs than newer dwellings. Although, it should be noted that leaky house syndrome is a systemic condition that is more likely to affect newer rather than older dwellings.

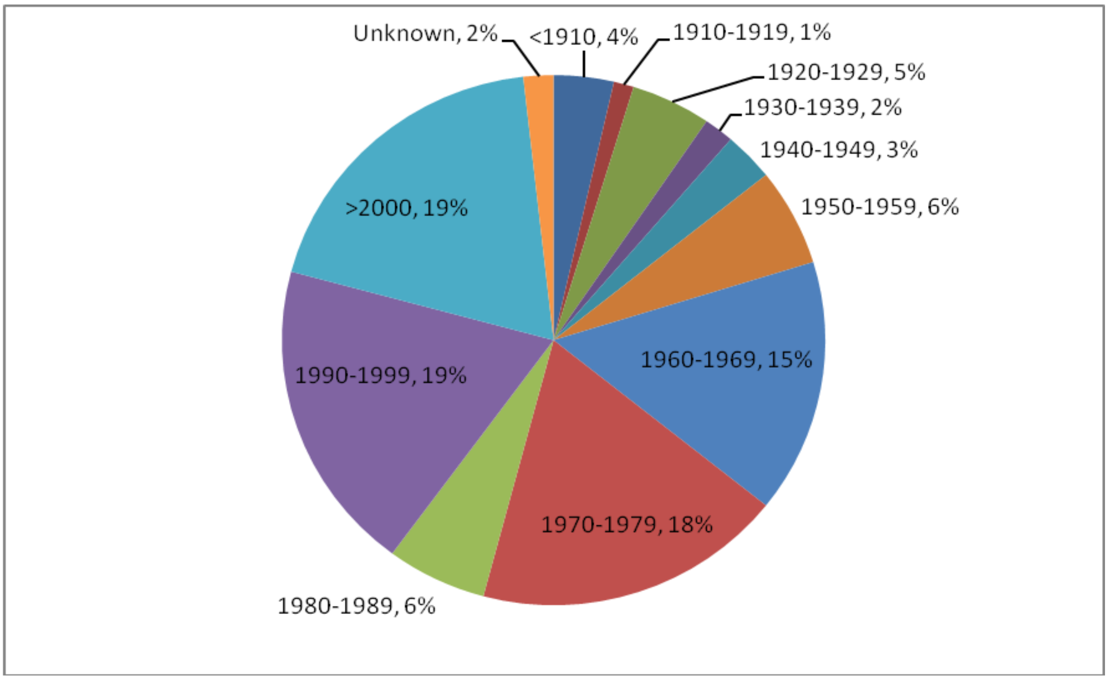


Figure 8 Age of the houses in the heat pump sample

4.4.2 Insulation

The majority of houses in the sample have insulation in their ceiling (85%). Just over a quarter of the floors were confirmed to have insulation (26%). Over a third of the houses (39%) had a concrete slab floor – generally, these houses are in the 'unsure if it has insulation' category. Just over one-half of the houses were confirmed to have wall insulation (56%), while in 17% of houses, we could not confirm insulation and the occupants did not know.

4.4.3 Glazing

Most houses in the heat pump sample had single glazing (75%), a few had double glazing (14%) and some a mixture of the two (11%). The latter tends to arise when owners extend a dwelling or when windows are successively replaced.

4.4.4 Layout

Open-plan dwellings are more likely to be heated and cooled more effectively where single-point heating systems are used. Typically, New Zealand dwellings have been cellular, often with hallways connecting different rooms. The use of open-plan designs is more apparent in new dwellings. But even among new homes, an extensive use of hallways and enclosed spaces is apparent.

Central heating and heat-transfer systems can be used to distribute heat from a heating appliance. This is not common in New Zealand. This study suggests that, if there is an emerging change in heating, it is the use or installation of a multiplicity of spot heaters. Many of these are not used, in hallways and bedrooms. Heat pumps are among these supplementary heaters, many of which are in hallways. Heat pumps placed in hallways with limited space between the wall on which the heat pump is located and the opposite hall wall, will most likley have limited circulation. Similarly, high stud hallways may require sizeable and more expensive heat pumps to make an appreciable difference to household comfort.

4.4.5 Orientation solar gain and shading

Solar gain in winter and shading in summer optimise the performance of heat pumps. This is because they reduce the range of indoor conditions the heat pump (or other heating and cooling appliance) needs to deal with. Orientation of windows primarily to the north, with minimal windows to the south, is desirable. However, excess northern glazing can also be associated with overheating in summer, unless there is appropriate shading.

The HEEP study found that orienting living areas to the north, reducing south wall glazing and the installation of effective shading was not a prominent feature of New Zealand dwellings. Glazing, for instance, tends to be distributed relatively evenly around the four walls of most dwellings. Subsequent studies have found similarly, with orientation being largely determined by site characteristics.

The orientation and glazing characteristics of the dwellings in the heat pump study appear to be typical. On average, the north, south, west and east of New Zealand dwellings have 25% of the total glazing. There is no evidence in the HEEP data that New Zealand houses are oriented to deliver passive solar gain into living areas (Isaacs et al., 2010). For maximum solar gain, a building will be located, oriented and designed to maximise window area facing north (or within 20 degrees of north). This requires a shallow east-west floor plan.

Reducing heat loss and maximising solar gain also requires more windows on the north-facing long wall of properly oriented houses. There needs to be shading for summer solar gain as well as minimising south wall windows.

4.5 Interface between household and dwelling

The higher-income heat pump households tend to be over-represented among larger dwellings (Table 11). This is statistically significant.

Table 11 Income and dwelling size

Household income	<100 m^2		100–149 m^2		150–199 m^2		>200 m^2	
	Hshld	%	Hshld	%	Hshld	%	Hshld	%
Less than $50,000	9	39	20	33	4	12	1	6
$50,000–100,000	8	35	27	45	17	52	6	38
More than $100,000	6	26	13	22	12	36	9	56
Total	*23*	*100*	*60*	*100*	*33*	*100*	*16*	*100*

The participants with household incomes between $50,000 and $100,000 are also over-represented among the dwellings with full insulation with or without double glazing. This probably reflects their tendency to be in newer dwellings. However, while these patterns are indicative, neither of these associations are statistically significant.

The relationship between household size and dwelling size is not statistically significant nor is there a discernible pattern in the association between the two. This is consistent with a raft of housing research that has highlighted the contradiction between the increasing size of dwelling and the demographic decline in household size.

4.6 The heat pumps

Just over a quarter of the heat pumps (26%) in the study dwellings were installed in the year prior to monitoring. The two oldest heat pumps in the sample were installed over 20 years ago in a Christchurch house (Figure 9).

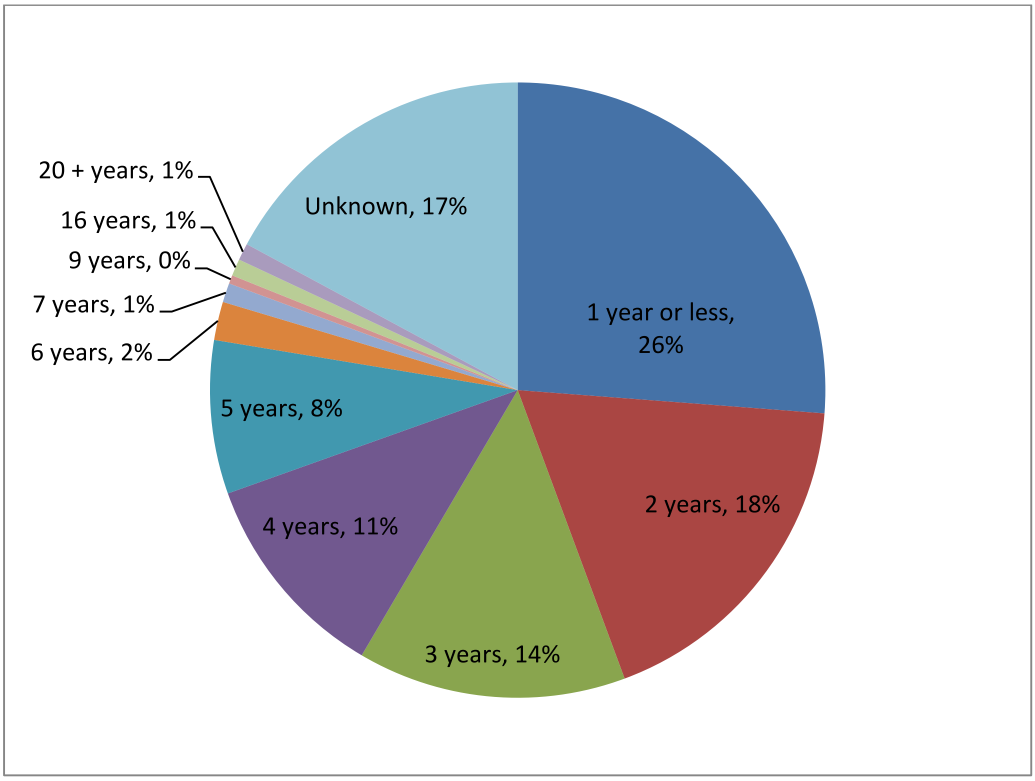


Figure 9 Age of heat pump in the sample

Most heat pumps (82%) were high-wall systems, 3% were ducted and 14% were low wall systems. The remaining 2% were high-wall systems installed at floor level. The cooling and heating inputs and capacities were recorded from the labelling on the heat pump external unit.

The heating capacities (expected heat output) are reported in Figure 10. The largest system was 20 kW, which is ducted and heats most of the house. Just over half of the sample (51%) heat pumps have a heating capacity of 5–8 kW.

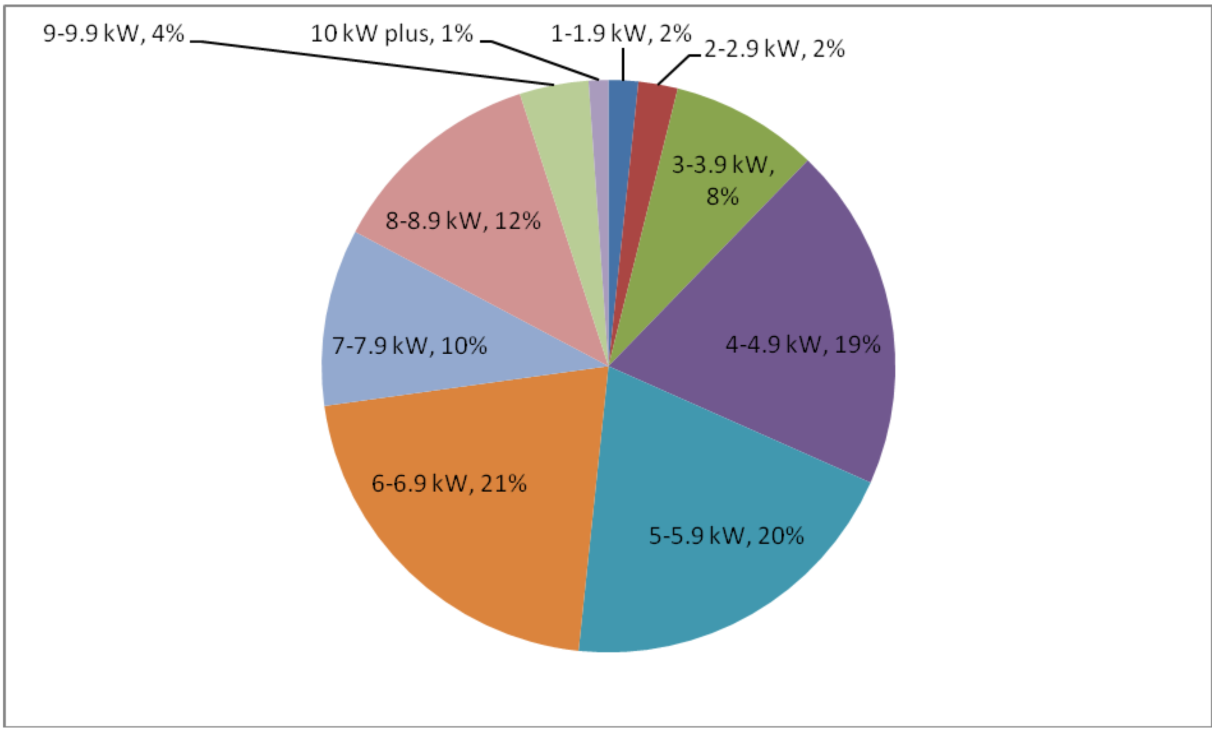


Figure 10 Heating capacity of heat pumps in the heat pump sample

The remainder of this section is concerned with four aspects of the study participants' heating and heat pump use:

- The circumstances and timing of heat pump installation.
- The extent to which heat pumps substituted other heating appliances.
- The location of heat pumps.
- The seasonal and daily patterns of heat pump use.

4.7 Circumstances around heat pump installation

Most heat pumps were installed by householders into their existing dwellings. As Figure 11 shows, of householders who recalled the month of installation, there is a pronounced tendency to install heat pumps in the pre-winter period. This is consistent with patterns of use by householders, which are dominated by winter heating rather than summer cooling.

Of the 160 heat pump householders, 22 came to dwellings with the heat pumps already installed, and 18 householders had heat pumps installed as part of a new build.

Of the 118 householders installing heat pumps into existing houses, 97 householders reported that the installation of a heat pump was undertaken as a one-off job. The remaining 21 householders reported that they installed heat pumps while undertaking renovations or repairs. Eight householders installed heat pumps while undertaking major renovations, while three householders installed heat pumps while undertaking minor renovations or repairs and maintenance.

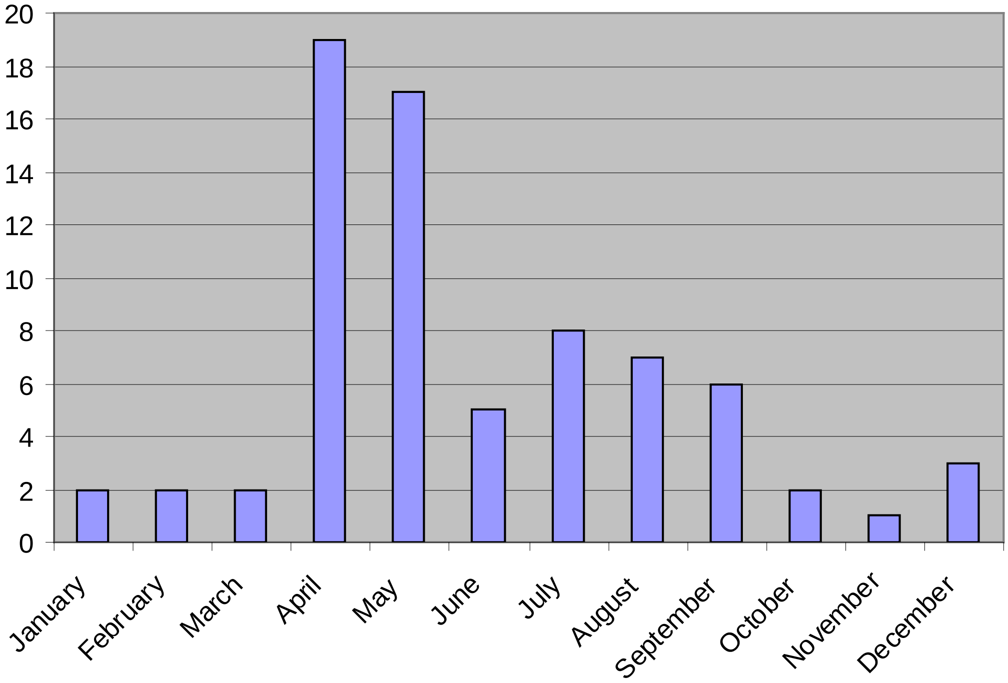


Figure 11 Month of heat pump installation

There also appears to be a tendency for heat pumps to be installed relatively soon after moving into a dwelling. Of the 73 householders that moved into their current dwelling in 2005 or thereafter, 18 householders came to dwellings with heat pumps. A further 33 householders installed heat pumps in the same year as they moved to their current dwelling, and 14 householders installed a heat pump in the year following their occupation. Therefore, about 67% of those moving into dwellings from 2005 on had heat pumps within 2 years of occupation.

4.8 Substituting or complementing other heating appliances

The majority of householders – 116 of 160 householders – reported having heating appliances in their dwellings prior to the installation of a heat pump. Of those 116 householders, 57 householders (49.1%) reported that they substituted an existing heating appliance with a heat pump, and 56 householders (48.3%) reported supplementing their previous heating systems with a heat pump.

The remaining three householders reported that they substituted an existing heating appliance with a heat pump, and both were used as supplementary rather than main heating devices.

- One householder replaced an open fire and a supplementary nightstore with a log burner and a heat pump respectively.
- Another householder had an existing log burner used as the main heat source, which was supplemented by a nightstore. The nightstore was replaced by a heat pump.
- The final householder in this set replaced a gas heater with a heat pump and also used an existing oil column heating.

Fewer householders reported replacing an enclosed log burner with one or more heat pumps. In general, where log burners were installed already, these householders were using heat pumps as a heating supplement beyond the living room or lounge.

Figure 12 shows that the heating and fuel source most likely to be substituted by heat pumps is reticulated and bottled gas or electrical appliances that were deemed by the householder as less efficient.

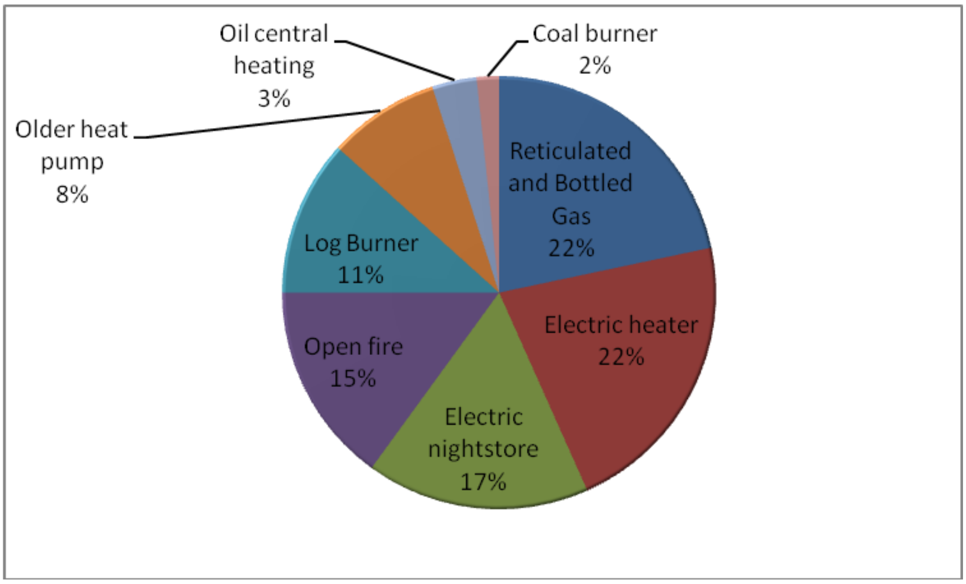


Figure 12 Heating substituted by heat pumps

4.9 Space heating and cooling appliances

Most householders report only having one heat pump, and a fifth (20%) of householders report two or more heat pumps. Across all householders, there is a total of 200 heat pumps. Around a fifth of householders used at least two forms of heating in the year prior to interviewing. As Table 12 shows, almost all householders reported using their heat pump. Enclosed wood burners are the next most commonly used heating device, followed by an array of plug-in electrical heating appliances.

Table 12 Householder-reported heating devices used in the year prior to interviewing (n=160)

Heating device	Number of households	Percent of households
Electric heat pump	155	96.9%
Enclosed fire/wood burner without wetback	29	18.1%
Gas or LPG central	11	6.9%
Electric nightstore	5	3.1%
Electric underfloor	6	3.8%
Enclosed wood burner with wetback	6	3.8%
Open fire	6	3.8%
Gas or LPG portable	4	2.5%

Householders reported that most heat pumps are located in living areas. Specifically, 88 heat pumps (44%) are located solely in lounges, but there are another 38 heat pumps (19%) that are located in multi-function areas combining living with dining, kitchen and/or family room. In addition to those heat pumps, a further 17 heat pumps (8.5%) are located solely in dining areas, with a further 6 heat pumps (3%) located in kitchen/dining areas. There are 5 heat pumps solely in kitchens, 13 heat pumps in bedrooms, 5 heat pumps in so-called family rooms and 11 heat pumps in hallways. The remainder are in games rooms, offices and used to provide whole-house heat by way of open-plan designs or ducts through the roof space.

Although heat pumps and other heating appliances tend to be located in living areas, it is clear that householders believe, often incorrectly, that those appliances have heating impacts through the dwelling. House audit and installation data suggests only 20% of households had their primary heat pump heating just one room of their house. A further 5% had the heat pump located in a linking space such as hallway where it could heat multiple rooms and 74% were heating more than one space. This occurred either through open plan living, having spaces permanently open to each other or a central heat pump system. On average, the primary heat pump service heats approximately 45 m^2 of floor space for the houses in the sample.

Some householders report that they occasionally use their heat pumps for cooling. Around 58% of householders report that they have used their heat pump for this purpose. But, only a small number of households specifically acquired their heat pumps for cooling purposes.

4.10 Seasonal use

Figure 13 shows householders indicate a tendency for heating (main heater) to be limited in the summer season, peaking during June, July and August. This pattern is similar for any additional main heating appliances (Figure 14).

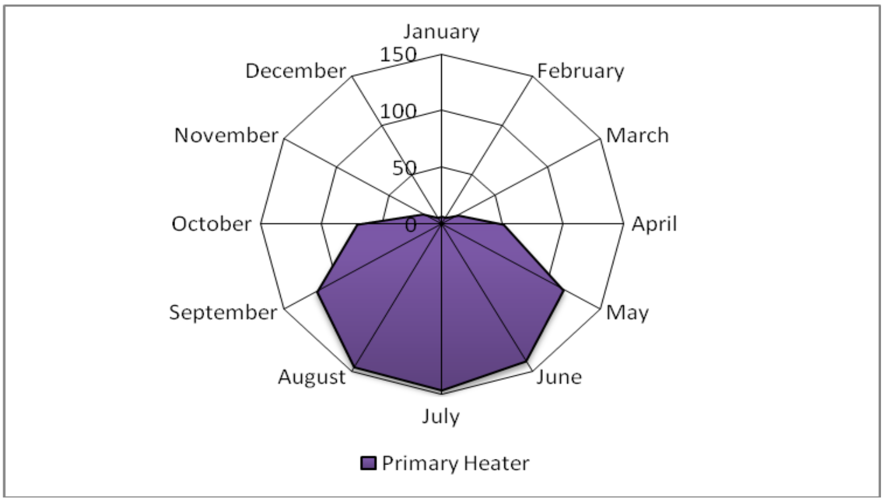


Figure 13 Reported seasonal heating for main heater (n=157)

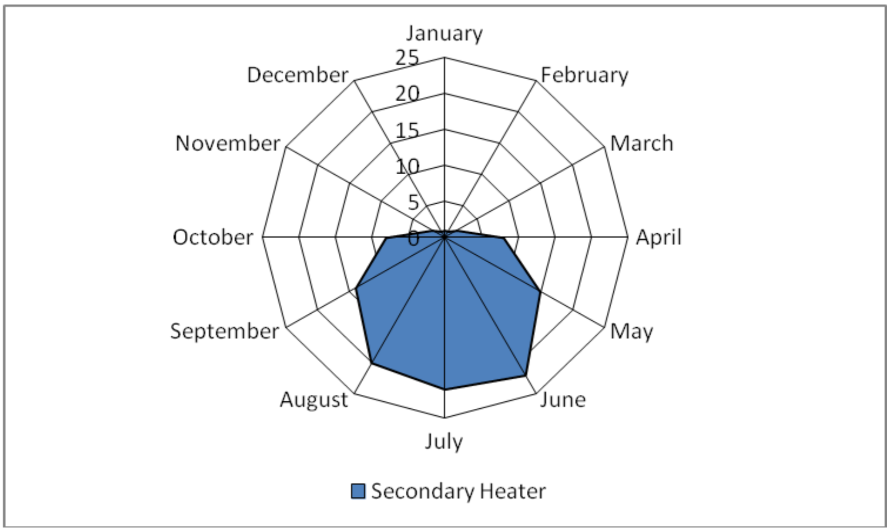


Figure 14 Reported seasonal heating for additional main heating appliance (if any) (n=25)

Of those who do use heat pumps for cooling, this is most pronounced in February (82.6% of coolers), January (70.7% of coolers) and March (30.4%). Just over a quarter (23.9%) of the householders that use their heat pumps for cooling do so in December. There are small proportions of householders reporting cooling in April, October and November.

4.11 Daily and weekly cooling and heating schedules

Past studies have revealed three tendencies in New Zealand heating practices:

- Heating is usually inadequate and results in low dwelling temperatures.
- New Zealanders have tended to evening heat even when people are in a dwelling for much of the day but certainly if a dwelling is vacated during the day.
- New Zealanders tend to spot heat. That is, they generally concentrate their evening heating into an area that can be closed off from the remainder of the dwelling. This practice is associated with the very low temperatures that have been typically found in bedrooms.

It is clear that these heat pump households have retained some of these patterns, but others appear to be changing. In terms of continuity, there is still a tendency for lower than desirable temperatures in these dwellings. This is considered in section 5. There is also a tendency for evening heating. This pattern is evident in both the household interview data and the monitoring data. On weekdays, 90.6% of households report they use their main heating appliance between 5pm and 11pm in winter. On weekends, there is more daytime heating, but heating is still concentrated in winter evenings (Table 13).

Table 13 Weekday and weekend heating schedules for main heating appliances

Heating appliance use	Main heater		Additional main heater	
	% weekday (n=160)	% weekend (n=160)	% weekday (n=24)	% weekend (n=24)
Morning (7am–9am)	60.6	63.1	16.7	33.3
Day (9am–5pm)	35.0	51.3	16.7	25.0
Evening (5pm–11pm)	90.6	86.9	83.3	87.5
Night (11pm–7am)	25.0	25.0	16.7	20.8
Used-by time varies	1.9	2.5	8.3	8.3

Figure 15 shows the proportion of the heat pump houses that used their heat pumps to heat at different times of the day. As Table 13 shows, this pattern of use is also evident among the 24 households who had an additional main heating appliance. What is clear from the monitored data when compared to previous studies is the way in which heat pumps extend the heating periods. As Figure 16 shows, heat pumps in the study households are associated with morning heating and higher proportions heating during the day, overnight or over 24 hours.

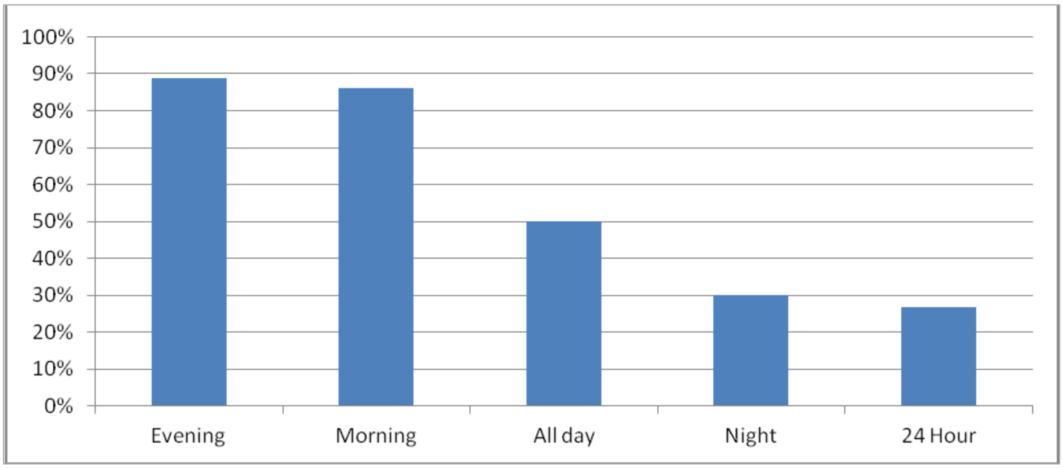


Figure 15 Proportion of households heating by time of day during winter

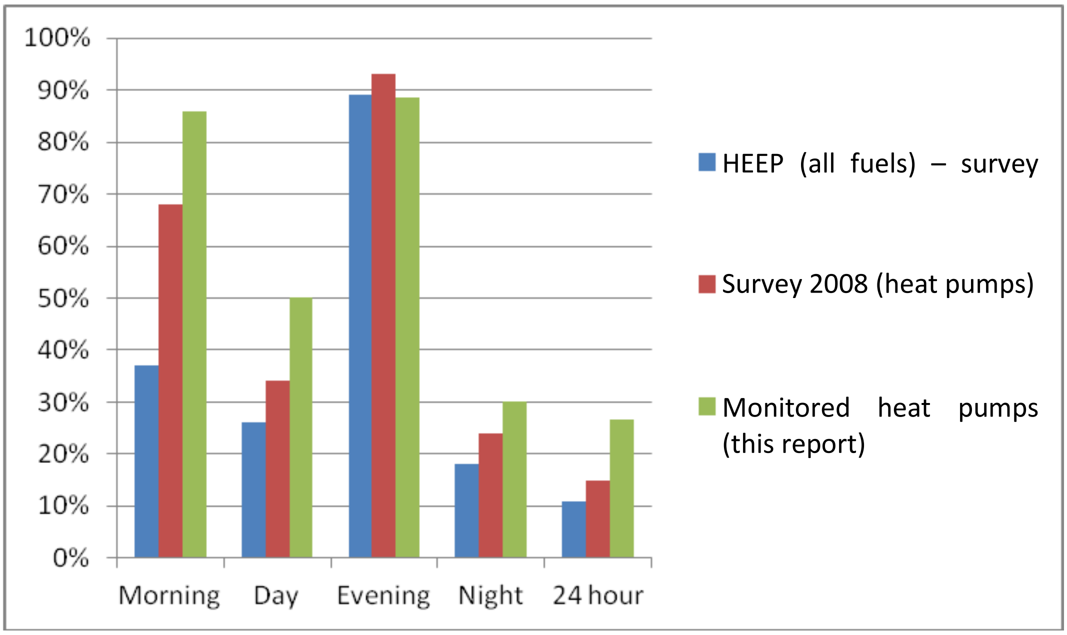


Figure 16 Winter heating schedules

The second emerging pattern is the way in which some households are using heat pumps as supplementary heaters. As previously, heat pumps have been used to replace supplementary heating devices such as nightstore heaters. There were also 18 dwellings that specifically acquired one or more heat pumps as supplementary heating devices. Vignettes of each of those households are presented in Table 14.

Table 14 Heat pump and other heating devices use for those households who report their heat pump is NOT their primary heating device

Case 1: Heat pump was purchased to supplement existing wood burner (without wetback). It is predominantly used on nights the householder will be out in the evening and doesn't want to light the fire. The heat pump and the wood burner heat the same parts of the house – the lounge and hallway. The householder reports the wood burner is used from June–September on weekday evenings and during the day and evenings on weekends. The heat pump is used for heating weekday evenings only from June–August. The heat pump is also used for cooling in the evenings in February and March.
Case 2: Householder brought heat pump with them from a previous dwelling. It is used to heat a second lounge, which previously had no heat source. In the year prior to interviewing, the householder reports the heat pump was used during September to heat this lounge area on weekday and weekend mornings. The house had an existing wood burner, which the householder used from May–October. The wood burner heats both lounges and the dining room in the evenings. Electric bar heaters are used very occasionally for spot heating in areas like the study. The heat pump is not used for cooling.
Case 3: Heat pump is to supplement an existing wood burner. The house has one heat pump with two outlets to heat upstairs and downstairs. The householder reports that the wood burner is their main heating device in the evenings in winter months, heating most areas of the house. The heat pump is also used week round during the winter months (June–August) via the downstairs outlet to heat bedrooms and a lounge area during the day. The upstairs outlet is used in January and February during the day week round to cool the upstairs bedroom and living area.
Case 4: This household uses a Moisture Master as their main heating device. The heat pump is in the lounge and was only used about five times in the year prior to interview. The heat pump is not used for cooling.
Case 5: The heat pump was initially purchased to supplement an inefficient open fire (that fire was replaced the following year with a pellet burner). The pellet burner is the main heat source used weekday evenings and weekends during the day and evening from May through to September. The householder reports the heat pump is used more like a heater for the mornings. It is turned on up high for a short time and then off again and used only in June/July. Both the pellet burner and the heat pump heat an open-plan lounge/dining/kitchen area. In addition, when the pellet burner is on, this also heats the hallways.
Case 6: The household uses a wood burner for heating – it is used overnight to heat the whole house from May–October. The heat pump is not used for heating. The heat pump is used for cooling the lounge area in the late afternoon during the summer months (January-March).

Case 7: The house has a heat pump in the hallway that supplements a wood burner in the living area. Both are used from April–November. The wood burner is reported as being on all day and night over this time and heats the lounge and dining room. The heat pump is on in the evenings and overnight to heat the hallway. The heat pump is not used for cooling.
Case 8: The house has a wood burner and a heat pump. Both are used from May–September, and both heat the lounge, dining and kitchen areas in the house. The heat pump is used 7 days a week in the mornings and sometimes during the day on weekends. The wood burner is used all day and then left to burn down overnight. The heat pump is also used for cooling in the mid/late afternoon during the summer (January–March).
Case 9: Heat pump installed to supplement a wood burner. The house uses both heating devices from May–August. The heat pump is used only in the mornings. The wood burner is used during the day and the evening. The heat pump heats the lounge, dining and kitchen areas, and the wood burner heats these areas and the hallway. Heat pump is not used for cooling.
Case 10: Heat pump installed to supplement a wood burner. The heat pump is in the hallway and is used for heating in the morning from July–August. The wood burner is used from July–October during the day and evenings to heat the lounge, dining room, kitchen and a second lounge. In addition, oil column heaters are used in the bedrooms overnight during the months of July and August. Heat pump is not used for cooling.
Case 11: Heat pump installed to supplement a wood burner. The heat pump is used from April–October in the mornings to heat the lounge, dining and kitchen areas. The wood burner is also used April–October. It heats the whole house and is used predominantly in the evenings but will get turned on before kids get home from school on really cold days. The heat pump is very infrequently used for cooling – in the early afternoons January–February if a very hot day.
Case 12: The heat pump replaced a hallway electric nightstore heater and is used to supplement a wood burner. Heating is between June and September for all heating devices. The heat pump is used to warm four bedrooms and a bathroom and is programmed to come on from 8pm to 10pm and then again from 5am to 7am. The house has two wood burners – one heats the lounge area and is used weekdays in the evenings and weekends during the day. The other wood burner heats the dining room and kitchen and is used week round in the evening. The heat pump is used for cooling in the evenings in February.
Case 13: The heat pump is in the family room and supplements a wood burner. The heat pump is used from April– October in the evening week round. It heats the lounge, dining and kitchen areas. The wood burner heats the lounge and bedrooms and is also used in the evenings from May–September. The heat pump is not used for cooling.
Case 14: Heat pump in the hallway supplements a wood burner in the living room. The heat pump is used in the evenings and overnight from June–September. It heats the hallway, bathroom and bedrooms. The wood burner is used all day and into the evening and left to die out overnight. The wood burner is used from May–September and heats the lounge, dining and kitchen areas. In July and August, an oil column heater is used sometimes in the lounge before the fire is lit. No heat pump cooling.
Case 15: The heat pump is in the lounge and supplements a wood burner. The house already had both heating devices when the householder moved in. The heat pump is used in the evenings in April and May and heats the lounge and kitchen areas. The wood burner is used evenings from June–September and heats the lounge, kitchen and bedroom. The heat pump is used for evening cooling in January and February.
Case 16: Heat pump installed in dining room of open-plan area supplements existing wood burner. Heating months were not specified, but the heat pump is used week round in the mornings before work to heat the dining room as well as lounge and kitchen areas. The wood burner is used from early afternoon and into the evening. The wood burner heats the lounge, dining and kitchen areas of the house. The heat pump is used very occasionally for cooling in January and February.
Case 17: Heat pump installed to supplement wood burner with a wetback. The heat pump is used in the evenings from August–October and heats the dining room, kitchen and hallway. The wood burner heats the whole house and is used from May–August 24 hours a day. The heat pump is not used for cooling.
Case 18: House has three multiple heat pumps used to supplement a wetback wood burner. The wood burner heats the lounge area and is typically on 24 hours a day from June–September. There is a heat pump in the lounge, which is used between May and September on days it is not cold enough to use the fire or if they've been out and the fire is not lit. A second heat pump, which heats the hallway area, is used from May–September in the mornings about every second day over this period. The third heat pump heats the downstairs area and is used once or twice a week to dry out mustiness. The heat pump is used for cooling approximately 10–15 times over summer in January and February if it is very humid.

Effectively, these householders are using multiple spot heaters. Only one of the households in the study could be described as using central heating. In that instance, the heating system was powered by a very large heat pump and was run 24 hours a day. The installation of multiple spot heating devices suggests a desire for whole-house heat. This is also indicated by the distribution of what householders described as their main heating devices. All the study householders identified one heating appliance as their main heating appliance. The distribution of those heating appliances is set out in Table 15. Of those, a further 24 householders had an additional heating appliance that they described as also a main heating appliance. Almost 46% of those were enclosed wood burners. Table 16 indicates their locations.

Table 15 Areas heated by main heating device specified by the householder (n=160)

Room	Number of households	Percent of households
Lounge	119	74.4
Dining room	85	53.1
Bedroom	28	17.5
Kitchen	85	53.1
Hallway	27	16.9
Other area	20	12.5
Whole house	21	13.1

Table 16 Areas heated by additional main heating device specified by the householder (n=24)

Room	Number of households	Percent of households
Lounge	13	52.0
Dining room	6	24.0
Bedroom	2	8.0
Kitchen	7	28.0
Hallway	1	4.0
Other area	5	20.0
Whole house	3	12.0

Compared to heating, cooling shows a more fragmented pattern. Of the 139 households that cooled at some time during the year-long monitoring period, the largest single category, over 35%, showed no sustained pattern of cooling.

5. INDOOR ENVIRONMENT FOR HOUSEHOLDS USING HEAT PUMPS

There is now a substantial body of research evidence showing that New Zealand dwellings tend to be excessively cold in winter, subject to damp and vulnerable to mould (Isaacs et al., 2006; Howden-Chapman et al., 2005; Isaacs and Donn, 1993). Previous research suggests that those conditions are contributed to by a tendency to both under heat and spot heat in New Zealand. However, the research also suggests that those practices are themselves generated by design deficiencies in the stock, poor thermal envelopes and the limitations of New Zealand's heating systems (Isaacs et al., 2009; Saville-Smith and Isaacs, 2007).

One of the promises of heat pumps is that, because of thermostatic control and programme features, householders will be able to maintain relatively stable temperatures. The reality is, however, that most householders do not keep their heat pumps on consistently. Not all have a single set point temperature. Moreover, over a third (35.6%) of heat pump households reported that they are not always warm in winter. A further 7.5% reported that they were only sometimes warm in winter, and one householder reported being consistently cold (Figure 17). This raise concerns about the efficacy of heat pumps in modifying poor heating practices as well as their heating performance.

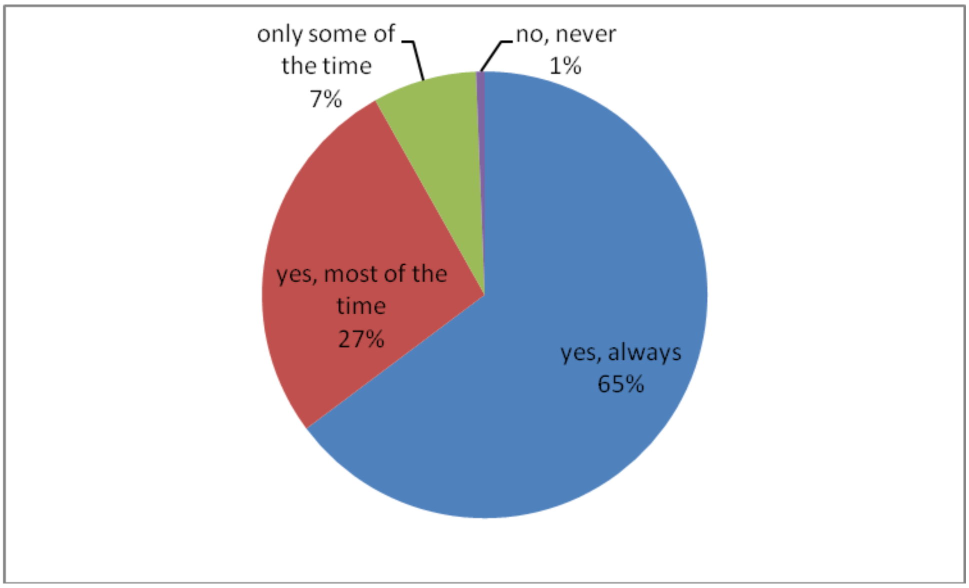


Figure 17 Whether current heating used keeps householder warm in the winter months

This section is concerned with the indoor environments that heat pump households achieve. It starts with an overview of indoor temperatures and considers the extent to which achieved temperatures align with the set points that householders report using in winter. It then presents some comparisons between the temperature data emerging from this study compared to the temperature data collected in HEEP. The section concludes with humidity measured in the spaces heated by the primary heat pump.

5.1 Winter temperatures

Winter cold and damp in New Zealand homes has been associated with excess winter mortality. Substantial investments have been made through government programmes to increase the thermal performance of New Zealand homes. Somewhat less attention has been given to the heating efficiency of space heating, certainly compared with attention given to the emissions performance of space heating appliances. In the context of the latter, particularly in airsheds with persistent air quality problems, heat pumps have been seen as a desirable form of heating during winter. From the perspective of indoor air temperatures, the outcomes of heat pump installation and use are more equivocal.

The average 24-hour indoor air temperature, in the space heated by the primary heat pump, is 17.3°C (Table 17). The median average temperature over 24 hours is also 17.3°C. This is still below World Health Organization (WHO) recommended temperatures of a minimum average of 18°C. It is certainly inadequate for anyone who is unwell, disabled, elderly or very young. For those people, the WHO recommends an average air temperature of 20°C throughout the year. The inadequacy of the temperatures achieved in these spaces is indicated by a comparison with the British Watt Committee on energy recommendations.

Table 17 Average indoor temperatures during winter (June, July, August)

	Morning	Day	Evening	Night	24 hr
Heat pump sample	15.2	17.2	19.2	16.2	17.3

Building on WHO, the British Watt Committee on Energy suggests that all households, including low-income households, should be able to achieve living rooms at 21°C for 13 hours a day. For bedrooms at 18°C for 8 hours overnight and 5 hours during the day and other spaces at 18°C for 13 hours daily. No temperatures should fall below 14.5°C (Markus, 1994).

It should be noted that temperatures were only measured in the areas identified as having the primary heat pump. As a consequence, the Watt schema of temperatures cannot be fully tested in the heat pump houses. Nevertheless, it must be of some concern that, of 141 dwellings with measured winter temperatures, 57% of so-called heated spaces had measured average temperatures below 14.5°C, over 24 hours in winter. Just less than 55% of households had median temperatures over 24 hours greater than 17°C.

In the evening, 6% of households experienced temperatures in the heat pump area of less than 14.5°C. The average and median winter evening temperature in these spaces was 19.2°C. Nevertheless, 26% were below 18°C, and only 34% had an average evening winter temperature of 20°C or more. These temperatures reflect a persistent tendency to retain New Zealanders' traditional practice of heating during the evening. Over the set of 141 monitored dwellings, the area heated by the primary heat pump was reaching both an average and a median of 19.2°C. Even so, 12.5% of households were achieving average evening temperatures of less than 18°C and 65.2% less than 20°C.

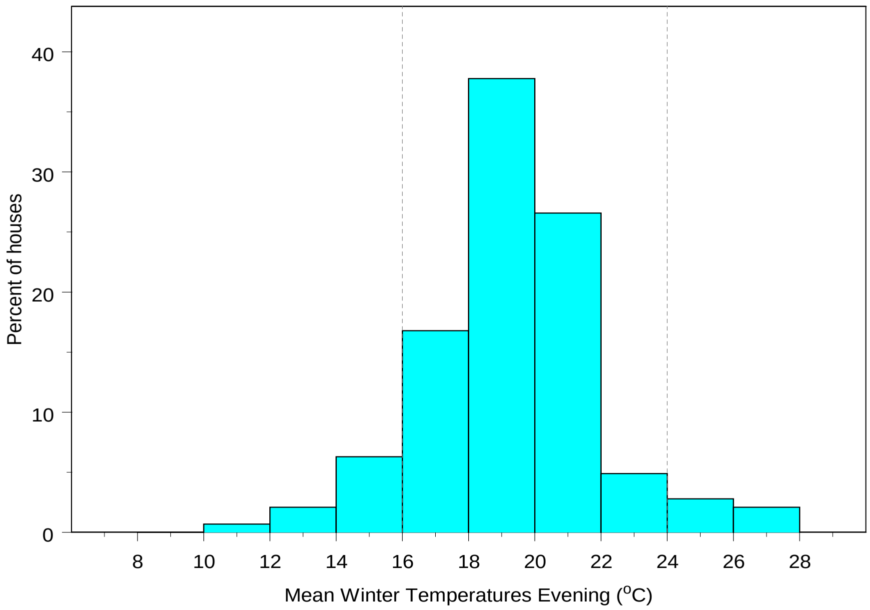


Figure 18 Winter temperatures in the main space heated by heat pump (evening)

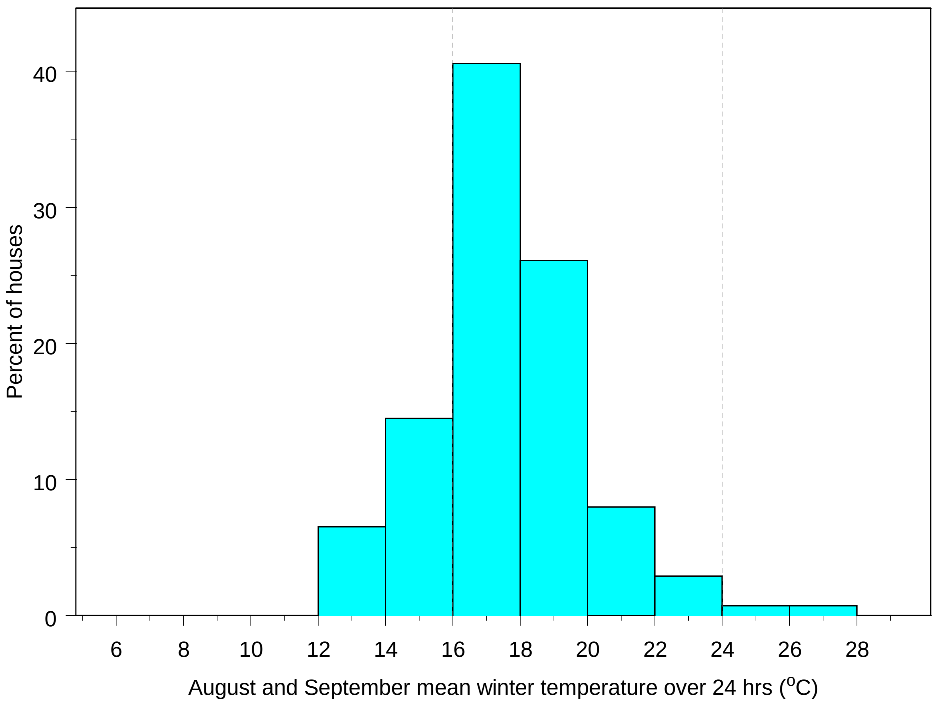


Figure 19 Mean temperatures over 24 hrs during August and September

In addition, higher temperatures on winter evenings are also associated with the temperature benefits of solar gain. Over the monitored dwellings, the difference between the mean average winter morning temperature and the mean average evening temperature is 4°C. The mean average morning temperature is 15.2°C with average day temperatures of 17.2°C. After the peak of 19.2°C in the evening, temperatures fall again to an average of 16.2°C at night.

There are indications that heat pumps are associated with some changes in heating practices. While temperatures in heat pump heated spaces are still lower than desirable, heat pumps are encouraging both some morning and some overnight heating. Certainly there appears to be a divergence between indoor temperatures within regions, with external air temperatures having only a minor effect on indoor temperatures of some dwellings. This suggests improvements in heating practices, heating appliances or the thermal envelopes of some dwellings relative to others.

5.2 Delivered temperatures and set points

This raises the issue of whether those temperatures reflect lower than desirable set points or some other limitation of achieving desirable indoor temperatures. Most householders reported the set points that they use for their heat pumps, and most have a single set point. A few, however, had variable set points. In one household, this involved the young men in the household looking for lower temperatures than their mother. In a small number of households, the set point was adjusted according to the time of day.

An analysis of average set points relative to achieved temperatures reveals a distinct difference between set points and achieved temperatures. To explore the relationship between set point and delivered temperatures, monitored and interview data was matched. Of the 160 households with interviews, there are 125 households that have both monitored data and set point data available. This latter set provides the data platform for the following analysis.

The average difference between the set points reported by householders and monitored temperatures during winter evenings is -2.2°C. The median difference is -2.1°C. For some dwellings, the difference between reported set point and monitored temperatures on winter evenings is very considerable. There are, for instance, four dwellings where monitored temperatures are in excess of 4.0°C higher than reported set points. Typically, however, the difference tends to be where monitored temperatures are less than the reported set point. Just over 23% of dwellings had achieved temperatures over -4°C in relation to the reported set point. Four dwellings had average winter evening temperatures more than 10°C below the set point reported by the householders. Analysis of the householder interviews suggests that there are a number of reasons for these differences.

For the four dwellings in which the achieved winter temperatures exceeded the set points of the monitored heat pump by 4°C or more, three factors have emerged:

- Extended use. Two had all-year use, one used the heat pump 24 hours a day and the other 16 hours a day on both weekends and weekdays.
- Assiduous filter cleaning and maintenance.
- Multiple heating appliances often in the same area as the heat pump.

The circumstances that generated considerably lower achieved winter temperatures compared to set points are more diverse and complex. There are those whose heat pumps have been installed as supplementary heating in an attempt to warm areas in the dwelling not serviced by the main heating appliance. The dwelling (identified as Household 1 in the following) with the largest gap between set point and monitored temperature of -12.8°C had installed a heat pump in the hallway of a villa. It was installed in the belief it would both heat the hallway and raise the temperatures of the bedrooms off that hallway. They expressed considerable disappointment that the heat pump had failed to meet those expectations. For this household, the wood burner kept the living area warm. They were persuaded by friends, family and installers that a heat pump in the hall would resolve the cold temperatures in the remainder of the house. Notably, although dissatisfied with the resultant temperatures, the householders report themselves satisfied with the information provided to them.

They set their heat pump at 27.3°C but use it primarily for morning heating. The space in which the heat pump is located remains, however, very cool. The 24-hour average temperature was 14.3°C. Average winter temperatures in HP1 over that period were:

- 12.6°C morning (7am–9am)
- 14.3°C day (9am–5pm)
- 15.7°C evening (5pm–11pm)
- 13.6°C night (11pm–7am).

These temperatures are very low. The rise in temperature from day into evening probably represents the effect of the wood burner, which is used to heat the lounge, dining room and kitchen. The wood burner is used typically in July–October both during the week and on weekends. It is lit during the day and burns through the evening. Oil column heaters are now used to warm the bedrooms. The most significant impact on winter indoor temperatures from the householder's perspective has been the installation of insulation. Table 18 presents this household's assessment of the comparative merits of their heat pump and their wood burner.

Table 18 Household 1's assessment of their heating appliance performance

Performance criteria	Heat pump	Wood burner
Convenience and ease of use	Excellent	Good
Cost to run	Good	Good
Heating performance	Poor	Excellent

Household 1 contrasts with another of the households (Household 2) whose set point is substantially higher than the temperatures achieved. Household 2 is a one-person household using two forms of heating: the heat pump in the lounge and an electric blanket. This might be described as the traditional heating pattern in New Zealand, which was also evident in HEEP. Heating the lounge, ignoring temperatures in other areas of the dwelling and compensating for low bedroom temperatures with blankets and/or electric blankets.

In Household 1, disparity between set point and temperature achieved in the lounge is -11.9°C below the set point. The temperatures achieved for this dwelling were 17.1°C on average over a 24-hour period in winter, both peaking in the day and evening at 18.1°C. The deficit arises from the householder using the heat pump rather like a fan heater or LPG gas heater, turning it on and off as they feel cold or warm. The set point is placed at 30°C because the householder believes that this will heat the space more quickly even though the comfortable temperature for this householder is around 18°C.

The third household (Household 3) with the set point extremely high relative to monitored temperature also sets the heat pump at 30°C. They too turn the heat pump on for instant heat, usually in the mornings between 7am and 9am. At other times, they rely on a pellet burner, which is also situated in the area serviced by the heat pump. The pellet burner is used in the evenings on weekdays and from 9am to 11pm on weekends from May through to around September. In winter, the 24-hour average temperature is 16.3°C. The peak is in the evening at 19.1°C. The morning temperature during the period reported as the time of heat pump use was 13.7°C. This reflects some overnight heat loss, but this is relatively low and suggests an efficient thermal envelope. Table 19 shows this householder's rating of their heat pump and their pellet burner.

Table 19 Household 3's assessment of their heating appliance performance

Performance criteria	Heat pump	Pellet burner
Convenience and ease of use	Excellent	Excellent
Cost to run	Good	Good
Heating performance	Good	Excellent

All of the heat pumps in these dwellings had been installed by the households interviewed. One household (Household 4) whose heat pump set point was on average 11.8°C above achieved temperatures came into a dwelling with a heat pump already in situ in the living area.

For Household 4, winter 24-hour temperatures in this dwelling were 16.0°C with an overnight average temperature of 13.8°C and a morning temperature of 14.0°C. Daytime winter temperatures in the living room heated by the heat pump average 16.9°C, and temperatures peak in the evening at an average of 18.2°C. The householder also uses a low-energy panel heater in the children's bedroom from June–November. The heat pump in the living room is typically used according to the householder from April–October. The reported heating schedule includes morning, day and evening heating on both weekdays and weekends. The heat pump is set at 30°C. The householder reports that the heat pump, along with other electrical heating appliances, keeps the house warm most of the time in winter. However, the heat pump is perceived as being not "as warm as a fire". The difference between set point and achieved temperatures for HP4 does not seem to be explained by the 'switch on, switch off' approach notable in two of the other dwellings. Nor does it seem to arise from significant heat loss at night.

The age of heat pumps does appear to have an impact on some householders' behaviour. For instance, in another household the achieved temperature in the heat pump-heated lounge is 9.1°C less than the set point. The heat pump is described by the householder as "old, big and bulky". The heat pump was in situ when the house was purchased. Two factors have contributed to the gap between set point and temperature. The first is the heat pump noise and draught, which means that the heat pump is only used in July and August. It is switched off by 7pm at night. The second is that the house is seen by the householders as well insulated and oriented for solar gain. As such, they report being warm most of the time, although their average 24-hour temperature in the living room is only 15.6°C during winter. By evening, the living room temperature is 17.9°C, and this falls to an average of 13.6°C by the next morning.

It should be noted, however, there is no evidence of a direct and significant statistical relationship between heat pump age and evening winter temperatures.

5.3 Summer temperatures

Most householders report that they rarely or never use their heat pump for cooling. There are also a small number of dwellings in which heat pumps are used in summer for heating rather than cooling. This is consistent with high summer temperatures measured in the heat pump spaces of these dwellings in summer. Certainly, the potential for heat pumps to modify temperatures over the course of a year is not used. All the monitored dwellings had mean average 24-hour temperatures in excess of 16°C. The majority, 83.1% were in the range of 18–24°C, and some 15.4% of dwellings had temperatures in excess of 24°C (Figure 20).

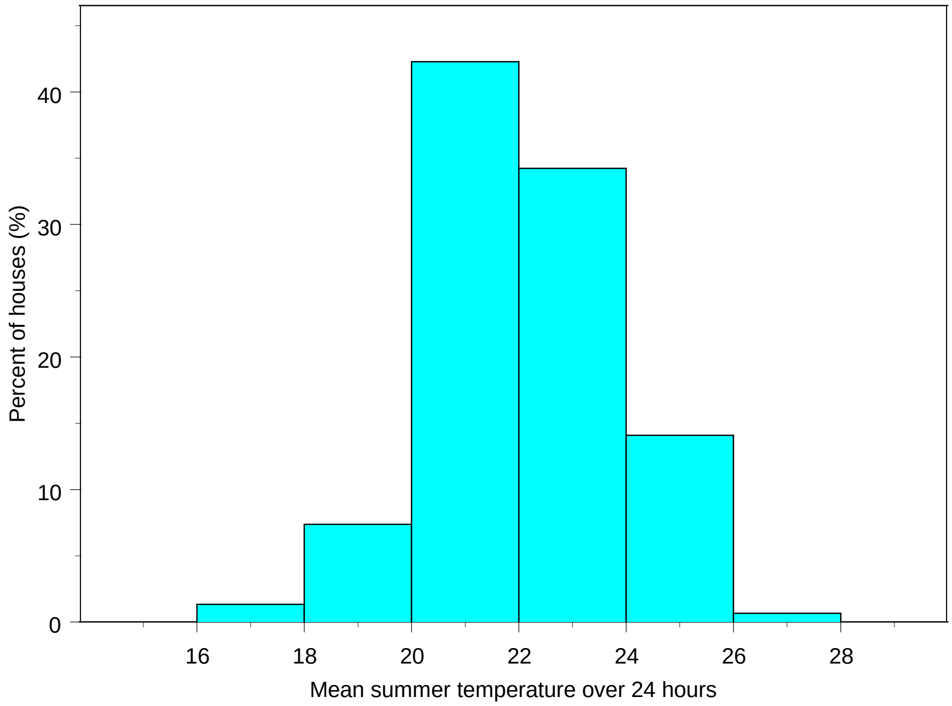


Figure 20 Mean summer temperature over 24 hours

These indoor summer temperatures are strongly influenced by external temperatures (Figure 21). This confirms that using heat pumps for summer cooling is by no means pervasive or habitual. It also suggests that the dwelling itself is either over glazed with excessive solar gain, poorly ventilated and/or under insulated. This is consistent with the issues of still poor temperature control found in the winter temperatures. Notable is the association found in HEEP between dwelling age and temperature is less evident among these dwellings. This indicates that some of the older dwellings have been subject to retrofit with insulation.

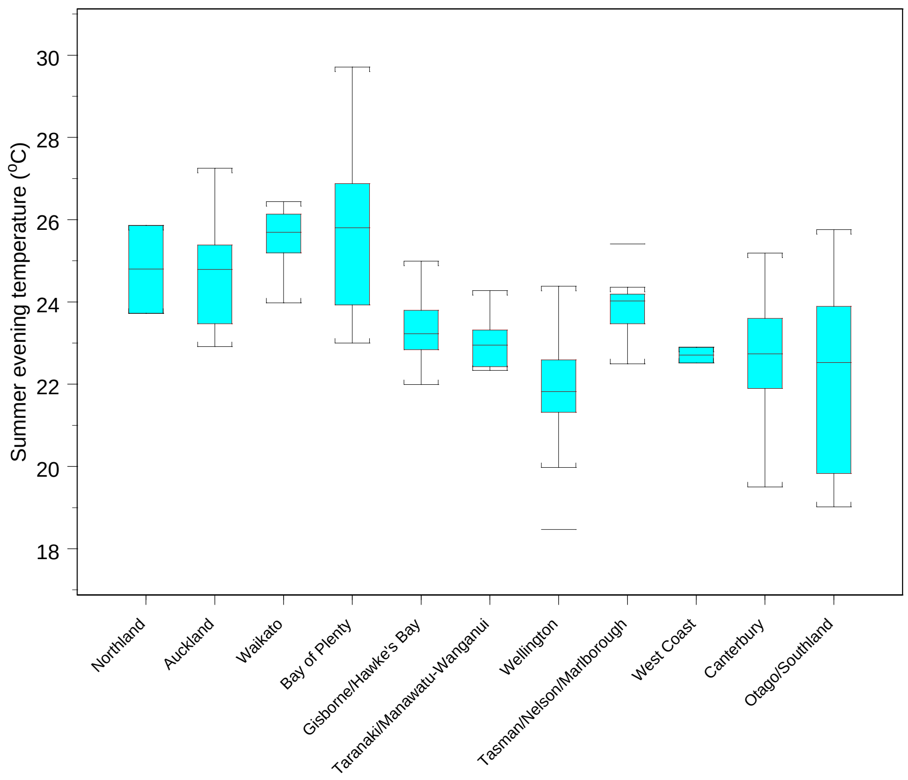


Figure 21 Mean summer 24-hour temperature by region

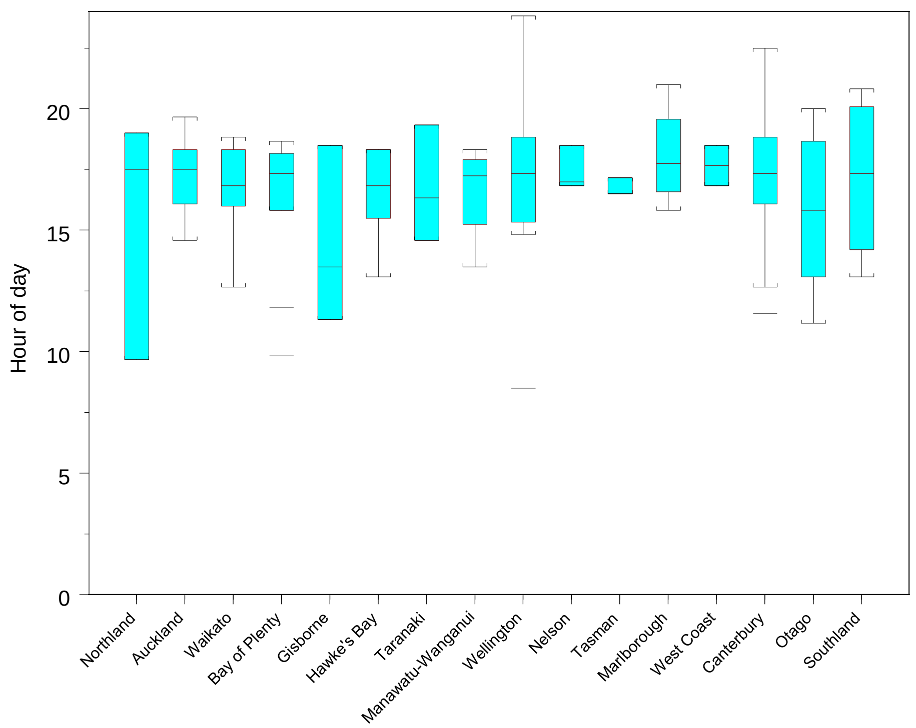


Figure 22 Time of day absolute maximum reached in house (summer)

5.4 Humidity

The measurement of humidity has been limited in New Zealand studies. There are a number of reasons for this. First, the equipment to measure humidity has been less accessible than equipment to measure temperature. Second, there is still debate internationally around the optimal boundaries for humidity. Third, and most importantly, relative humidity is strongly related to indoor temperatures and exterior humidity. Problems of mould and damp in winter can often be mitigated by raising indoor temperatures.

Arundel et al. (1986) suggest that the ideal relative humidity range is 40–60% (Figure 23). Despite the apparent wide range, there has been no compelling evidence suggesting that those boundaries should be narrowed.

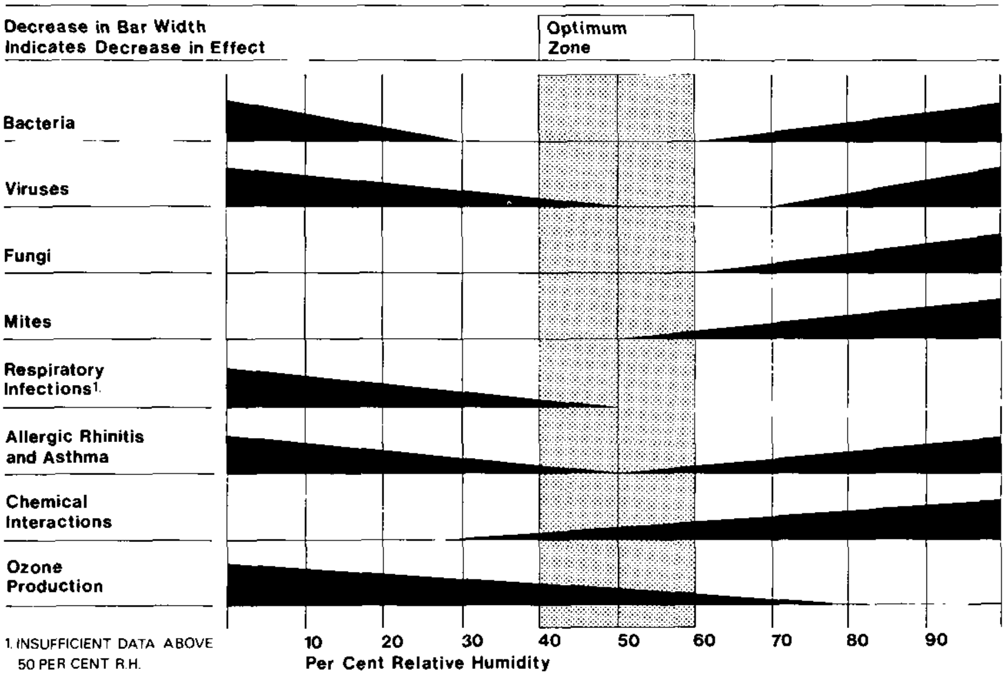


Figure 23 Range of relative humidity for minimising health effects (from Arundel et al., 1986)

Just over 10% of houses have a mean relative humidity of under 40% over winter. Around 33% of houses have a mean winter relative humidity of over 60%, although for less than 4% this is above 70% (Figure 24).

In the heat pump houses, indoor humidity broadly reflects inter-regional climate variations. Of course in some regions, such as Otago/Southland, there are considerable climate variations within the region itself, which can mute the impact of climate. Even so, there are considerable intra-regional variations in humidity (Figure 25).

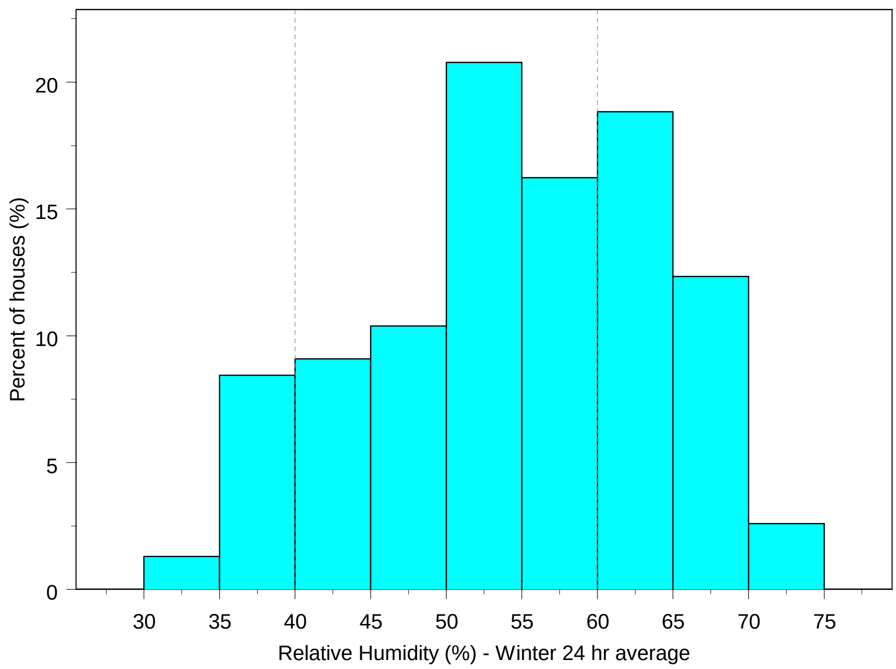


Figure 24 Mean relative humidity over 24 hours during winter

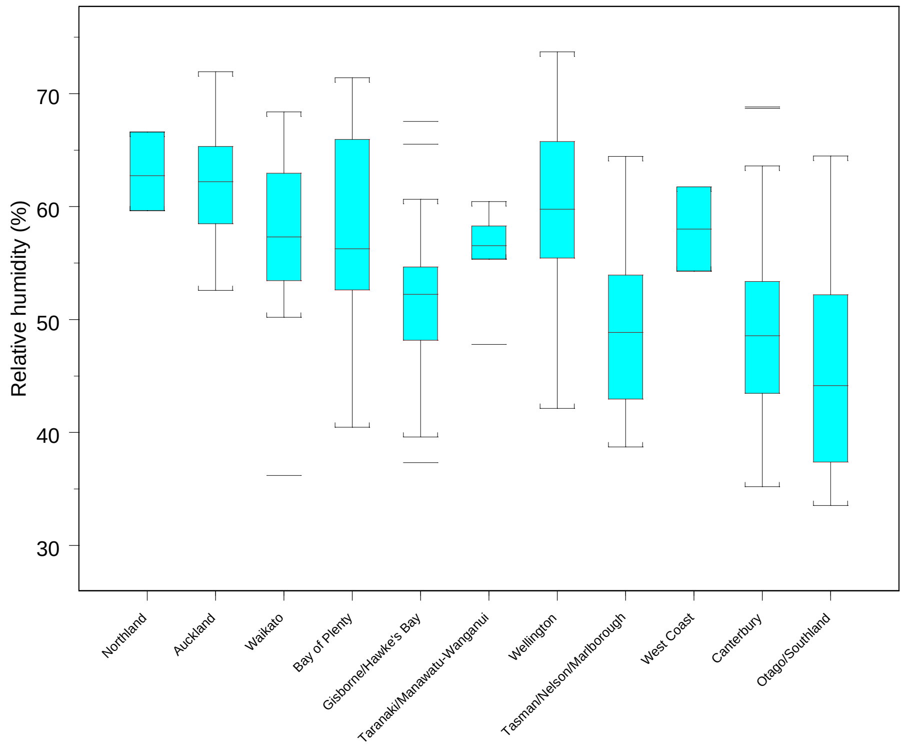


Figure 25 Mean winter relative humidity over 24 hours by region

It is clear, however, that some dwellings have distinctly different relative humidity levels compared to dwellings in the same region. For instance, one dwelling in Waikato had a relative humidity of only 35%. This was a dwelling that had persistently high indoor temperatures around 27°C.

5.5 Are indoor temperatures improving?

Two previous studies of temperature have been completed in New Zealand, which allows some comparison to be made with the data collected from this study (Isaacs et al., 2010). The most robust of these is the HEEP study. Comparisons, however, must be treated with care. HEEP measured the living rooms and the main bedroom in each of the participant dwellings. This study has only measured the temperature in the area the primary heat pump was intended to heat. Because of this, the analysis of the heat pump study data is restricted to heat pumps in living rooms. This allows a direct comparison with HEEP but makes the sample quite small.

There is some evidence of an increase in average temperatures although not substantial enough to meet either the WHO or Watt Committee's temperature recommendations for living rooms. There does appear to be some modification when the difference between internal and external temperatures is measured (Table 20 and Table 21).

Table 20 Temperature comparisons with previous New Zealand studies – North Island

Average winter temperatures over 24 hours °C	Top of the North Island		Bottom of the North Island	
	Heat pump study 2010–2011	**HEEP 2001–2004**	**Heat pump study 2010-2011**	**HEEP 1999, 2002–2004**
Living room:				
Mean temperature	17.7	16.5	17.1	16.1
External:				
Mean temperature	11.5	11.9	10.5	9.3
Mean temperature difference	***6.1***	***4.6***	***6.6***	***6.9***
Sample size	52	112	29	74

Table 21 Temperature comparisons with previous New Zealand studies – South Island

Average winter temperatures over 24 hours °C	Christchurch		Southern South Island	
	Heat pump study 2010–2011	**HEEP 2002**	**Heat pump study 2010–2011**	**HEEP 2003**
Living room:				
Mean temperature	17.5	16.1	17.7	14.7
External:				
Mean temperature	8.6	10.3	7.8	7.3
Mean temperature difference	***8.9***	***5.7***	***10.1***	***7.4***
Sample size	27	34	16	30

Figure 26 shows there are some regional differences in achieved winter evening temperatures suggesting a climate effect. However, within regions, there is considerable diversity.

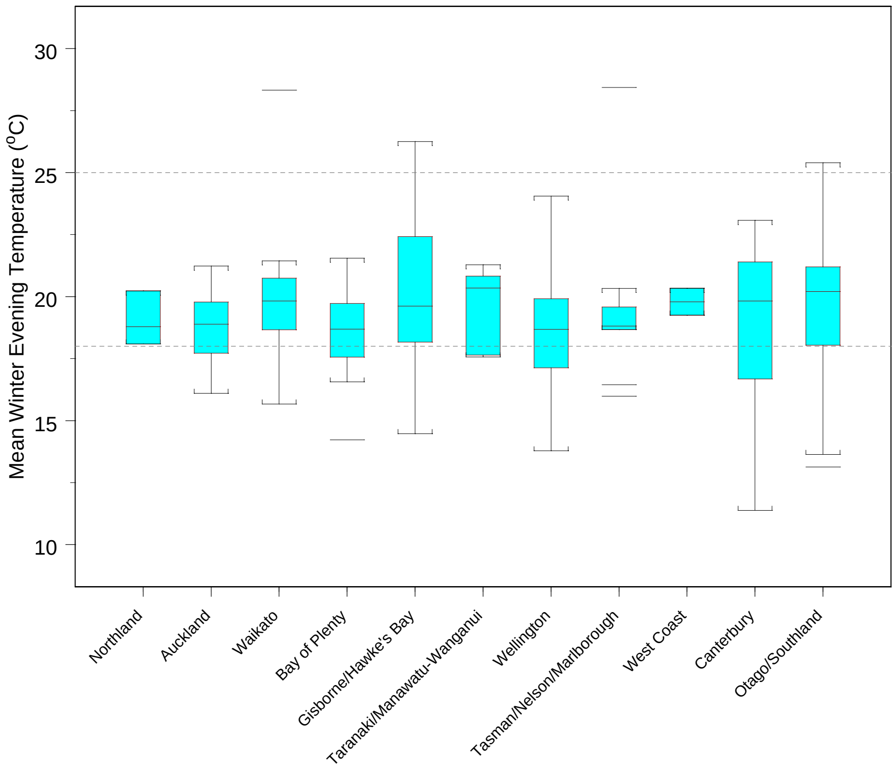


Figure 26 Mean winter temperatures in area heated by heat pump by region (June– August)

Regional diversity suggests that other factors are influential. This can be expected to fall into one of three categories.

- The type and performance of heating appliances.
- The thermal performance of the dwelling envelope.
- The heating practices of householders and consumption constraints as determined by household incomes.

Establishing any of these definitively is problematic in a sample selected for the presence of a heat pump. Consequently, the diversity of the sample is limited. This is particularly problematic with regard to the impact of heating appliances. There is no statistically significant association evident, possibly because of the constitution of the data set. However, there are signs that heating appliances and achieved evening winter temperatures are associated.

Table 22 shows the temperature achieved in the monitored heat pump space on winter evenings by the reported main heating appliance. The distribution of heating appliances in households below 18°C and above is similar to the overall distribution of appliances in the sample.

Table 22 Temperature achieved in monitored heat pump space on winter evenings

Main heating appliance	Average winter evening temperature °C		
	Less than 18°C	**18°C or higher**	**Total**
Single appliance – heat pump	68.8%	75.0%	73.4
Single appliance – other type	15.6%	8.3%	10.1
Multiple appliances	15.6%	16.7%	16.4

A similar pattern is found when the difference between reported set points and achieved temperatures are considered (Table 23).

Table 23 Difference between reported set point and achieved winter temperature

Main heating appliance	Greater than -3.0°C (n=49)	-3.0°C–3.0°C (n=70)	Greater than 3.0°C (n=6)	Total (n=125)
Heat pump	73.5%	75.7%	66.6%	74.4%
Heat pump and wood burner	4.1%	5.7%	16.7%	5.6%
Heat pump and other appliance	12.2%	7.1%	16.7%	9.6%
Heat pump not main heater	10.2%	11.4%	0.0%	10.4%

There is a pattern evident in the relationship between insulation and achieved winter evening temperatures. It is evident that over half the households achieving less than 18°C average winter evening temperatures have no or poor insulation. However, it is equally evident that 18.6% of the households with fully insulated dwellings also have evening winter temperatures in the area of the monitored heat pump of less than 18°C. Those dwellings, are, however, somewhat over-represented among households achieving an average temperature between 18°C and 24°C on winter evenings in the heat pump area. This association is not statistically significant (Table 24).

Table 24 Average winter evening temperature in heat pump area

	Dwelling insulation level			
	None or poor	Average	Full	Total (n=125)
Less than 18°C	27.3%	23.1%	18.6%	23.4%
18.0°C to 24.0°C	65.5%	73.1%	81.4%	72.6%
24.1°C and above	7.2%	3.8%	0.0%	4.0%

What is statistically significant is the association between household income and average evening winter temperatures in the area heated by the heat pump. This is most evident in dwellings where there are low average winter evening temperatures. Higher income households are considerably under-represented in this category. Only 14.8% of households with their heat pump are achieving less than 18°C compared to their 27.1% representation in the sample overall (Table 25). Conversely, households with incomes of less than $50,000, who made up 27.1% of the households, constituted 37% of the households with average winter evening temperatures of less than 18°C.

Table 25 Household income and average evening winter temperatures

Household income	Average evening winter temperature			
	Less than 18.0°C	18.0–24.0°C	24.1°C and above	Total
Less than $50,000	37.0%	25.9%	0.0%	27.1%
$50,000–100,000	48.2%	41.2%	100%	45.8%
More than $100,000	14.8%	32.9%	0.0%	27.1%

6. HEAT PUMP ELECTRICITY CONSUMPTION AND COSTS

The impact of the wider distribution of heat pumps in residential dwellings has national as well as householder implications. This section is concerned with both those scales. At the national scale, it is concerned with the extent to which heat pumps are associated with lower or higher levels of electricity consumption for space heating. This has profound implications for the nation's consumption of electricity. Particularly, where there may be peaks arising from heat pumps being used at certain times of the day and over particular periods of the year. There are also implications for households around the extent to which heat pumps impact of household costs and the relation to the amenity value heat pumps deliver.

6.1 Heat pumps and national annual electricity use

Compared to other electrical appliances used for space heating, heat pumps use electricity more efficiently than other domestic electricity-based heating appliances. This does not mean, however, that using heat pumps necessarily reduces the annual electricity consumption used for heating New Zealand dwellings. Nor does it necessarily mean that households using heat pumps will find their overall electricity consumption, or even their electricity for heating, has decreased or their heating expenditure lessened. Among the heat pump dwellings, the average electricity use by heat pumps alone is 36% higher than all the electricity use for heating found in the HEEP study.

HEEP found that electricity-based heating in New Zealand households was 920 kWh annually on average per dwelling. The heat pump dwellings in this study use 1,220 kWh annually on average per dwelling. The actual electricity consumption for heating is likely to be higher in heat pump dwellings. Many of these dwellings also use other forms of electrical heating.

The consumption of electricity by heat pumps also shows some regional variation. Electricity consumption for heat pumps ranges from 700 kWh annually on average in Auckland/Northland to 2,230 kWh annually per house in Otago/Southland (Table 26).

Table 26 Annual electricity use by heat pumps by region

Region	Average dwelling heat pump electricity annually (kWh)	Standard deviation (kWh)	Count of houses
Auckland/Northland	700	100	35
Waikato/BOP	1,220	460	23
Gisborne/Hawke's Bay	770	350	10
Taranaki/Manawatu-Wanganui/Wellington	1,150	230	22
Nelson/Tasman/Marlborough	1,190	490	10
Canterbury/West Coast	1,350	140	45
Otago/Southland	2,230	400	19

This is statistically significant, but any conclusions about regional use need to be treated with some caution. The sample was drawn to be nationally representative. The data is not necessarily representative at the regional level, and there are considerable standard deviations in some regions.

The peak period of heat pump use is winter. Figure 27 gives a histogram of the total energy use over the prime winter months of June, July and August for all the heat pumps in the study. Peak daily consumption on weekdays is still from 5pm–11 pm, but there is evidence of an emerging pattern of morning consumption between 7am and 9 am. There is limited heat pump use in summer. Notably, heat pumps are being used both for summer cooling and summer heating. Cooling, in particular, is sporadic.

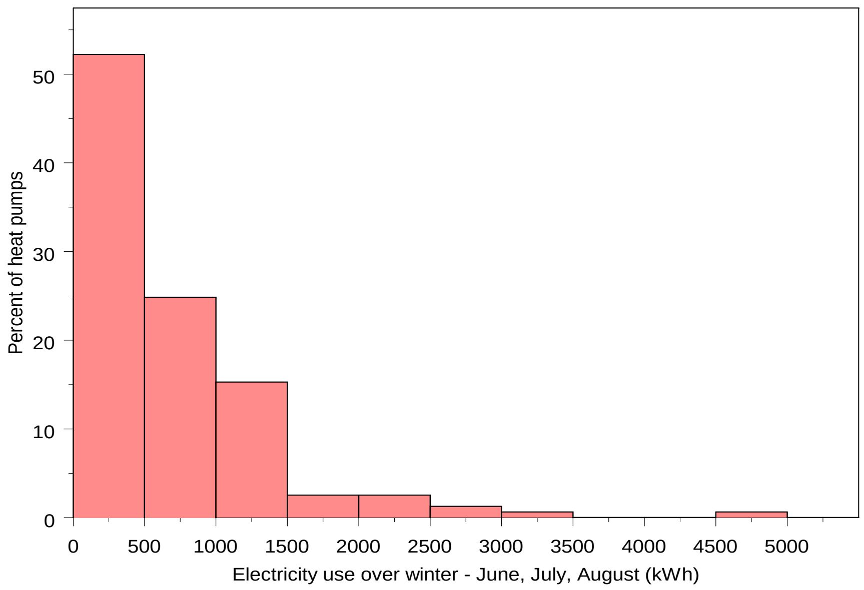


Figure 27 Electricity use by heat pumps over winter

6.2 Energy consumption and amenity

Electricity consumption by heat pumps is associated with the array of main heating appliance householders use. A single main heating appliance that is a heat pump is associated with higher levels of energy consumption than where a heat pump is supplementary (Table 27). Households reporting a single main heating appliance that is not a heat pump are over-represented among those with heat pump electricity consumption of 920 kWh or less annually.

Table 27 Average annual heat pump electricity consumption (kWh)

Main heating appliance	920kWh or less (n=85)	921 kWh or higher (n=70)	Total (n=155)
Single appliance – heat pump	64.7%	84.3%	73.5%
Single appliance – other type	18.8%	1.4%	11.0%
Multiple appliances	16.5%	14.3%	15.5%

The differences between the households is particularly sharp when the average and median heat pump electricity consumption is examined (Table 28).

Table 28 Average versus median heat pump electricity consumption

Main heating appliance	Average annual kWh	Median annual kWh
Single appliance – heat pump	1,361	937
Single appliance – other type	446	314
Multiple appliances	1,136	684

Households for whom a heat pump is one of two main heating appliances have an average use of 83.5% compared to households where a heat pump is the main heating appliance. Where heat pumps are supplementary to another main heating appliance the average heat pump electricity consumption is less than a third compared to when use is as the main heating appliance. In these cases the main heating source is typically a wood burner. The median consumption of electricity by heat pumps shows a similar pattern. The median annual kWh heat pump consumption for households that use other heating for their main heater is only 314 kWh. For households who use heat pumps as their main heating appliance, median heat pump electricity consumption is 937 kWh.

Although on average heat pumps are using 1,220 kWh per dwelling annually, 60% of heat pumps use less than 1,000 kWh per year (Figure 28). Perhaps more importantly for householders, for much of the time, their heat pumps are neither heating nor cooling.

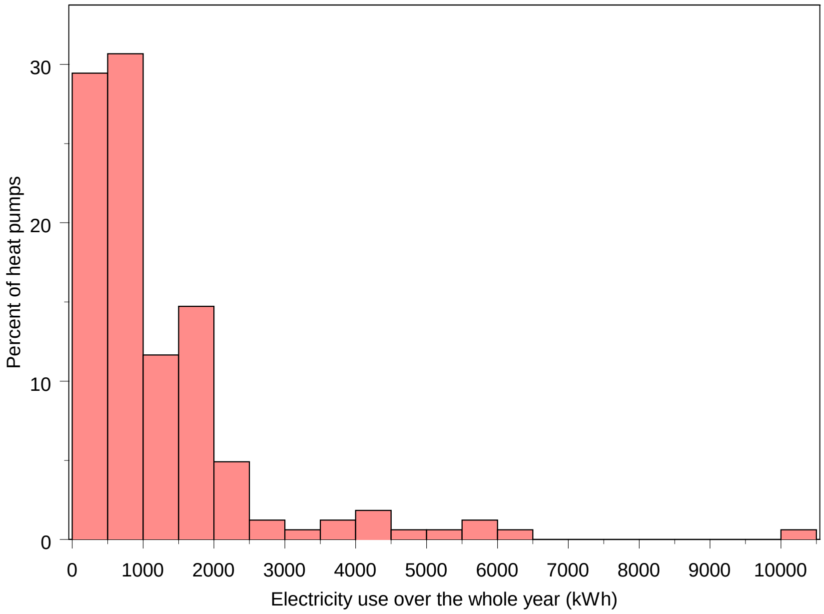


Figure 28 Electricity use over the whole year by heat pump (heating and cooling)

Electricity billing data was collected for a number of the households participating in the study. Figure 29 gives a comparison between the annual electricity billing data for the whole household with the heat pump electricity usage for that household. The usage collected from the monitoring equipment installed as part of this study. The relationship between the total household electricity usage and household heat pump electricity usage is not strong. This indicates:

- households have very diverse and complex patterns of electricity use
- heat pump use is often variable and frequently limited.

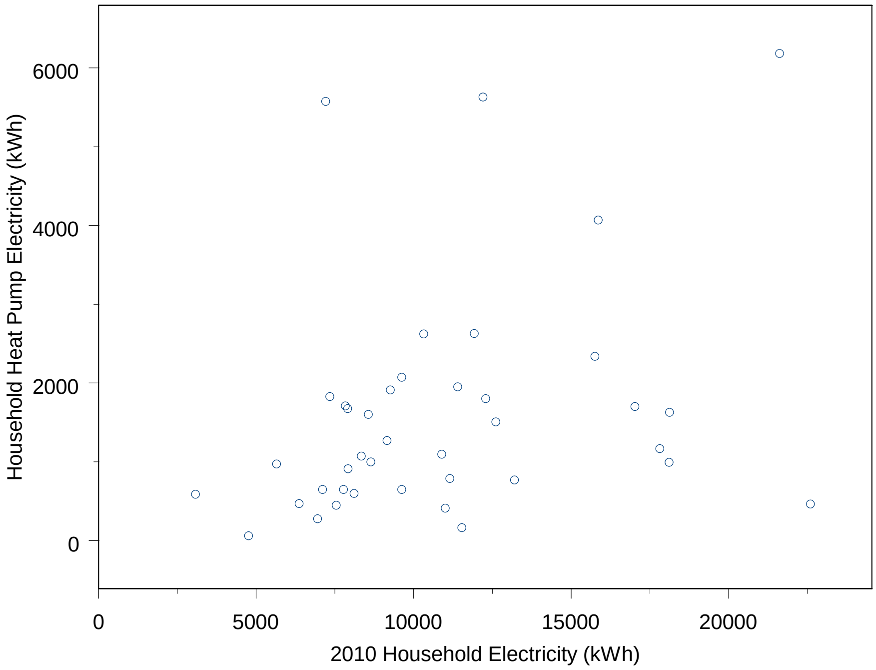


Figure 29 Comparison of household heat pump electricity with total electricity

The proportion of time the heat pumps are on during the three winter months (June, July and August) and the three summer months (December, January and February) are shown in boxplots in Figure 30. The definition for when a heat pump is not 'on' includes when it is on standby or in a low-energy state (<40 W)

Over winter, the on time for a heat pump is variable between households. In winter, half of the households have their heat pump heating for just less than 25% of the time. The other households have their heat pump heating for more than 25% of the time. In summer, the usage of heat pumps is much reduced. Half of households have their heat pump working for less than 1% of the time.

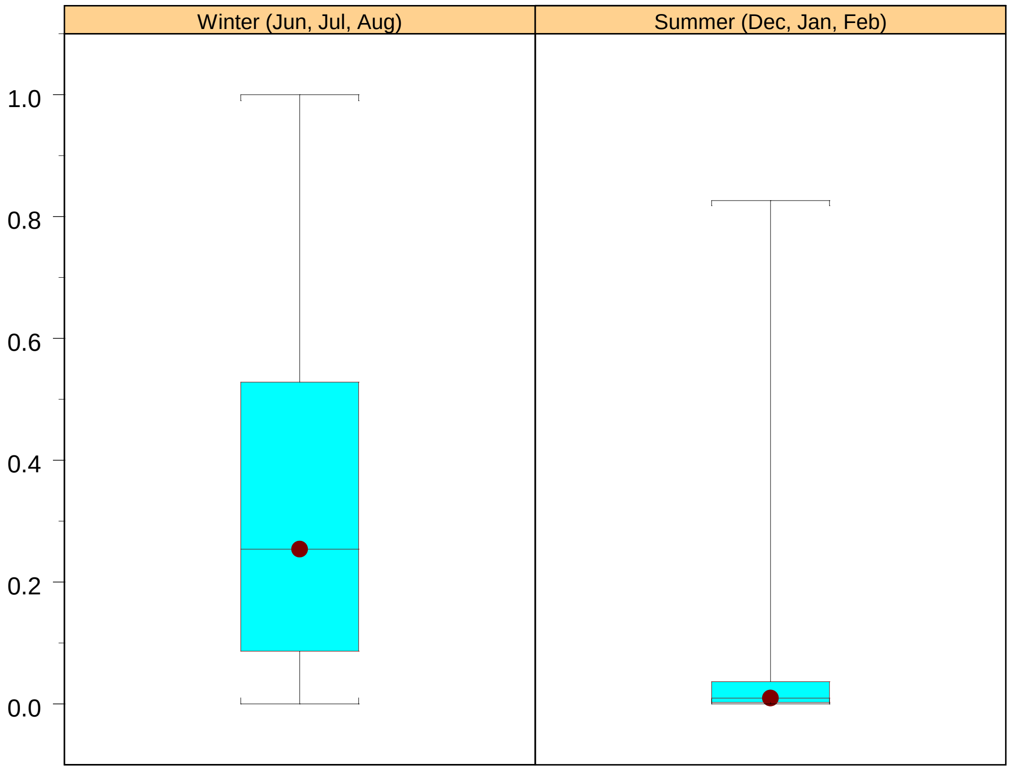


Figure 30 Proportion of time heat pumps are operating for winter and summer

The proportion of the time each heat pump is within 500-watt intervals is shown graphically for the winter months in Figure 31 and for summer in Figure 32. The heat pumps are arranged in order of the proportion of time they are above the standby level (40 W).

The higher energy levels do not show a consistent trend as the amount of time the heat pump is on increases. There are heat pumps that are on for a large proportion of the winter months but operate predominantly in a 40–500 W range. These are indicated by the tall bars of light orange to the right of the graph). In contrast, there are other heat pumps that are on for a similar length of time that are predominantly operating in the 1,000–1,500 W range.

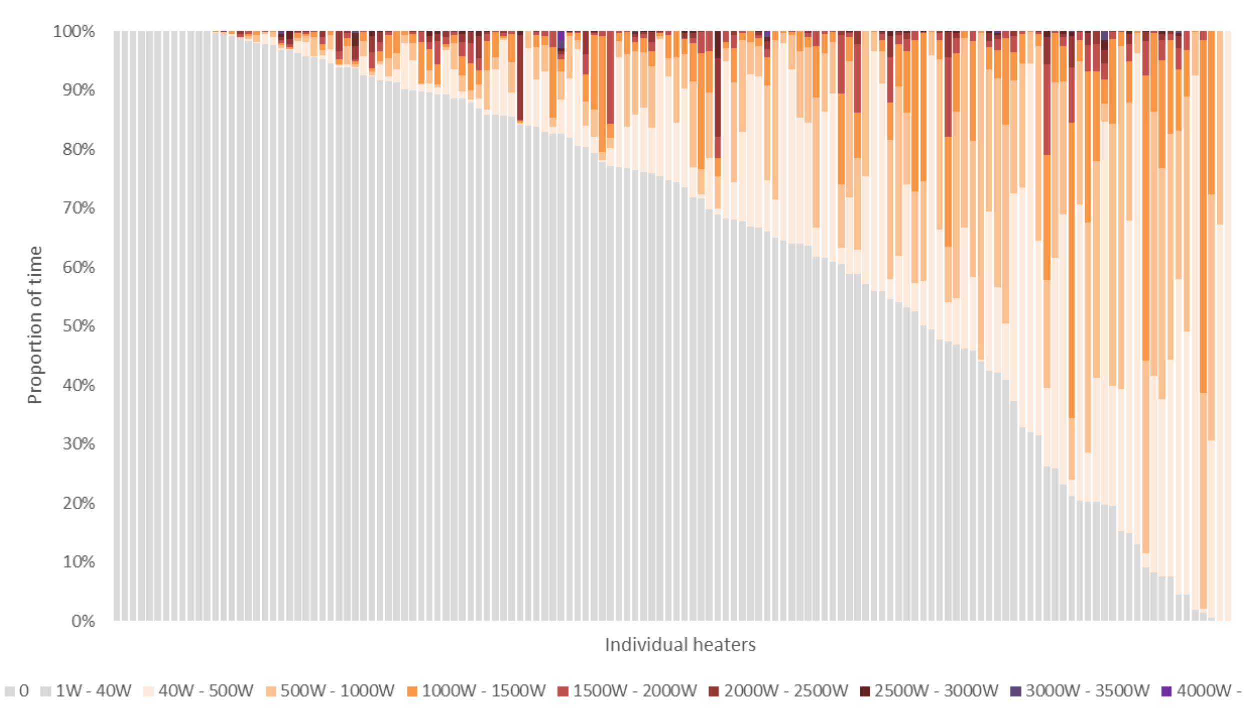


Figure 31 Proportion of time each heat pump is in each range over winter (June, July, August) (n=136)

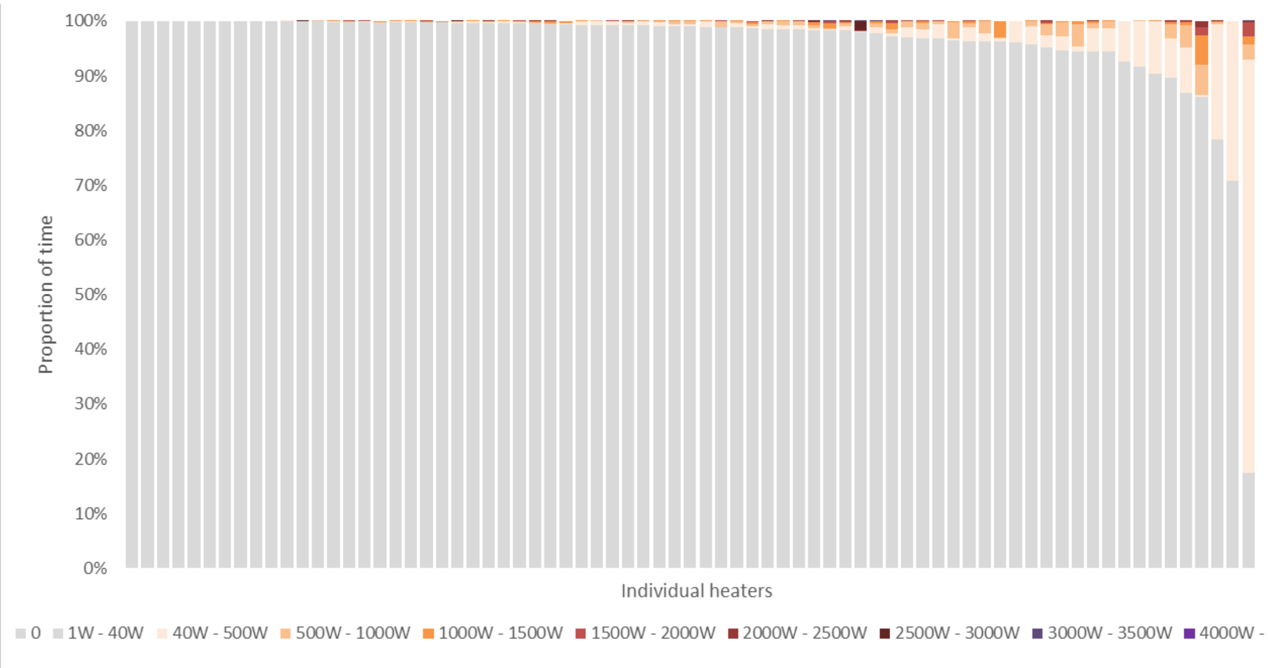


Figure 32 Proportion of time each heat pump is in each range over summer (December, January, February) (n=73)

A load duration curve is a common method to display information on the demands placed on an electrical network. This type of graph shows the proportion of the time a load is above a particular threshold. Figure 33 shows load duration curves for the 136 heat pumps over the three winter months. It shows a considerable variation in the demand placed upon the electrical network by individual households.

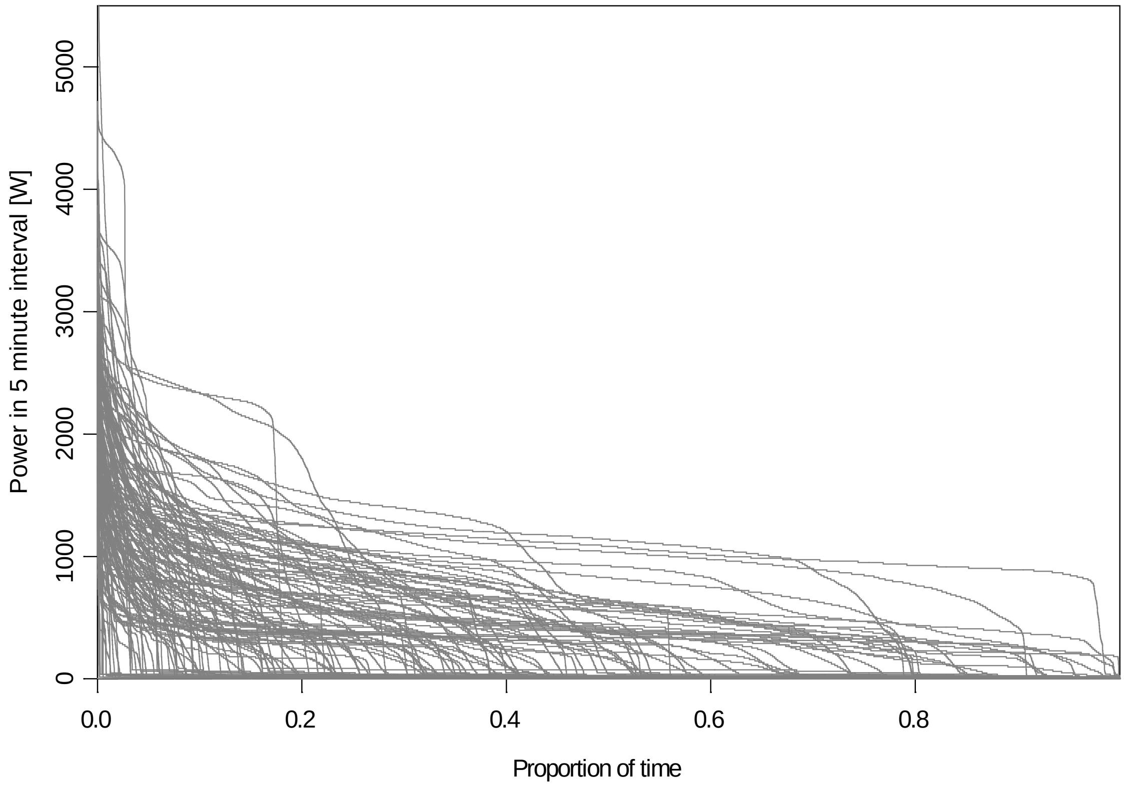


Figure 33 Load duration curve for the 136 heat pumps in use over winter (June, July, August)

The patterns of use evident in different households is illustrated below in individual heat pump load duration curves. Figure 34 shows a load profile of a heat pump that predominantly operates at one energy level producing a curve that is quite flat. This may correspond to a fixed-speed heat pump that is either operating or off. Figure 35 shows a load duration curve that has a range of energy values between the highest level, over 1,500 W, and a low level of around 400 W. This may relate to an inverter heat pump that is able to adjust the speed of its motor to more efficiently match the required heating demands. Figure 36 shows an example of a heat pump that operates at two particular levels. Figure 37 shows a heat pump that runs at one level for over half of the time during the winter months.

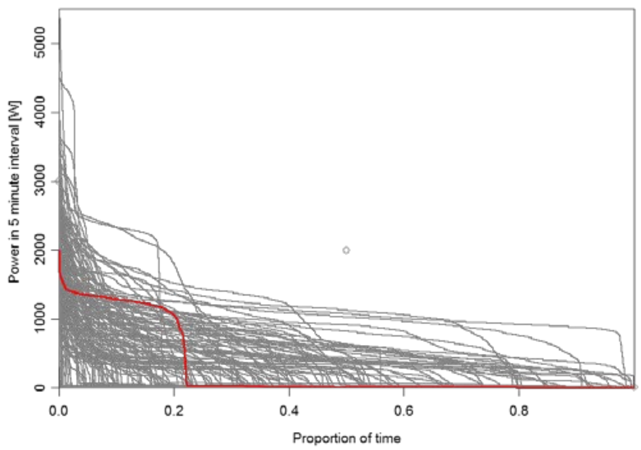


Figure 34 Load duration curve of a heat pump predominantly operating at one level

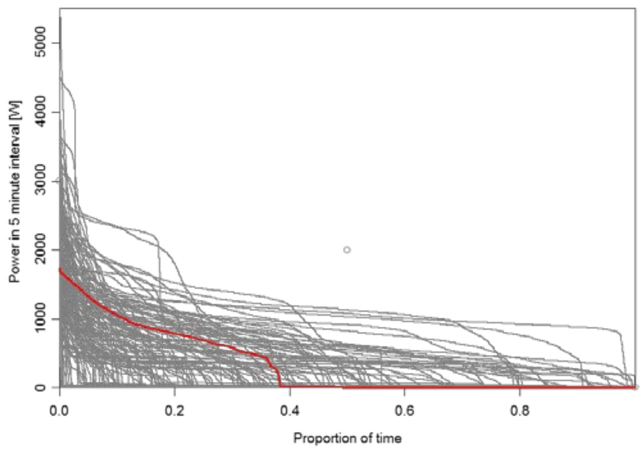


Figure 35 Load duration curve of a heat pump with a varying level

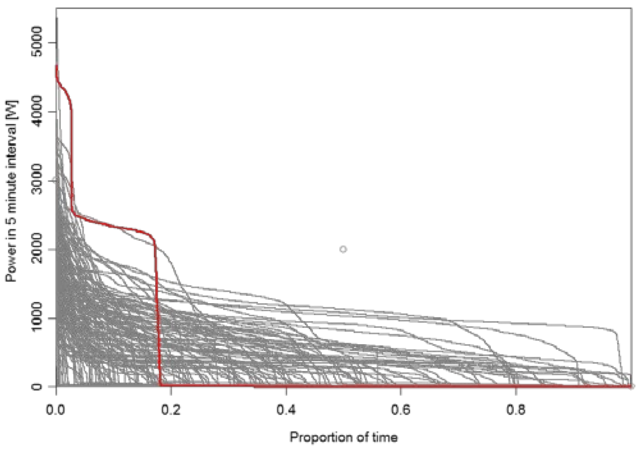


Figure 36 Load duration curve of a heat pump operating at two levels

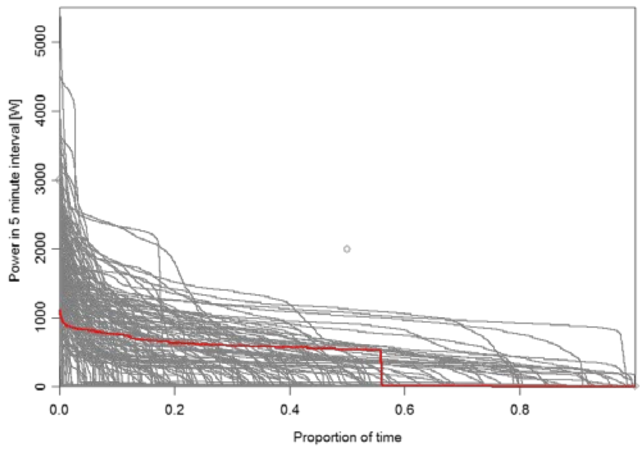


Figure 37 Load duration curve of a heat pump operating for extended period at one level

6.3 Performance information of an individual heat pump

Measuring the heat output of an individual heat pump requires knowledge of the airflows and temperatures into and out of the indoor unit of the heat pump. While this can be done in a laboratory or even as a one-off measurement within a specific house (Christensen et al., 2011), it is not practical to undertake these types of measurements over a full heating season as the level of intrusion for the occupants would be unacceptable. Instead, the heat pump performance was examined using methods developed in HEEP to estimate the heating load from solid-fuel burners (see section 16 in Isaacs et al., 2010). This method used the temperatures measured in the house and the R-value of the house or space being heated alongside the new information of the energy input of the heat pump. This allowed an estimate of the performance of the heat pump to be made.

The error for using this method for solid-fuel heaters was known to be high (over 20%). However, attempting to apply this technique to heat pumps proved to be difficult and could not be universally applied. Many heat pumps were operated for only a short time for which averaging over time became difficult. It was also difficult to calculate the R-values for the spaces being heated. This was due to the heat pumps being frequently located within central hallways of the house with varying connections to the other living spaces. Many times, other heating sources were present including solid-fuel burners, unmonitored resistance heaters or multiple heat pumps. This meant the change in temperature within the living room could not be solely connected to the operation of the heat pump.

In the first year of monitoring, the method was attempted on households from the Wellington, Otago and Southland regions. While heating outputs could not be established for all of the houses, seasonal heat outputs could be estimated for 26 households. Dividing the estimated seasonal heat output of the heat pumps by the measured electricity input gives the MHPF. A histogram of the MHPF's from the 26 households is shown in Figure 38.

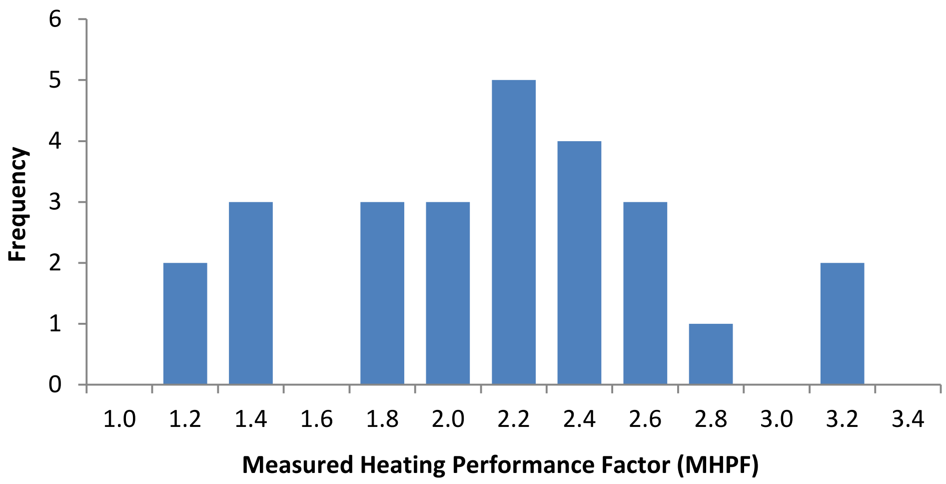


Figure 38 MHPF for a non-random sample of 26 heat pumps from households in Wellington, Otago and Southland

Many people believe that they are likely to get three times or more heat out of their heat pump than the electricity they put into it. Figure 38 shows that, on average for the 26 heat pumps, the delivered heat was only 2.05 times the electricity used by the heat pump. However, the range of performance was large, ranging from MHPF = 1.15 up to MHPF = 3.20. That means that some heat pumps are delivering heat only a little above the electricity consumed by the heat pump. Two heat pumps provide more than three times the output compared to the electricity input. Therefore 24 of the 26 heat pumps achieve heat outputs of less than three times the electricity input. Low ambient and outdoor temperatures are often cited as the main reason for low performance. However, the two lowest-performing heat pumps were located in Wellington and not the cooler Otago or Southland regions. Both of these heat pumps had a MHPF of 1.15. By way of contrast, one of the highest-performing units, MHPF of 3.19, was also located in Wellington. These numbers roughly align with the suggested output of an air sourced heat pump in the USA (Department of Energy, 2015) of between 1.5 and 3 times the energy input.

The gap between common expectation and delivery is indicative of some of the limitations of New Zealand's current approach to heat pump energy ratings. Energy rating labels give a performance (COP) for test conditions at a set temperature level (7°C). Most heat pumps are unlikely to experience this type of constant temperature over the heating season. The actual performance of a heat pump over the heating season (MHPF) is likely to be lower than the test COP. The performance of heat pumps may be better indicated by ratings provided at a number of different temperatures, both ambient and outdoors.

Other heating appliances are influencing temperatures and electricity consumption. There are indications that householders modify their heat pump use to manage costs. Householders give mixed views around the impact of heat pumps on household energy costs. Of the 128 householders that discussed that aspect of their heat pump operation, 44 householders reported that their energy costs had increased since acquiring a heat pump. Of that same group 37 householders reported a decrease in energy costs. A considerable number reported that they simply did not know, and 26 householders said that their energy costs stayed the same (Figure 39).

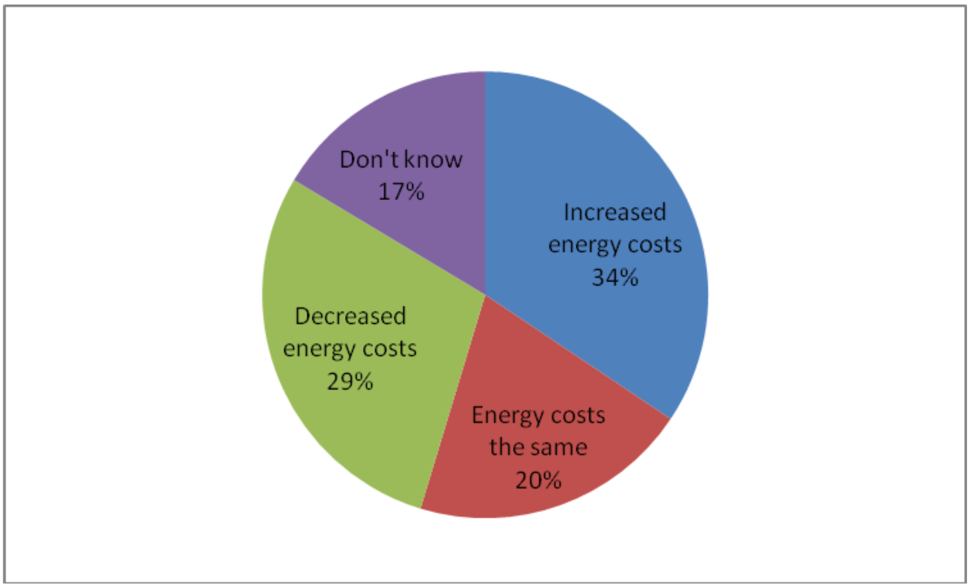


Figure 39 Change in energy costs since acquiring heat pump

The ability to manage winter temperatures and electricity costs is enhanced by householders having multiple heating appliances, particularly non-electrical heating appliances. This appears to be confirmed by an analysis of the relationship between winter evening temperatures and annual heat pump electricity among those who report their main heating appliance as heat pump only. In that context, lower heat pump electricity consumption is correlated with lower evening winter temperatures. For households that use both heat pumps and another appliance such as a wood burner as their main appliances, this pattern is also apparent but much less distinctly. However, among those households that report their main heating appliance as something other than a heat pump, the correlation is quite different. The temperature around the heat pump is highest where there is low heat pump electricity usage.

This suggests two situations. First, that heat in some areas in which the monitored heat pump is operating is primarily provided by the other heating appliance with some or no supplementation by the heat pump itself. Second, is where high heat pump electricity consumption and low temperatures prevail. This is because the heat pump is placed as a supplementary heater in an area distinct from the heating effect of the main heating appliance. This inevitably raises issues for householders around the costs of the temperatures associated with heat pumps. In analysing this, three costs need to be taken into account: acquisition costs, installation costs and energy costs.

In relation to acquisition and installation, most householders did not distinguish the installation cost from the appliance cost. This reflects a tendency for suppliers to combine both prices. The average cost per heat pump was $3,232 with the median at $3,000. However the range of costs varied significantly. There was one situation with no expenditure at all, the household having acquired and installed their heat pump as a prize in a competition. At the upper of the scale the cost was $12,000 where a ducting system was installed with the heat pump, as a central heating system.

Among the householders that installed heat pumps, there was no single reason that emerged as a typical driver for take-up. This seems to suggest that heat pump take-up is partly driven by a tendency to take up new technologies. Nineteen householders that acquired a heat pump (3.9%) did so because they considered that heat pumps would provide a cheaper energy option than their current heating arrangements. Around 11% saw heat pumps as having a health benefit, while 29% thought they would be easy and convenient to operate. Around a fifth (21%) of households installing heat pumps considered them energy-efficient alternatives.

7. INSTALLATION AND MAINTENANCE

This section is concerned with the installation and maintenance of heat pumps. It presents data drawn from observation and assessment of the heat pumps when on site. It also presents data related to householders' perceptions of the installation experience as well as the maintenance requirements associated with heat pumps.

7.1 Installation

Studies overseas have shown the quality of the installation of a heat pump strongly influences its efficiency. It can also affect the weathertightness of the building, and the heat pump may not last as long as it should. When on site to install monitoring equipment, an installation check was also performed. The installation check carried out is based on the one used in EECA's good practice guide for heat pump installation (Energy Efficiency and Conservation Authority, 2009). Further details are provided in Appendices B and C. In all cases, the installation check was carried out without any heat pump installers being present. This meant some checks (such as the ones for pipework) could not be carried out.

Table 29 shows that outdoor units are generally well installed in relation to the EECA checklist measures. The major problems relate to poor consideration of vibration and noise problems in locating the outdoor units. It should be noted that, where outdoor units were poorly installed, they were frequently very poorly installed. For instance, the 10% of outdoor units that were unstable were very unstable. Often they had been connected to a bracket to keep the unit off the ground, but the bracket hadn't been connected to something solid.

Table 29 Outdoor unit check results

Checked item	Yes	No	Not sure or not answered
Is the outdoor unit secure with no likelihood of falling over?	87%	12%	2%
Is there any vibration or noise disturbance to owners and/or adjacent properties?	6%	91%	3%
Is the area around the unit clear so there is no likelihood that the air supply routes will become blocked?	79%*	7%	0%
Has the unit been installed to provide future servicing access?	95%	4%	1%
Is all the exterior ducting neat and tidy, with all flashing and waterproofing completed?	91%	8%	1%
Is the unit clearly labelled?	97%	3%	0%

*For 14% of units, growth of plants surrounding them could cause problems in the future.

Similarly, although most units were considered adequate in relation to the question of exterior ducting, very few heat pumps had sealed gaps around the pipes coming out of the ducting. An example is shown in Figure 43. Most installations were done with the pipework going straight through the external wall and then down the outside of the building. Clearance of the unit from the ground is also an issue, with 33% of units found to be fixed with less than the recommended 100 mm.

Figure 40 Not fixed to the ground

Figure 41 Very little clearance under the unit

Figure 42 No clearance under the unit


Figure 43 Ducting open at the end

By comparison, the indoor units of most heat pumps were installed without visible ducting, and only 3% had an obvious stability problem with the units (Table 30). Notably, over a fifth (22%) of households believe that the heat pump is not installed in the optimum location.

Table 30 Indoor unit check results

Checked item	Yes	No
Is the indoor unit secure and does not vibrate?	97%	3%
Is the unit neatly installed with no pipework or ducting visible?	98%	2%

As Table 31 indicates, in a large number of houses, it was not possible to see the drainage hose (23%). There are a number of reasons for this including the possibility that the unit is draining into an existing drain possibly on the roof or under the house. It may be, however, that drainage has not been installed or is draining under the house. In either of these cases, there could be moisture issues in the dwelling. Draining hoses directing on to paths is extremely undesirable (19%). The water can make paths slippery, encourage moss growth and pose a safety hazard especially, but not only, if it freezes.

Table 31 Drainage check results

Checked item	Yes
Is the drain hose from the indoor unit properly installed?	52%
Is the drainage hose on to a concrete (or other solid surface) path?	19%
Drain cannot be seen	23%
Drain is under house	5%


Figure 44 Draining on to concrete path – very typical


Figure 45 Drainage pipe directed into a drain

All hard wiring for a heat pump must be completed by a registered electrician and have an energy certificate. In undertaking a check of the electrical work, participant householders were asked if they were aware of electrical certification (Table 32). Over half of the participants (52%) were not aware of an energy certificate for the electrical work associated with their heat pump's installation. Only just over a third (34%) of participants knew they had an energy certificate for their heat pump installation.

Table 32 Electrical check results

Checked Item	Yes	No	Don't know
Does the electrical work have an electrical code compliance/energy certificate?	34%	14%	52%
Has a copy of the code compliance/energy certificate being given to the owner?	34%	15%	51%
Is the unit connected to a separate circuit (if over 5 kW output), hardwired back to the mains distribution board?	60%	29%	11%
Is there a circuit breaker in the system?	83%	10%	7%
Has the circuit been properly labelled on the distribution board?	59%	41%	11%

In the course of the checks, a number of cases were found where the heat pump had not been earthed. Similarly, there were a number of dwellings that did not have an isolator switch. Discussions were held with electricians if it was needed or if a circuit breaker would meet the regulations. The rules around this are not clear, and the discussion was not resolved.

Where the circuit was existing, the condition of the wires are unknown. Inverter units with a heat output of 5 kW or more are required to have a dedicated circuit. Of the heat pumps checked, 29% were not installed on a separate circuit, and the circuits for 11% of heat pumps were unknown. Installing the heat pump on a power point was common. For those that did not have an isolating switch that was accessible (7%), it is impossible to turn the heat pump off without affecting electricity to other parts of the house.

With the 60% of heat pumps installed on a separate circuit, they tended to be either:

- installed at the time of building the house
- installed close to the distribution board of the house
- installed on a disconnected circuit – often the underfloor heating or nightstore heater(s) had been removed and the circuit reused for the heat pump(s).

Figure 46 One of the worst examples of wiring found


Figure 47 Placement of isolator switch means it is impossible to use

Despite some observed problems with installation, levels of satisfaction with installation and subsequent service among householders are high. Around 60% of the households that installed heat pumps reported themselves as very satisfied and 15.6% reporting themselves as satisfied.

Nevertheless, there are indicators that installation and service was not optimal for some householders in relation to some aspects of supply:

- 30.7% of householders had no information on operation and maintenance or had not read or found the information too difficult to understand.
- 41.9% of installing householders were not informed about a timer on their heat pump.
- 47.5% of installing householders were not engaged by the installer in discussing the appropriate heat pump programme.
- 33.8% of installing householders reported that the installer did not check that they knew how to use the heat pump controls.
- 33.8% of installing householders got no installation guarantee.
- 8.1% of installing householders reported that the installer failed to leave an operations manual for their heat pump. A further 1.3% reported that they did not know whether the installer had left an operating manual or not.
- 10% of installing householders reported that no product warranty or guarantee for a heat pump had been left with them by the installer. Once again, 1.3% reported that they did not know whether the installer had left a warranty or guarantee for the heat pump.
- 17.5% of installing householders reported that installers left no contact details. Also, 1.3% reported that they did not know whether the installer had left contact details or not.
- 18.8% of installing householders reported that no verbal instructions on the operation of the heat pump were given.

There were also some specific problems that a few householders identified:

> *Concrete slab outside sunk and had to fix that up. Didn't affix heat pumps properly. No earth wire and no electrician certificate.*

> *Had to get service people back in over a period. Install 31.7.07. $146 31.7.08. $245.25 31.8.08. $112 12.8.08. $132 19.8.08. As weren't satisfied with heat and kept coming out and felt should have been under warranty and wasn't, but final guy got it right – he was good. Took over a year to get it running properly.*

> *Just in too much of a hurry to get it done. No time to spend with person who has difficulty understanding.*

> *One area they put cable outside door that opened out onto a latch, now can't use the latch. Didn't pick up at the time.*

The views and experiences expressed by householders in the in-depth interviews are consistent with the information around installation and maintenance instructions. The installation and maintenance information was collected when heat pumps were being audited and the monitoring equipment was being installed. In most cases, the users of the heat pump were happy with the instruction they received. However, around a fifth of householders did not have the maintenance and servicing requirements explained to them. In one case, a householder was told by the installer that heat pumps could be maintenance free simply by removing the filter and offered to do so.

Most householders had received some instruction on operation, an operating manual, a warranty and advice of maintenance. The probability of not having this information seems to have been substantially higher when installation had been undertaken by a previous owner or landlord. The on-site check with householders revealed that householders were most likely to have access to a manual and least likely to have information of maintenance and servicing (Table 33).

Table 33 Householder information check results

Checked item	Yes	No	Don't know
Does the householder have the operating manual?	84%	4%	12%
Has the householder been given a copy of the warranty?	66%	8%	26%
Has the operation of the system been explained to the householder?	66%	16%	18%
Has the householder been advised of maintenance and servicing requirements?	62%	22%	12%

7.2 Maintenance

Almost three-quarters (73.8%) of heat pump householders report that they maintain their heat pump themselves. 30 householders(18.8%) have no one maintaining their heat pump and 11 householders (6.9%) have someone come in to maintain the heat pump. Those that maintain their heat pump themselves focus on filter cleaning and include those who report that their heat pump does not require regular cleaning or whose cleaning is erratic.

Comments from householders that see themselves as cleaning and maintaining their heat pumps:

> *We don't get anyone in to do it. We do it when we remember!*

Don't use it often enough for it to need a lot of cleaning. Husband has taken filters out to clean it once or twice.

Take the filter out and wash it. Once a year – usually at the start of winter.

We do it but wasn't totally clear what to do, but we can do it. The costs they requested for service checks seemed to be reasonably high, so we thought we'd do it ourselves.

The supplier/ installer – had to come the first time and now we do it ourselves. We clean filters every few weeks, inside and outside.

Showed us how to clean filter and I have done it once only, because not used much. Instructions should be easier to follow – because you do it only once every year and can easily forget.

Family does it for me.

There is resistance to getting others to maintain heat pumps because of costs. Some householders have their heat pumps maintained when they call an electrician or installer in for other reasons:

The installer wrote to us offering to change filters for $70 but we thought that was a bit much so we do it.

Installer/agent cleans the filters when they have come for other purpose, e.g. to help with operating the unit.

Have high unit done by someone else (but maybe not as often as should).

Haven't followed up on getting filters changed. They did it as part of the package – follow-up visit in the first few months. But haven't used it enough to change them again and everything costs money so it hasn't been a high priority.

Those that do have an annual contract pay between $70 and $95 for someone to clean their heat pump. Nevertheless, even when there is a willingness to pay for maintenance, getting maintenance organised can be a barrier to actually maintaining a heat pump.

Doesn't get cleaned and maintained. Need to ring the installers, just haven't got around to that.

Many, however, simply do not do anything about their heat pumps. There was a considerable lack of understanding about the need and how to maintain heat pumps. Typical comments include:

I didn't realise they need a filter. Installer didn't advise about the maintenance. I only found out about the filter from an acquaintance the other day.

"What do you mean by clean and maintain it?" Didn't think it needed it.

But I wasn't aware I had to until BRANZ told me I had to clean them. I also thought you had to wait to dry the filters before you could put them in again.[4]

Don't know much about them.

[4] Ideally the filter should be dried off before inserting back into the unit.

BRANZ showed us, didn't know until then to do it.

Haven't been told to clean it.

Seems to work fine. Not concerned about it.

Will ask son about why it hasn't been done.

No one has mentioned the cleaning of it.

7.3 Information used by householders

This raises issues around the extent to which householders have utilised a credible information source to make decisions about their heat pump acquisition. Also, the capacity to operate their heat pumps safely, efficiently and cost-effectively.

Householders who acquired heat pumps reported using one or more information sources when selecting a heat pump:

- Friends or family – 30% of installing householders cited this source.
- Installers – 26.3% of installing householders cited this source.
- Internet – 19.4% of installing householders cited this source.
- Consumer magazine and independent reviews – 9.5% of installing householders cited this source.

Many were reliant on the trade and manufacturers. Notably, none of the householders cited either EECA or BRANZ as a source of information around heat pumps. Householders that installed heat pumps expressed a positive view about information they could access on heat pumps. Table 34 sets out householder satisfaction on various aspects of heat pump information. The area in which householders are least likely to be satisfied with the information available to them is around the operation and maintenance of a heat pump. The study showed 9.8% of installing householders dissatisfied in this regard and 8.9% neutral.

Table 34 Installing householder satisfaction with aspects of heat pump information

Satisfaction with information	Information on heat pumps				
	% benefits and limitations	% different models	% fitness to Need	% cost information	% operation and maintenance
Very satisfied	36.4	31.6	33.0	28.2	33.9
Satisfied	38.1	41.2	38.3	41.9	31.3
Neither satisfied nor dissatisfied	8.5	7.9	7.0	6.8	8.9
Somewhat dissatisfied	2.5	5.3	7.0	6.8	7.1
Very dissatisfied	0.0	0.0	0.0	0.9	2.7
N/A – didn't look for this information	14.4	14.0	14.8	15.4	16.1
Total	100.0	100.0	100.0	100.0	100.0

Householders declare that they are satisfied overall in relation to their ability to select, operate and manage a heat pump. However, they are quick to encourage others to take considerable time over choosing and using heat pumps. The following is a typical selection of comments from householders about what people need to think about when selecting and installing a heat pump.

> *Think carefully about where they put it. Instead of getting one and expecting it to do all, get two if they can afford it. Get it from someone who will do a good installation job.*
>
> *A great source of heating in tandem with something else. Do your homework. It's not cheap.*
>
> *Perception that it is cheap. Especially in the South Island, need one that will cope with very cold overnight temperatures – heat pumps have to work hard.*
>
> *That they put it in the right place. Get several quotes before they purchase.*
>
> *Get a decent one and speak to someone who knows about them or who has got one.*
>
> *Get a professional person to look at their house and tell them the best type and place to put it.*
>
> *Get a specialist to find the best place for it to go so it heats the whole house, not just one room.*
>
> *Put it on the floor. Clean the filters all the time.*
>
> *Be careful where it is situated, depends on the size of the house. Get good technical advice to make sure it will work in your house, that it is effective.*
>
> *Find someone that knows what they are doing. See photos of previous jobs done.*
>
> *Get the best you can – and one that can tolerate low temperatures.*
>
> *Put right heat pump size in your house. Insulate as well.*
>
> *Go to a reputable firm, people who specialise in them, not a retailer. Get a quality job, price isn't everything. Go to someone who knows what they're doing.*

Noise can be an issue, some brands are a lot noisier than others. Look at energy output and energy efficiency – brands differ. Be careful where you put them. Location is everything really.

Noise! The positioning of it – and the size for coverage. Consider what they would use it for, e.g. for cooling as well as heating. Get one that isn't draughty.

Check out the brands – go for a really reliable one. Shop around – we didn't and just went with what the builder recommended. The company that manufactured it is out of business, so we can't get parts.

Don't hesitate. Don't wait another year, just go and do it. Have a good look around, reasonable price, best connection. Don't buy services if you don't connect with person.

Make sure it's the right heating option, it doesn't suit every house, get one big enough to heat the area, look at gas and wood burner options too.

Don't put outside part near bedrooms.

This suggests that heat pump-using householders are aware of a number of complexities around heat pump installation and use that they could have reflected more upon. In addition, it is also clear that, for some householders, heat pumps have a number of characteristics that not all household members find desirable.

Sometimes the wife complains about draughts. If a heavy frost can take a while for it to crank up and heat the place in the morning (timer helps with this). Also every now and again, it does a defrost so slows right down – but once warmed up and going, it doesn't defrost again for a while.

Shuts off when it gets too cold outside. Doesn't send out the really hot heat like a fire would.

Noise. Draught (fan).

In winter when it's too cold, it cuts out.

A bit draughty at times. Doesn't really work when it is really cold.

Not used to heat pump. English and hadn't used it before. As soon as you turn it on, the heat disappears. Don't like the type of heat – prefer fire or radiator. It's noisy. Get a draught from it. The air feels cold. Don't like it blowing on you. Don't like the appearance of it. It's an old, big bulky one. Don't like anything about it, except it's convenient – in the morning, you can turn it on and get instant warmth.

Not really – only thing it doesn't heat all the house. I miss not being able to stand in front of the wood burner!

It's not like central heating! Not the same temperature in all the rooms. Used to central heating.

Doesn't keep lower half warm.

Slight annoyance at the noise, but get used to it.

The colder the weather, the worse they work.

The hum! It was badly installed – the overflow dripped on the deck.

Size too big – bulky, ugly. Feel we should have complained. Should have a smaller one.

Sticks out in lounge, small house and too big.

When on, heat will sometimes blast out cool air.

It's sold as an economic way of heating, but it's hard to judge because we haven't used it a lot, because it doesn't do what we wanted. Sometimes it's hard to get a constant temperature at the right temperature. Hard to get the fan right. I don't like it blowing at me. It shuts off and then starts up again. Heat from a wood burner is much nicer and heat you get from it is fantastic.

8. FINDINGS AND NEXT STEPS

8.1 Take-up of heat pumps

Why heat pumps are taken-up by householders has not been a core focus of this study. However, the data related to installation drivers suggest that those householders associated heat pumps with desirable health, energy efficiency and convenience benefits. Nevertheless, most householders find it difficult to articulate precisely why they acquired a heat pump. Many had very little understanding of how heat pumps worked, how they should be installed or how they should be maintained. The interviews suggest that the take-up of heat pumps is part of a broader dynamic that can be rationalised by householders as having a specific material and functional purpose. But, it actually reflects well established patterns of innovation take-up. Research into innovation take-up shows that the spread of technologies reflects the extent to which the ‘chasm’ between ‘early adopters’ and the ‘early majority’ is crossed. A success crossing depends on social proof (Figure 48).

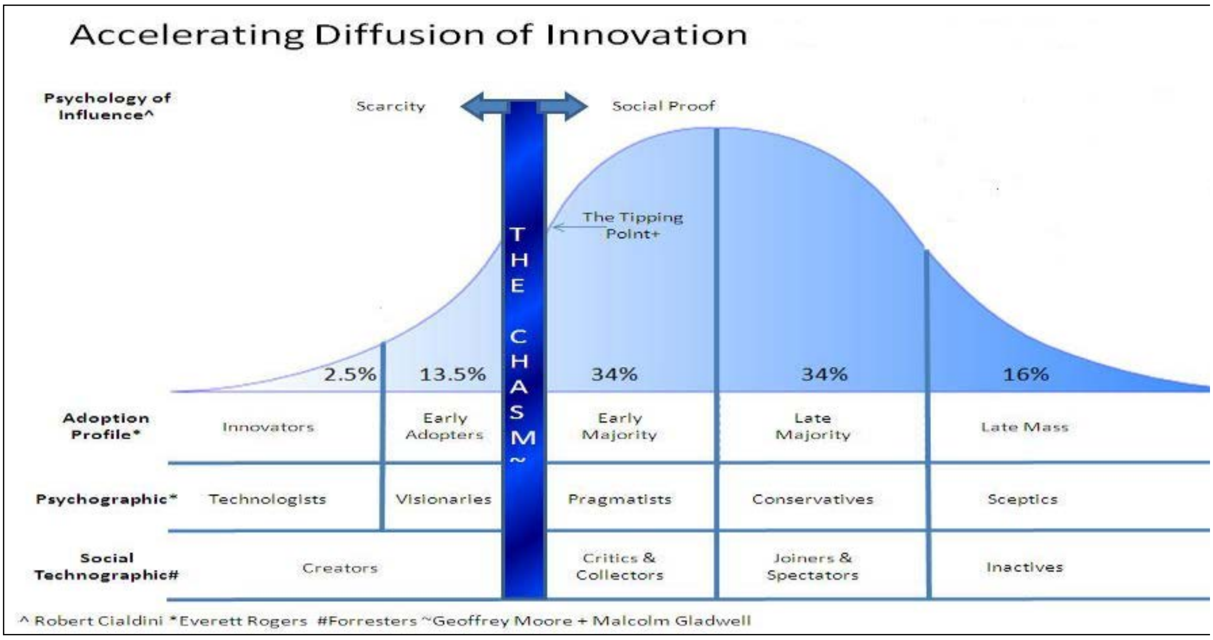


Figure 48 Innovation take-up and technology diffusion

Products, practices, systems and behaviours are taken up by some people because other people have already adopted them. This has its own momentum, and in some cases, poor practices, inefficient and costly products and poorly performing systems can become adopted. This is simply because the proportion of the population using those practices or products reaches a tipping point. Likewise, some technically efficient, fit-for-purpose innovations and technologies languish because they fail to jump the early adopters to early majority chasm (Maloney, 2010; Cialdini, 2001; Rogers, 1962; Moore, 1999; Gladwell, 2000).

The interviews suggest that social proof is a significant part of the take-up of heat pumps. The study shows 30% of the householders that acquired a heat pump had got information about heat pumps from family members or friends. About two-fifths (39.4%) of householders with heat pumps report that their neighbourhoods have a heat pump. Householders consistently referred to seeing other people installing heat pumps, which motivated them to acquire a heat pump. Typical comments include:

> *Husband has them at work and he found it good.*

Generally everyone was doing it.

On friend's recommendation – who had done a lot of research on heat pumps.

Working for a client that got one so decided to get one also.

Number of people I know have one.

Other people are having them and saying how good they are. Brother-in-law [ ] has one.

Friend referral – had noticed difference in friend's house. I am in real estate, and there is a difference in homes [with heat pumps working].

8.2 Satisfaction levels

There are high levels of satisfaction among these study householders with heat pumps. This is not surprising given that they self-selected to acquire a heat pump or live in a dwelling with a heat pump. The vast majority (94.4%) of householders in this study report that they would recommend a heat pump to their friends or family. Over three-quarters of householders typify the ease of use and convenience of a heat pump as excellent and 41.9% of householders describing the heating performance as excellent. In comparison, 15% of householders describing the running costs as excellent.

Despite the self-selected nature of this group, that is, ones that choose to acquire heat pumps, there are two indicators that heat pumps may not be meeting desired expectations. The first is a small set of householders that have at best neutral and sometimes negative views of heat pump performance. In terms of assessed convenience, this is a small group of 3.2% of householders. However, in relation to running cost, 27.5% have a neutral view or simply cannot come to a view on running costs. A further 6.3% of households express negative views on running costs. Together, these constitute about a third of householders in the study. The neutral/negative group of householders is smaller in relation to heating performance but constitutes almost a fifth of households (19.5%).

The second indicator of ambivalence towards heat pump performance is the 'make-do' attitude to performance and householders appear to make compromises around specific aspects of heat pumps. This is true even for those with apparently high levels of satisfaction. Householders often find that their heat pump is located in ways that they believe make it less efficient or that it disturbs family members:

I would have put it on a different wall, because it's too close to the dining table and one of the children doesn't like it blowing on them. It could have been fitted to do a more efficient job in kitchen and dining room. Probably trying to do too many things with one heater.

It would be better in the bedroom, but my wife doesn't like the whirring noise.

Stuck on the wall, but should be on the floor.

It should be on an internal wall – it's on an exterior wall.

For the rooms it's in it's ideal – covers more than one room. Not there to heat the bedrooms. I could have had extra duct into bedrooms but didn't realise that until later.

First heat pump – bad advice. Too small a heat pump for the area. Pump not efficient because of pipe to external pump.

No. Not really that effective. Installed in the hall. We were trying to minimise our cost and get heat in bedrooms but it hasn't done it. If we had it any lower than 27–30 degrees, it wouldn't be worth having it on, because of where it's installed. Would have to spend a lot more money on something like underfloor heating to heat bedrooms –- or have more heat pumps. It hasn't really worked for our house although we were fully insulated house before getting the heat pump.

The location is not a good one, but it is the only option, because of where the windows are.

But it doesn't feel that hot. Still sitting around with a cardie on. It was the only location they could put it in – it is sited as best as it could be for heat flow – had quite a few conversations about where to put it! It's in an old house, not open plan, so heat doesn't go into all rooms.

Where it should have gone wasn't an option. Should have been on the deck, but wouldn't have looked good there.

We still use two dehumidifiers and the heat pump to keep the house dry.

Probably not [the best location] but only place we could have it because of windows and outside wall needed for the outside part.

The installer wanted to put it on the patio (the outside part) because of the wall inside but told them weren't interested if they did that so we did get it where they wanted. Also installers wanted to put it on where [BRANZ] thought was the wrong side of house, it's now in the best side.

Not quite. Even with fans turned doesn't quite direct heat onto person, it directs it wrong place. It does warm the room [though].

8.3 Issues and actions

Heat pump manufacturers have actively sought to improve the aesthetics, operational ease and performance of heat pumps over the years. More efficient heating appliances such as clean efficient wood burners and heat pumps have been one factor in the temperature improvement within New Zealand dwellings. The increased temperatures that are emerging in various studies are not yet optimal nor are those improvements evenly distributed across households. However, more effective heating combined with improved insulation, including double glazing, are impacting positively on stock performance. Certainly, the households in this study show a pronounced movement towards healthier indoor temperatures compared to the heating practices and temperatures evident in the HEEP study. The use of electricity for heating is also higher in these houses compared to HEEP. However, anxieties that heat pumps would be extensively used for cooling does not appear to be evident among households.

There are, however, a number of issues for householder, the energy sector and the heat pump industry that have emerged from this study. The first is the matter of heat pump performance. It is clear that advertised COP values can be misleading. While participants in the industry and energy sector are well aware that COPs are based on testing under laboratory conditions, householders are not necessarily aware of this or its implications. In practice, a heat pump may operate intermittently in very low ambient temperatures, and extra energy may be required to defrost the coils or operate a heating unit. The net effect of this is to reduce the overall efficiency of the heat pump. The difference between COP and actual performance under actual operating conditions (MHPF) may be considerable. Consumer confusion can be exacerbated by the limited testing and disclosure regime in New Zealand. In New Zealand, this is typically undertaken at a single temperature setpoint. In other jurisdictions, testing and disclosure and specified ambient as well as outdoor temperatures provide a better signal to the consumer of the expected performance range from a particular heat pump model. For example, in the USA, it is mandatory to include an EnergyGuide label on heat pumps. This label includes a standardised Heating Season Performance Factor (HSPF) for heating and a Seasonal Energy Efficiency Ratio (SEER) for cooling (Department of Energy, 2015). These factors are weighted averages of the COP's at various temperature setpoints to best represent the conditions the heat pump will experience in practice. These

not directly relevant for New Zealand because they include American customary units (BTU) and consider different climates. These labels however, give relative guidance as to the selection of well performing heat pumps for the USA market.

The second area in which householders need to be better prepared and informed is around the issue of operating costs and payback periods. Householders can be confused by electricity expenditures beyond that they had envisaged when they purchase a heat pump. This often arises when they are advised about the 'most efficient' manner of operating a heat pump. The idea of efficiency is often interpreted as translating into reduced electricity expenditure due to more efficient heating. The relationship, however, between household heating expenditure and heat pump efficiency is a complex one. Householders need to understand that the efficient use of electricity by a heat pump does not necessarily imply a reduction in domestic electricity expenditure. Householders also need to be supported to better assess appropriate sizing, placement and installation of heat pumps. This study shows considerable deficiencies in this area. There is also a clear need to increase the skills and capabilities of installers. Instituting a process of second-year installation checks may also be desirable.

For many occupants installing a heat pump, it is their first experience with them. Guidance is needed on what the occupants can expect their heat pump installation to look like. Also, what information they need from their installer to be able to use their heat pump correctly. This would also help tenants in rental properties who often will not have a manual for reference. Tenants in rental properties did not tend to know about heat pump maintenance and servicing requirements. This resulted in some very dirty filters and most likely inefficient heat pumps.

Appropriate sizing and placement of the indoor and outdoor units are important. EECA's good practice guide is available on their website (Energy Efficiency and Conservation Authority, 2009). Both Manukau Institute of Technology and e-tec run courses on heat pump installation.

The electricity generation required by the number of heat pumps installed is a significant proportion of the expected electricity growth each year for New Zealand as a whole. This suggests that the potentially large increase in electricity demand has not been considered when introducing clean air regulations and promoting heat pumps for their energy efficiency.

There is also potential for a large increase in the winter peak load. As the survey has found most heat pump households are heating in the evening when the demand for electricity is the highest.

It is of concern that there have been few measurements of the performance of heat pumps for heating and cooling in New Zealand. There is an opportunity for further work in monitoring the patterns of use of heat pumps in New Zealand homes. Such monitoring would permit investigation into the importance of installation quality, the heat pump room location and the operating regime. It would also provide critical data on their actual performance in use, as compared to the name plate rating.

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Appendix A Examples of monitored data

This section gives yearly monitored data from five different households to illustrate varying heat pump usage.

This variation is shown using ‘carpet plots’ of the indoor temperature and heat pump energy use. A carpet plot is a plot of three variables; the horizontal axis gives the day of the year (increasing from left to right), while the vertical axis gives the time of day started off at midnight at the bottom of the graph extending to 11:59 pm at the top of the graph. At the intersection of these two variables, the variable of interest is plotted as a blob of colour according to the scale on the right. Missing data is displayed as a while colour.

The carpet plot displays all of the data at once but also allows seasonal patterns as well as time of day patterns to be examined.

For the temperature graphs (such Figure 49), the colours used for the comfortable range of between 18°C and 24°C are shown by shades of green. Temperatures over 24°C are shown by colours ranging from orange to deep red represented warmer temperatures. Temperatures below 18°C start off a light blue becoming increasingly darker as the temperature drops. For the heat pump energy use graphs (such as Figure 50) the greater the energy use of the heat pump the darker the shading of blue.

Figure 49 shows the resulting temperatures of a household which heats to a high level. Elevated temperatures are experienced throughout the day and night during winter and the summer evening period (areas of red colour)

Figure 50 gives the carpet plot of the heat pump energy use. The heat pump looks to be on 24 hours a day at a high energy level (areas of dark blue) during winterr. This house has the highest electricity use for a heat pump in the sample.

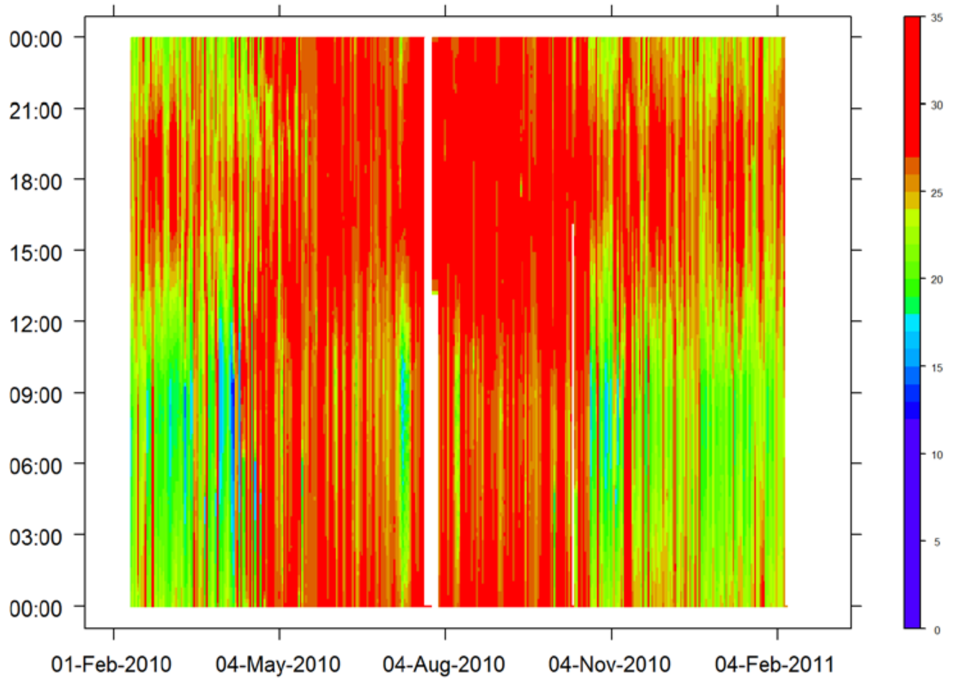

Figure 49 House 1: Living room temperature

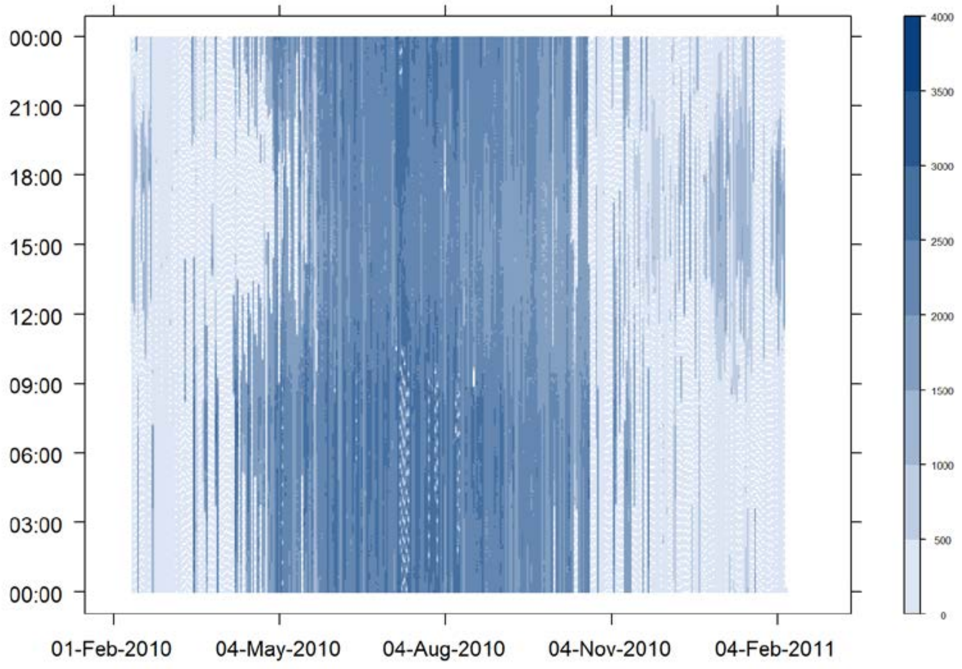

Figure 50 House 1: Heat pump electricity use – central system

Strong heating is also seen in the indoor temperatures in Figure 51 with the corresponding heat pump energy use in Figure 52. There is less intensity of heating than was the case for House 1 but in winter there are still many times when the temperature is over 27°C (shown in red). In particular, overnight the temperature is often over 27°C.

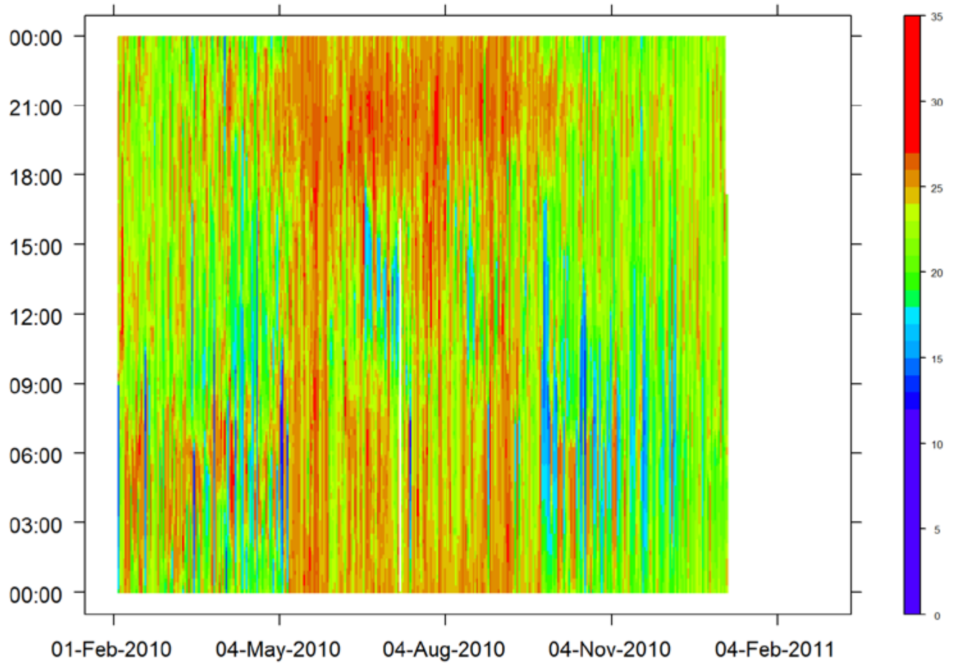

Figure 51 House 2: Living room temperature

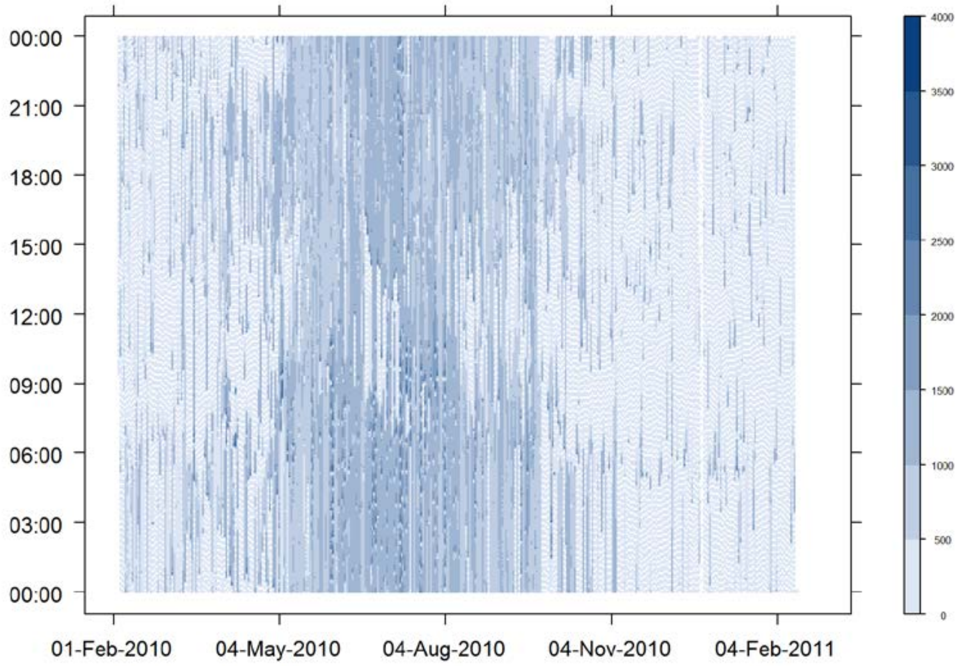

Figure 52 House 2: Heat pump energy use

The household in Figure 53 heats to 18–24°C (green scale) during the day from 7–8am until 10–11pm. The system is off overnight and the temperature drops below 12°C. The heat pump looks to either be used on a timer, or the householders are very consistent in when they turn it off and on. The hour's difference in start and finish time over winter could be due to them using the timer but not adjusting the clock for daylight saving (shown in energy graph). In the weekends, they also have it come on slightly later than weekdays.

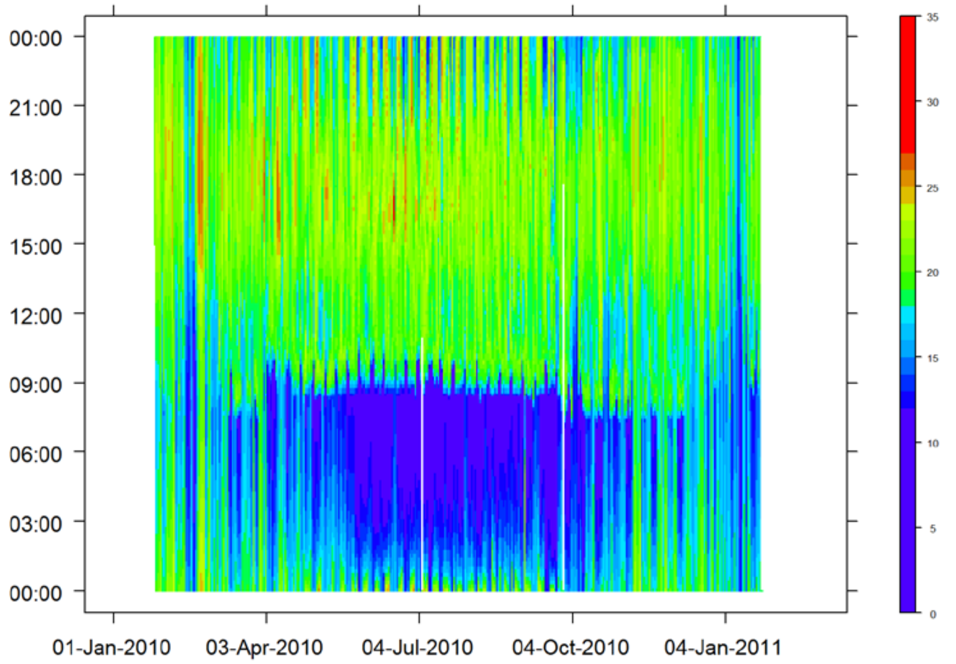

Figure 53 House 3: Living room temperature

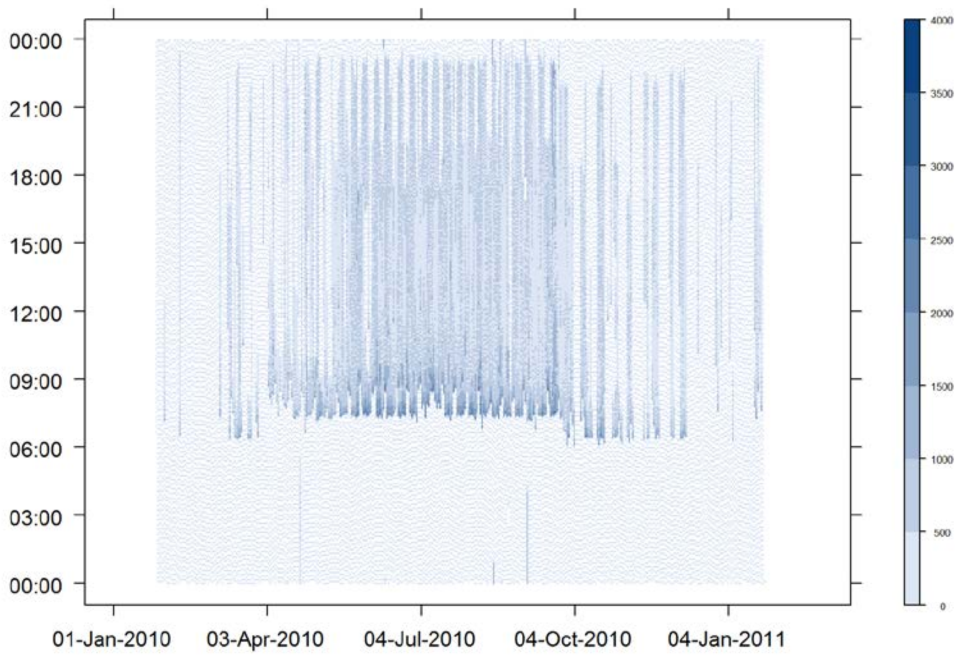

Figure 54 House 3: Heat pump energy use

The household in Figure 55 delays heating until May until after they have experienced some cold days in April (the blue area). The heat pump is then used throughout the day and night over the winter. Over the winter the temperatures are generally within the 18-24°C comfort range (shown as green). It is interesting to note the absence of colder conditions at the end of the winter (no blue areas in October). This supports a common belief that people hold off their seasonal heating until they feel quite cold but are then reluctant to stop heating until the temperatures are warmer.

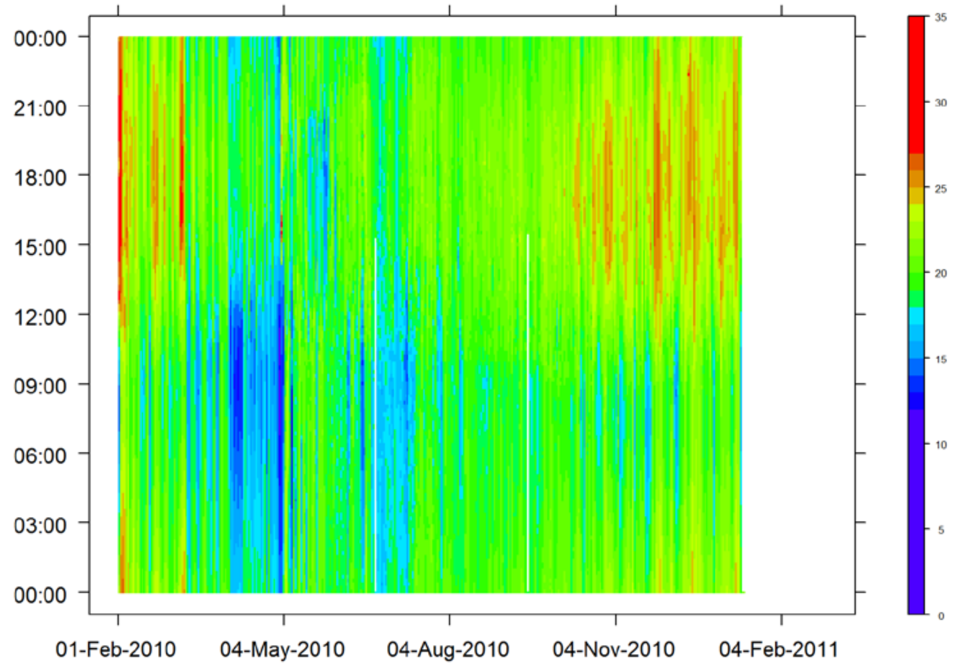

Figure 55 House 4: Dining room temperature

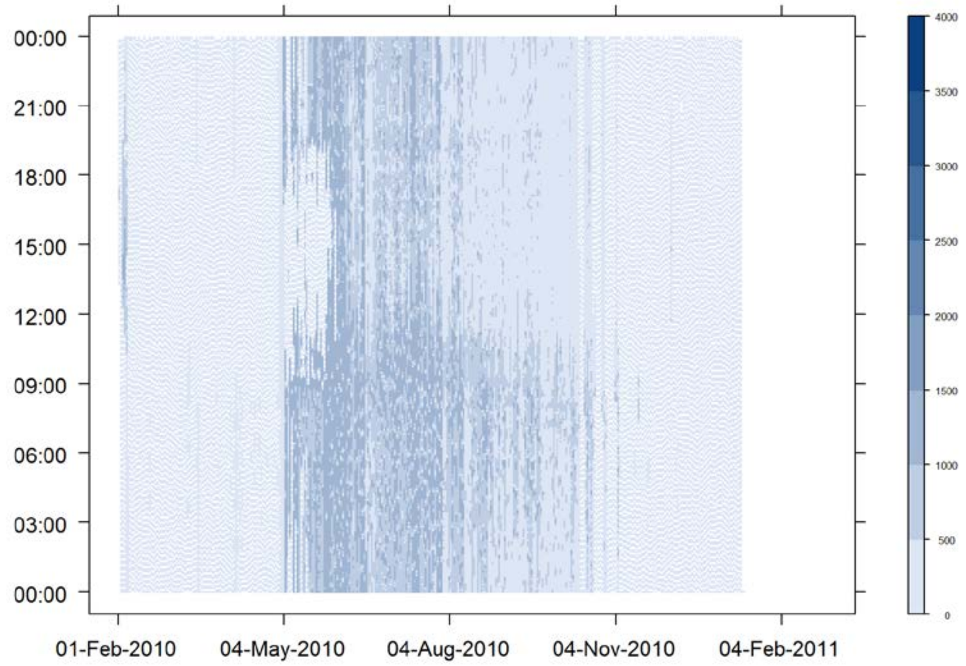

Figure 56 House 4: Heat pump energy use

Figure 57 and Figure 58, show a change of how the occupants use the heat pump during the winter heating season. For the first part of the winter the heat pump is set to come on at 6am and finishes around 10pm. From about July onwards the heat pump is left on overnight operating at a lower intensity of energy use (less dark colours). This is an example of where the change of usage can be further studied. If both resulting temperature patterns were acceptable, then the resulting energy use from the two operating periods can be compared

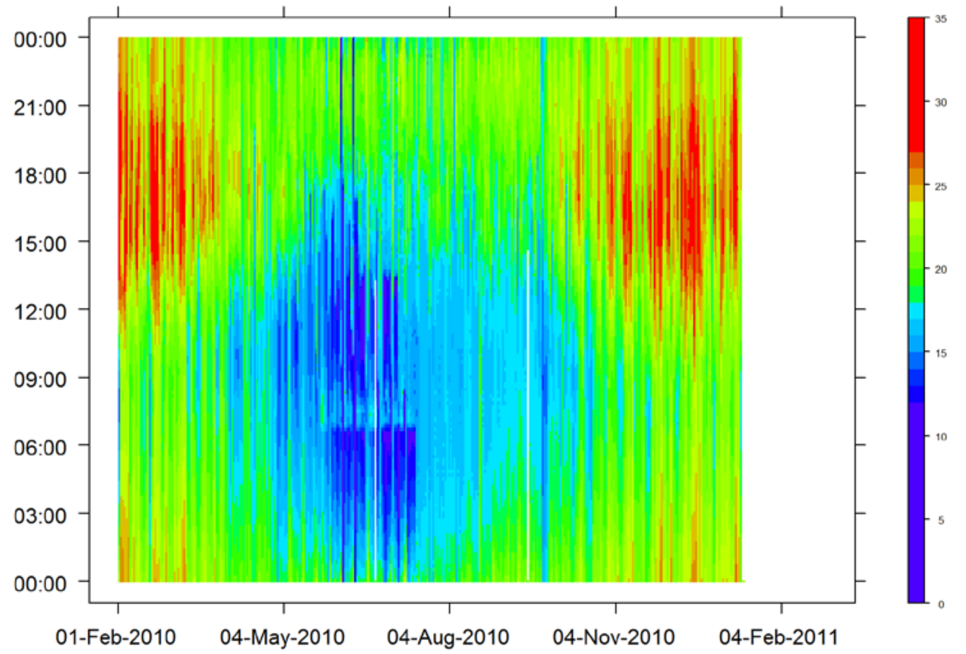

Figure 57 House 5: Living room temperature

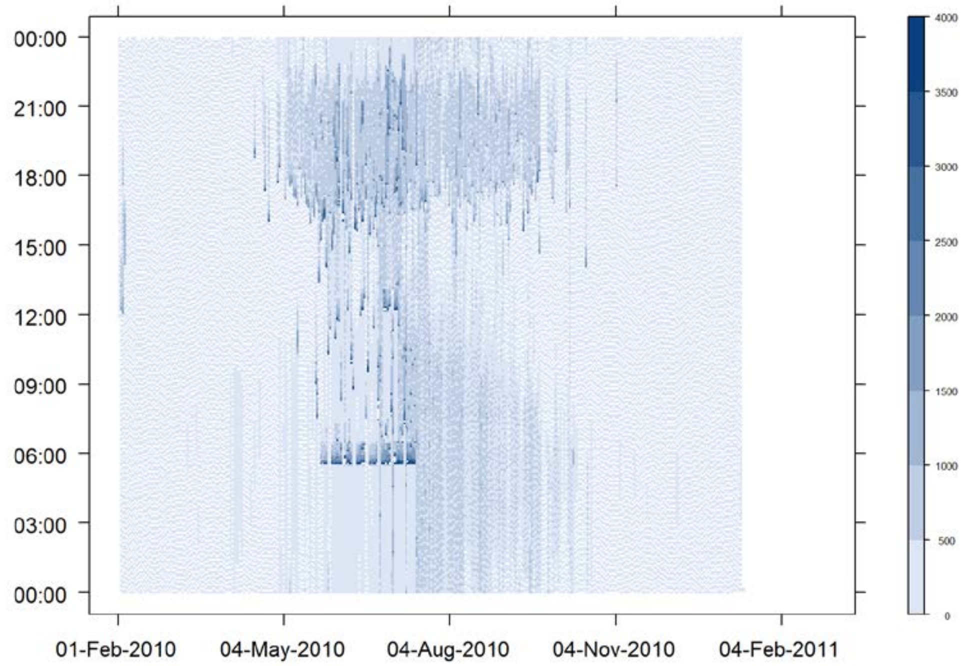

Figure 58 House 5: Heat pump energy use

Appendix B EECA quality assurance checklist for auditing

10.6 Quality assurance checklist for auditing

Carry out a quality assurance check on completion of installation of a heat pump system.

Outdoor unit

- ❑ Is the outdoor unit secure with no likelihood of falling over?
- ❑ Is there any vibration or noise disturbance to owners and/or adjacent properties?
- ❑ Is the area around the unit clear so there is no likelihood that the air supply routes will become blocked?
- ❑ Has the unit been installed to provide future servicing access?
- ❑ Is all the exterior ducting neat and tidy, with all flashing and waterproofing completed?
- ❑ Have all service covers been replaced?
- ❑ Is the unit clearly labelled?
- ❑ Have the installer's checklists been sighted?

Indoor unit

- ❑ Is the indoor unit secure and does not vibrate?
- ❑ Has the test run been carried out?
- ❑ Is the unit neatly installed with no pipework or ducting visible?
- ❑ Have the installer's checklists been sighted?

Pipework

- ❑ Is the pipework appropriate for the refrigerant used in the system?
- ❑ Has a leak test been carried out?
- ❑ Was the system evacuated?
- ❑ Is the system charged to a level appropriate for the pipe length?
- ❑ Are the stop valves fully open?
- ❑ Have the installer's checklists been sighted?

Drainage

- ❑ Is the drain hose from the indoor unit properly installed?
- ❑ Has the indoor unit drainage been tested by pouring water into the tray?
- ❑ Has the outdoor drainage pipe been directed away appropriately?

Electrical

- ❑ Does the electrical work have an electrical code compliance certificate?
- ❑ Has a copy of the Code of Compliance certificate been given to the owner?
- ❑ Is the unit connected to a separate circuit (if over 5 kW output), hard wired back to the mains distribution board?
- ❑ Is there a circuit breaker in the system and has the circuit been properly labelled on the distribution board?
- ❑ Is the energy rating label on the unit or available for viewing?

Instructions to the owner

- ❑ Has the operation of the system been explained to the owner?
- ❑ Does the owner have the operating manual?
- ❑ Has the owner been advised of maintenance and servicing requirements?
- ❑ Does the indoor unit have the energy rating label applied, or available?
- ❑ Has the owner been given a copy of the warranty?

Source: Energy Efficiency and Conservation Authority, 2009

Appendix C Installation checklist

BUILDING AUDIT

House No. [ ] **Date:** ____________________

Carried Out By: ___________

Plans available from council: Yes / *(If no plans available draw floor plan using scale 1 : 100)*

		tick (√)
1	Room Type (Unique identifiers as used in data labels e.g B1)	
2	Floor Coverings	
3	Window Size (if dimensions not on plans) *Fill in window area calculations over page*	
4	Exterior Shading of Windows (incl. glass doors) (0% = no shading, 100% = full shading)	
5	Opening areas of windows	
6	Windows Coverings (thermal drapes, blinds etc.)	
7	North Orientation	
8	Common Walls with Other Buildings (Indicate with X)	
9	Mould Growth (indicate on plans with wiggly line)	
10	Position of Data Loggers (pulse loggers, tiny tags, external tiny tags etc.)	
11	Location of Heating Appliances (Incl. outside units for heat pumps)	
14	Indicate Double Glazed Windows	
16	Average Room Height	
17	Total Floor Area (calculate from plans, break-down floors/sleepouts etc)	

PHYSICAL CHARACTERISTICS OF DWELLING

(go through with occupants to fill in any information not on plans, and make any corrections to plans)

House code:	

Year house built
(code the decade) 0= before 1910; 1= 1910-1919 etc 9= 1990s

(actual year)

Was the house built before 1978, between 1978 and 1996, between 1997 and 2000 or after 2000?
1 = before 1978 2 = 1979-19963 = 1997-20004 = 2001 onwards

If you have a garage, is it detached from the house?
1 = yes2= no 3 = don't have garage

Estimated house size (excluding attached garages)
(in sq ft or metres or 'don't know') *sq/m* *sq/ft*

House form?
1 = single
2 = double storey with upper storey smaller than the lower storey
3 = double storey with both storey the same size
5 = double storey with upper storey larger than the lower storey (hillside)
4 = other multiple level

Window Glazing?
1 = single 2 = double 3 = mixed

Window Frames
1 = wooden 2 = aluminium 3 = PVC 4 = mixed

Walls
What is the main composition of the outer walls
(code main two types)

Timber/steel frame with weather board, brick, or block veneer
Timber/steel frame with stucco finish or sheet cladding
solid timber 64 mm walls (i.e. "Lockwood")
concrete blocks
other
-9 don't know

Is there any outer wall insulation?
1 = yes2= no -9 = dk
if 1:
What type of wall insulation (multiple answers possible)
1 = aluminium foil 2 = batts etc 3 = loose fill
4 = polystyrene (how thick?) 5 = other -9 = don't know

How much of the wall is insulated?
Enter percentage of wall insulated.

Roof

What is the roof mainly made of?
(use code from list)

1 = corrugated iron/ steel
2 = ceramic/concrete/slate/asbestos tiles
3 = bituminous or coated metal tile
4 = poured concrete etc
5 = shingles
6 = other storey above
7 = other
-9 = dk

How bright is the colour of the roof?
1 = bright 2 = medium 3 = dark

Is there any roof or ceiling insulation?
1 = yes 2 = no -9 = dk

if 1:

What type of roof insulation
(multiple answers possible**):**

1 = aluminium foil
2 = batts (how thick) etc
3 = loose fill (how thick?)
4 = polystyrene (how thick?)
5 = other
-9 = don't know

How much of the roof is insulated?
Enter percentage of roof insulated.

Floor

What sort of floor does the house have?
(put code in box*)*

1 = slab on ground
2 = timber floor on piles with a perimeter wall around the bottom of the house
3 = timber floor on piles without perimeter wall
4 = pole house
5 = floor with basement garage underneath
6 = other storey below
-9 = dk.

If 2 or 3

Is there polythene, or other, ground cover under the house?
1 = yes2 = no

if other specify ……………………………………………………………………

Height of perimeter wall?
in meters, otherwise NA

Is there any floor insulation?
1 = yes 2= no -9 = dk

if 1:

What type of floor insulation
(multiple answers possible)
1 = aluminium foil,
2 = batts (how thick) etc,
3 = loose fill (how thick?)
4 = polystyrene (how thick?)
5 = other
-9 = don't know

How much of the floor is insulated?
Enter percentage of floor insulated.

House Air Leakage
How would you rate the house air tightness (see card 11)
1 = airtight 2 = average 3 = leaky 4 = draughty

Do you have ventilators in your windows?
1 = yes 2 = no
Are the ventilators functional or have they been blocked off or permanently closed?
1 = functional 2 = blocked/permanently closed -9 = not applicable

How many of your windows have these ventilators?
-9 = not applicable

Do you have any passive stack vents?
1 = yes 2 = no -9 = not applicable
How many?
-9 = not applicable
Wind exposure (see below)
1 = sheltered 2 = medium sheltered 3 = medium exposed 4 = exposed

PHOTOGRAPHS - CHECKLIST

	Exterior of house
	Location of all interior temperature loggers
	Meterboard layout
	Heat pump monitoring equipment in place
	Solid-fuel and LPG burner
	Fixed gas burner
	Heat pump

HEAT PUMP

Location - indoor unit	Location – outdoor unit	Model	Make	Serial number	Cooling input / Cooling capacity	Heating input / Heating capacity	High wall/low/ducted/ceiling/floor or cassette	Split/ducted	AGE

Heat pump questions for occupants

If this house is a rental or the owners did not install the house some of the questions won't be able to be asked.

1. House is rental

	Yes (1)		No (2)

2. Current occupants installed the heat pump

	Yes (1)		No (2)

3. Has the operation of the system been explained to the owner?

	Yes (1)		No (2)

4. Does the owner have the operating manual?

	Yes (1)		No (2)

5. Has the owner been advised of maintenance and servicing requirements?

	Yes (1)		No (2)

6. Has the owner been given a copy of the warranty?

	Yes (1)		No (2)

7. Has a copy of the code of compliance or energy certificate been given to the owner?

	Yes (1)		No (2)

8. When was the heat pump installed: ___________________________________

Installation quality check list – 1 per heat pump

Based on the EECA installation quality check list

Location of indoor system: ____

Location of outdoor system: ____

Outdoor Unit

1) Is the outdoor unit secure with no likelihood of falling over?

	Yes it is secure (1)		No it is not secure (2)
	Don't know (3)		

2) How is it fixed?

	Glue (1)		Screws (2)
	Other ____________________ (3)		

3) Is there a minimum of 10 cm clearance under the heat pump unit?

	Yes (1)		No (2)

4) Is in on the?

	Ground (1)		Roof (2)
	Wall (3)		Other ____________________ (4)

5) What is it attached to? ____

6) Is it level?

	Yes (1)		No (2)

7) Corrosion-resistant fixings

	Yes (1)		No (2)

8) Has the weather tightness of the building been compromised?

	Yes (1)		No (2)

9) Is there any vibration or noise disturbance to owners?

	Yes, disturbance likely (1)		No disturbance likely (2)
	Maybe disturbance (3)		Don't know (4)

10) Is there any vibration or noise disturbance to adjacent properties?

	Yes disturbance likely (1)		No disturbance likely (2)
	Maybe disturbance (3)		Don't know (4)

11) Is the area around the unit clear so there is no likelihood that the air supply routes will become blocked?

	Yes, it is clear (1)		No, it is not clear (2)
	Okay, but plants might cause a problem in future (3)		Don't know (4)

12) Does the unit have an isolator switch for future servicing?

	Yes, installed with an isolating switch and is on house and accessible (1)		No isolating switch (2)
	Yes, but not accessible (3)		Other: (4)
	Yes, but on heat pump (5)		

13) Is all the exterior ducting neat and tidy, with all flashing and waterproofing completed?

	Yes it is tidy and waterproof (1)		No it is not tidy or waterproof (2)
	Yes it is waterproof BUT not tidy (3)		Yes it is tidy BUT not water proof (4)

14) Is the unit clearly labelled with model, make, input and output?

	Yes clearly labelled (1)
	No not clearly labelled (2)

15) Does the unit show any sign of corrosion?

	Yes, Where ___________________________
	No

Drainage

16) Is the drain hose from the indoor unit properly installed?

	There is a pump (1)		Yes the drain hose is installed properly (2)
	No the drain hose is not installed properly (3)		Can't see (4)

17)Has the outdoor drainage pipe been directed away appropriately?

	Yes it is directed into _____________(1)		No it is on to a concrete (or solid) path (2)
	Can't see one (3)		It goes into a drain (4)
	It is under the house (5)		

Pipework

18)Are there any issues with the pipework?

Electrical

19) Is the unit connected to a separated circuit (if over 5 kW output) and hard wired back to the mains distribution board?

	Yes, separate circuit and hard wired back to board (1)
	No (2)
	Don't know (3)
	Uses a previously dis-used circuit (e.g. underfloor heating was removed) (4)
	The output is less than 5 kW and it is installed on a circuit with no large loads and the wiring is at least 2.5 mm twin and earth cabling with a 20 am MCB. (5)

20) Is there a circuit breaker in the system and has the circuit been properly labelled on the distribution board?

	Yes, there is a circuit breaker and it has been labelled (1)
	Yes, there is a circuit breaker but it hasn't been labelled (2)
	No there is no circuit breaker (3)
	Yes, there is a circuit breaker but it has a different label (4)

21) Is there any reason why you think the installation is inadequate that has not been mentioned above? If Yes what:

Indoor unit

22) Is the indoor unit secure and does not vibrate?

	Yes the unit is secure and does not vibrate (1)
	No the unit is not secure and/or it vibrates (2)

23) Is the unit neatly installed with no pipework or ducting visible?

	Yes the unit is installed neatly and no ducting is visible (1)		No the unit is not installed neatly and ducting is visible (2)
	Other (3)		

24) Is there anything else you would like to mention about the installation of the heat pump?