A NATIONAL STUDY OF RESIDENTIAL HEAT PUMPS IN NEW ZEALAND

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Abstract:

In recent years air source heat pumps have increased in popularity in both new and existing houses in New Zealand. BRANZ is currently monitoring a nationally representative sample of houses with heat pumps. These homes are having their heat pump energy use, temperatures and humidity monitored, a house audit, an installation quality checklist as well as in-depth interviews with the householders in the participant dwellings. This work allows us to understand how they are being used for heating and cooling, the in-situ performance, conditions achieved, the future uptake of heat pumps and the range of issues that arise nationally and for households around heat pump use and the increasing prevalence of heat pumps. Early results show that households with heat pumps use them extensively during winter and have warmer houses than typical. However, energy use from some of the houses is high and there is potential for savings through insulation and improvements in the installation of heat pumps. Results of this work suggest heat pump prevalence in New Zealand will continue to grow and so will the demand for energy.

Key Words: air-to-air heat pumps, monitoring heat pumps

1 INTRODUCTION

New Zealand has been experiencing rapid growth in the sales of air source heat pumps for space heating in the last few years (French, 2008). Heat pumps are seen by many as an energy efficient way to heat and can be used to cool. The growth of heat pumps has been accelerated by some clean heating programmes promoted by regional councils in New Zealand concerned with air quality, advertising by manufacturers and word of mouth among consumers. The market change has been so quick that very little is known about how they are used, their efficacy and the issues that may arise for households installing and operating them.

The Household Energy End-use Project (HEEP) which was completed in 2005, monitored all energy uses in a representative sample of 400 houses through New Zealand (Isaacs et al, 2010). HEEP also collected information on energy types and in-house temperatures in monitored dwellings. HEEP provides the most comprehensive data on electricity use in dwellings in New Zealand. At the time of the HEEP study, however, heat pumps were reasonably uncommon (4% of the sample). HEEP found solid fuel burners provided most of the heating in New Zealand houses (Isaacs et al, 2010).

Since the completion of HEEP, two separate surveys (one postal and one on the internet) have been done to track the uptake of heat pumps (French et al, 2008; Page, 2009). The surveys have found a rapid growth in heat pumps, with approximately 21% of houses in New Zealand having a heat pump in 2009. To understand more about how people are using heat pumps, how they are performing and the impacts of their increased use nationally, a monitoring project has been undertaken.

The project has a nationally representative sample of 171 houses with heat pumps and collects data on energy use, temperatures achieved, occupant attitudes and use, along with a house audit. Currently 85 houses have been monitored, with a further 86 to be monitored during 2011. Some clear patterns are coming through about how the heat pumps are being used and households opinions on them which are reported on in this paper.

1.1 Heat pump project

The project has been 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, but as the uptake of them is so low none are in the sample. Based on HEEP, a sample size of approximately 170 houses is needed to give a national picture of heat pump energy use within 10%. The number of houses required within each of the 16 regions in New Zealand was based on population (New Zealand Department of Statistics, 2009) and the percentage of houses with heat pumps in the region (Page, 2009). A survey company then randomly selected phone numbers from the region, rang and asked them if they had a heat pump, and if yes if they were interested in participating.

To date there has been a participation rate of around 50%. This is a high compared to other studies of this type. For example, HEEP had a participation rate of 24% (Isaacs et al, 2010). This is thought to be due to the high interest from heat pump users on how their heat pump is performing.

Houses have been monitored in Northland, Auckland, Waikato, Manawatu-Wanganui, Wellington, Otago and Southland (shown in grey in Figure 1). Houses are picked randomly within each region.

Houses in the remaining regions are being monitored during 2011. Not all houses could be monitored at the same time due to cost of equipment. For each heat pump, the real and reactive electrical energy is being monitored at a five-minute interval by VM smart meters (Energy Intellect, 2010). Each meter has a modem to send the data over the cellphone network daily. This system results in high quality data with minimal losses. Where possible, the houses also have other electricity uses monitored using the same equipment. This was possible only when the heat pump(s) was wired back to the meter or switch-board and there was enough space for our meter to be temporarily installed.

In all houses the temperature and relative humidity is monitored in the room with the heat pump at a 10-minute interval by a Hobo logger (Onset, 2010). The loggers are downloaded by a regional download officer three-monthly. This also gives the chance for participants to ask questions or for us to be updated on any changes in the household (such as a change in family members or a change of tenant). All energy, temperature and relative humidity data is quality checked, processed and stored at BRANZ, with analysis done in S-Plus. Social data is quality checked and stored at the Centre for Research, Evaluation and Social Assessment (CRESA), with analysis done in SPSS.

For each heat pump in the study details such as make, model and output are documented, as well as a survey completed on the installation quality from the Energy Efficiency and Conservation Authority (EECA) good practice guide for installing heat pumps (EECA, 2009).

During the months of heating an occupant interview is carried out with the household. Interviewing is designed to help understand why the occupants are using their heat pumps in the way they are, why they purchased them, help forecast future uptake and understand issues such as maintenance and noise.

A house audit is completed for each house in the study which records physical characteristics such as insulation levels, window size, orientation, type and openable area, roof colour, position of heat pump(s) and other heater locations.

Figure 1: Regions of New Zealand – Grey regions were monitored in 2010

1.2 New Zealand's Climate

New Zealand is long and narrow, approximately 1,600 km in length, with a land area of 270,000 sq km, ranging from Latitude 37°S to 46°S, see **Figure 1**.

The winter season in New Zealand (a Southern Hemisphere country) is during the months of June, July and August. The summer months are December, January and February. The majority of homes are in a coastal climate, but the central areas of both islands are more continental. The far south is cooler than the far north. For example, the daily mean winter temperature in Invercargill (in the far south) is 6.2°C compared to 11.9°C in Kaikohe (in the far north). The mean summer ambient daily temperature in Kaikohe is 18.8°C, but in Invercargill only 13.3°C – a difference of 5.5°C degrees. The annual range of monthly mean temperature (difference between the mean temperature of the warmest and coldest months) is relatively small. In the top of the North Island (Northland) and in western districts of both islands it is about 8°C, while for the remainder of the North Island and east coast districts of the South Island it is 9°C to 10°C. Further inland, the annual range can exceed 11°C, reaching a maximum of 14°C in Central Otago (MetService, 2011).

1.3 New Zealand housing

A typical house in New Zealand is timber framed with weatherboard cladding, a timber or concrete floor (new houses are typically concrete) and a long run steel roof. Houses are typically stand-alone with one or two levels. The construction of houses is influenced by New Zealand being an earthquake zone.

New Zealand has only required thermal insulation in new houses since 1 April 1978. These modest requirements were increased slightly for houses in the central North Island and all the South Island in 2000. The other two climate zones cover the remaining area of the North Island. Table 1 sets out thermal resistance requirements for common combinations of roof, wall and floor.

Table 1: Building Code thermal performance requirements 1978 to current

Year Commence	Standard	Coverage	R-Values (m² °C/W)			
			Ceiling	Wall	Floor	Glazing
1978	NZS 4218P:1978	New Zealand	1.9	1.5	0.9	0.15
2000	NZS 4218:1996	Zones 1 & 2	1.9	1.5	1.3	0.15
		Zone 3	2.5	1.9	1.3	0.15
2008	NZS 4218:2009	Zone 1 & 2	2.9	1.9	1.3	0.26
		Zone 3	3.3	2.0	1.3	0.26

Older houses are not required to upgrade to the current standard, but in some cases roof and floor insulation has been voluntarily installed. Beacon predicts in 2012 approximately 1.6 million of the 1.7 million houses in New Zealand will have inadequate insulation (Clark, 2007).

1.4 Heat pumps in New Zealand

The most common type of heat pump in New Zealand is the air source heat pump – also known as a reverse-cycle air-conditioner. Most heat pumps installed are split systems, although multi-split and ducted systems are available and may become more common. Twenty percent of houses have more than one heat pump. Traditionally New Zealand homes rely on individual heaters with less than 5% of houses with central heating.

Air-to-air heat pumps are required to comply with the Minimum Energy Performance Standards (MEPS) (New Zealand Standards, 2009). The MEPS ban the sale of low COP (Coefficient of Performance) heat pumps. As the technology improves, the standard required is raised to encourage all heat pump manufacturers to improve their heat pumps. New Zealand uses the same standard testing of heat pumps as Australia, although the MEPS requirement differs. This test method covers both cooling (Energy Efficiency Ratio – EER) and heating efficiency (Coefficient of Performance – COP).

2 Early results from the monitoring

Monitoring of the heat pumps in the study will not be completed until early 2012. However, some early results can be reported on as follows.

2.1 Change in the way we use energy – the type of energy

Two national studies have been done in New Zealand on how electricity is used in our households and temperatures achieved. These studies can be used to understand changes over time. The 1971/72 electricity study found 15% (1,260 kWh) of electricity use was for space heating (New Zealand Department of Statistics, 1973). HEEP found 12% (870 kWh) of electricity use was for space heating (Isaacs et al, 2010).

There have been a number of physical and social changes between the 1971/72 study and HEEP. There was a shift from inefficient open fires to enclosed solid fuel burners. HEEP

found 24% of the space heating energy use in the house was used for electric heaters. Most space heating was found to be done by solid fuel (56%) (Isaacs et al, 2010). Retrofitting insulation into houses is now becoming more common. While the number of occupants per dwelling has decreased, there has been an increase in appliances and their energy use (28% to 47%).

The movement to electrical based heating is evident in this study. The majority of the householders in this study have had the heat pump installed after they purchased their house – only 16% moved into a house with the heat pump while 8% installed at the time of building. Seventy-four percent of those moving into dwellings from 2005 on had heat pumps within a year of occupation. Fifty-six percent of householders with a previous heating appliance reported that they substituted that heating appliance with a heat pump. The remaining 44% reported supplementing their previous heating systems with a heat pump.

The types of heaters substituted vary considerably by region. For example in Canterbury where there are tight air quality regulations many householders have substituted non-compliant wood burners for heat pumps. However, as Figure 2 shows, the heating and fuel source most likely to be substituted by heat pumps among these householders is reticulated and bottled gas or electrical appliances.

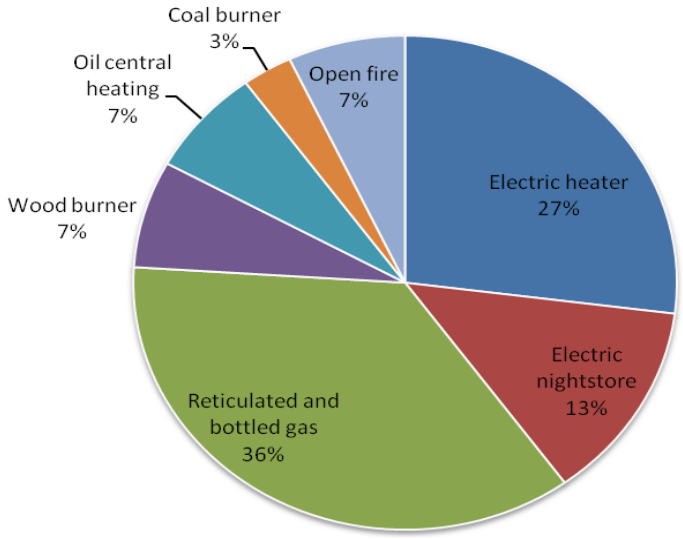


Figure 2: Heating substituted with heat pumps

The householders changing from an electric heater to a heat pump are likely to get a much better service with increased temperatures for possibly less cost (depends on temperature set point and hours of heating). Very few 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. Sixty percent of houses that are replacing a heater with a heat pump are changing to electricity. They may get a better service, but they will use more electricity.

2.2 Change in the way we use energy – the quantum of energy

The heat pump project has focused on heat pumps, and monitored their electrical energy information. Some additional electrical loads were also monitored, where possible, but other space heaters were recorded via written records.
Table 2 gives the annual space heating use for all energy types and for electricity only per house by region for houses in the HEEP sample (Isaacs et al, 2010) and the annual space heating use for heat pumps per house by region for houses in the heat pump study.

Table 2: Average annual space heating use per house (kWh) [1]

	Household energy use (HEEP) 2000-2005				Heat pump energy use 2010	
Region	**All energy types**	**Standard deviation**	**Electricity**	**Standard deviation**	**Electricity**	**Standard deviation**
Nationally	3,820	350	920	190	1,380	190
Auckland	3,190	840	1,630	720	740	100
Waikato	2,830	530	280	80	1,920	910
Wellington	2,630	730	780	600	1,420	310
Otago/Southland	6,810	910	3,130	420	2,400	440

In HEEP Auckland had a reasonably high electricity heating use (1,630 kWh) compared to the rest of New Zealand. The heat pump houses are shown to use approximately half as much electricity (740 kWh) as HEEP despite some houses using them for cooling. In the heat pump study most houses in Auckland tended to use the heat pumps as their main form of heating.

In Wellington the situation is reversed with the heat pump houses using almost double (1,420 kWh) the amount of electricity for space heating compared to the houses in HEEP (780 kWh). Again most houses in Wellington tended to use the heat pumps as their main form of heating.

Waikato's electricity use for heat pumps is high compared to Wellington and Auckland. Many of the houses in the sample seem to be high users with one in particular, which is estimated to use around 13,000 kWh per year.

Care should be taken with comparing between the two studies for Otago and Southland as the area for the sample is quite different. While HEEP had houses in the two main cities, houses with heat pumps were selected from the Otago and Southland regions. Something that was found in Central Otago (was that the households were often reluctant to rely completely on their heat pump(s) in most cases they also have a solid fuel burner, which they identified as their main heater during the coldest few months of the year.

The average heat pump electricity use over all of the houses is approximately 1,380 kWh, whereas the median is approximately 800 kWh. The electricity use for the heat pumps is not a normal distribution, but skewed to the right. Further investigation will be done to understand this when the full data set is collected, but early indications suggest it is the houses that are using heat pumps to heat their whole house (central heat pumps or multiple heat pumps in the house) that skew the distribution to the right.

[1] Manawatu-Wanganui has not been reported on due to the low sample size and high standard deviation.

2.3 Change in the way we use energy – the heating schedule and achieved temperatures

To understand the differences between how people were heating in HEEP and how people are heating with heat pumps, their heating schedules and temperatures reached have been analysed.

Figure 3 shows the reported heating schedules from HEEP and from a heat pump survey (French, 2008) and monitoring results from the houses with heat pumps during winter of 2010. Heat pump users are more likely to heat in the mornings as well as in the evenings compared to HEEP.

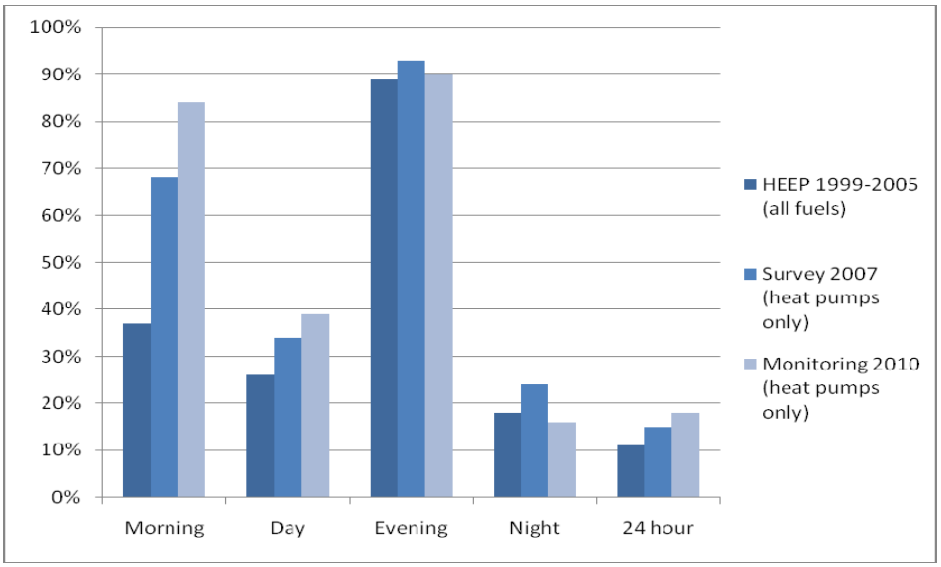


Figure 3: Heating schedules (Compiled from: Isaacs et al, 2010; French, 2008)

The 1971/72 temperature study concluded that "in homes throughout New Zealand, rooms tend to be heated to certain levels above the surrounding outside air temperature, rather than to a universal absolute temperature level" (New Zealand Department of Statistics, 1976). In the HEEP sample, the differences between external and internal temperature vary by region, with less difference between the average temperatures. This suggests they are heating more to a temperature level than in the 1971/72 study (Isaacs et al, 2010).

Figure 4 and Figure 5 are histograms of the mean living room evening (5pm to 11pm) temperatures during winter (June, July and August). Figure 4 is from HEEP (Isaacs et al, 2010) and Figure 5 is the first year results of the houses heated with heat pumps. There is a clear shift in temperatures between the two studies. Internationally 18°C to 24°C is suggested as an optimum temperature range for health (WHO, 2003; Raw et al, 2001). Lines have been drawn on both graphs at 18°C and 24°C.

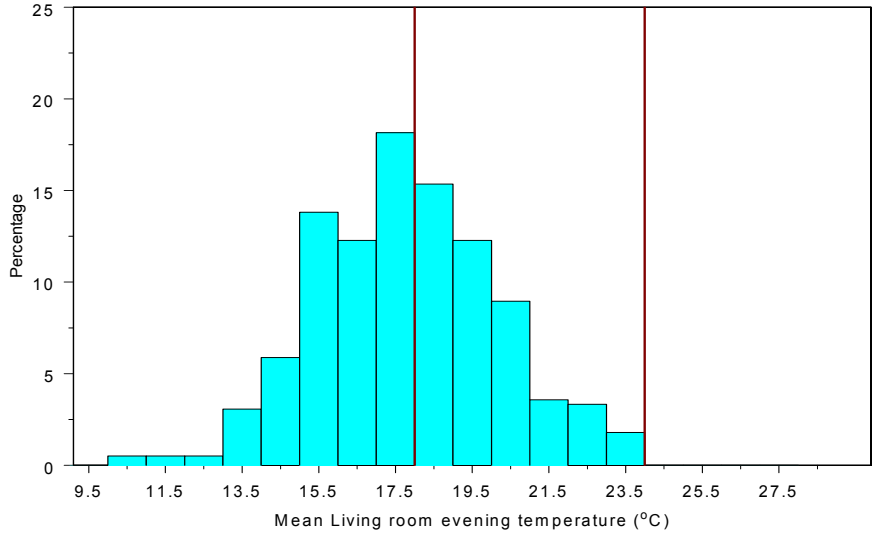


Figure 4: HEEP distribution of winter evening living room temperatures

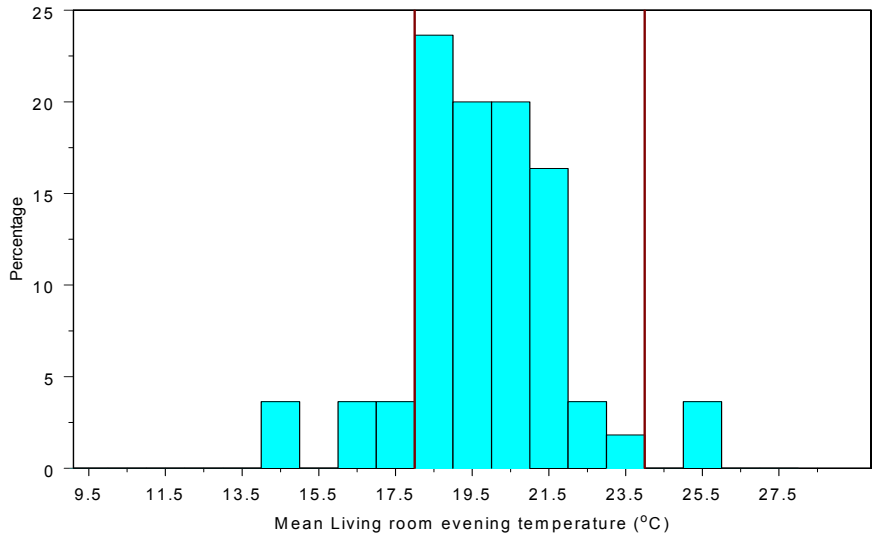


Figure 5: Heat pump houses* – distribution of winter evening living room temperatures (°C)

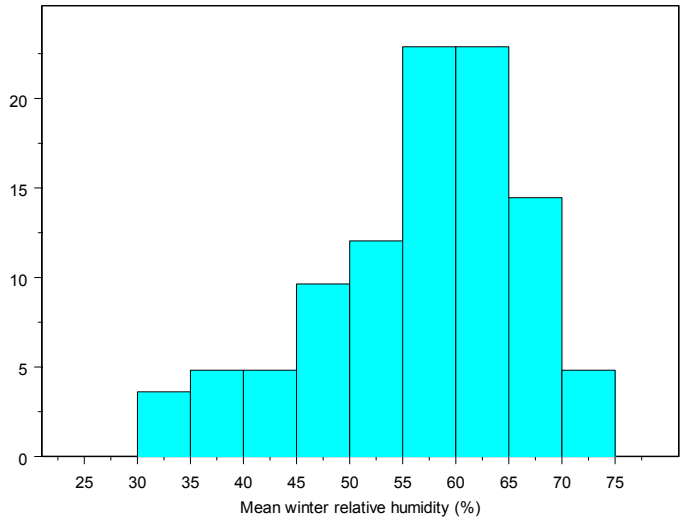
*Not all houses could be included due to either the heat pump heating a bedroom or hallway rather than the living room or insufficient winter data due to the loggers only being downloaded three-monthly. This graph has data from 56 houses.

In the houses heated by heat pumps, the lowest mean temperature was 14.2°C and the maximum mean 28°C. The average is 20°C, which is over 2°C higher than the HEEP average of 17.9°C. Eighty-four percent of houses in this project have a mean temperature in the living room during the evening between 18°C and 24°C. Ninety-six percent of houses are above 16°C. This temperature shift indicates people prefer to be warmer than what they were heating to in HEEP. With more houses in New Zealand heating to healthy levels, it can reduce the excess mortality in winter (Isaacs et al, 2003), as well as other illnesses that can cause days off work or school and visits to the doctor or hospitalisation.

Although no national studies have been done before now on relative humidity levels within New Zealand houses, studies have found our houses are often damp and mouldy and display signs of high relative humidity (Phipps, 2007). This study is monitoring relative humidity in the main room being heated by the heat pump (Figure 6). Within the houses in this project 49% have a mean winter relative humidity between 40-60%. Eight percent of houses have an average winter relative humidity below 40% and 42% above 60% relative

humidity. The average relative humidity for the houses is 56%, the minimum 33%, and the maximum 75%. Given the temperatures in New Zealand houses are warmer with heat pumps it is likely the relative humidity has also decreased.

Figure 6: Mean winter relative humidity (%) in the heat pump houses*



Includes 83 monitored houses during June, July and August 2010

3 Early results from the interviews

Interviews of the occupants in the monitored houses were carried out during September and October 2010. Early results are reported below on 68 of these houses.

3.1 Reasons for installing a heat pump

Householders are most likely to report that they have a heat pump because it is energy efficient (22.1 %), followed by convenience and ease of use (17.6 %), health reasons (11.8 %) and, finally, a desire for cheaper running costs (8.8 %). The energy efficiency and cheaper running costs are cited particularly by householders have previously been using other electrical heaters. The health reasons are cited primarily by those who have also been using gas.

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 informational social influence or social proof. Social proof is the phenomenon by which products, practices, systems and behaviours are taken up by some people because other people have already adopted them.

The householder data shows that social proof is a significant part of the take-up of heat pumps. Thirty-nine percent of householders with heat pump have got information from family members or friends and 39.7% report their neighbourhoods have a heat pump. Householders consistently refer to seeing other people adopt them was a motivation for acquiring a heat pump.

3.2 Householder Heat Pump Satisfaction

There are high levels of satisfaction among householders with heat pumps. Ninety-fine percent of householders report 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. Thirty-five percent of households describe the heating performance as excellent and 19% describe the running costs as excellent. Notably those households most likely not to be positive about heat pumps have experience living overseas and consider New Zealand houses as cold and their heating systems as inefficient and ineffective. Moreover, even among those that are satisfied, there appears to be a 'make-do' attitude to heat pump performance. Householders often report that their heat pump efficiency is compromised by its location or location decisions mean that the heat pump operation impacts negatively on some household members either by exposing them to noise or unwanted air movement.

4 Discussion

The initial results of the heat pump monitoring show that users are heating their houses in a different way to how they were in HEEP are few years ago. A higher number of households in New Zealand are now heating to a healthy temperature compared to HEEP, which has advantages for both the household and New Zealand as a whole. Healthier homes results in less winter mortality, fewer days off work or school, less doctor's visits and hospital admissions (Howden-Chapman et al, 2007).

Houses are being heated to a higher temperature and heaters used more frequently. In many cases, the electricity use of the heat pumps is higher than what was traditionally used for electric heating in New Zealand households. However, this does differ by region, with Auckland showing less electricity for space heating. Ideally, electricity use would be reduced but temperatures and relative humidity kept at a healthy level. This is possible through improving thermal performance of the house, having well-installed and correctly-sized heat pumps and sensible use. This project has already shown improvements can be made with the installation quality of heat pumps (Burrough, 2010).

The up-take of heat pumps has clearly been driven by informational social influence or social proof. That is the phenomenon by which products, practices, systems and behaviours are taken up by some people because other people have already adopted them. Informational social influence has its own momentum. Poor practices, inefficient and costly products, and poorly performing systems can become adopted simply because the proportion of the population using those practices or products reaches a tipping point. The householder data shows that social proof is a significant part of the take-up of heat pumps. Thirty nine percent of the householders that acquired a heat pump had got information about heat pumps from family members or friends, 39.7 percent of householders with heat pumps report that their neighbourhoods have a heat pump. Householders consistently refer to seeing other people adopt them was a motivation for acquiring a heat pump.

This project still has another year of energy, temperature and social data to be collected before final results can be reported on. Exploratory work will continue to be done before the data collection is complete. Work that will be carried out includes:

- Forecasting future uptake and energy use of heat pumps
- Calculating in-situ efficiency of heat pumps (COP)
- Examining installation quality
- Understanding occupants' knowledge of how best to use a heat pump
- Problems/issues with heat pumps from the users
- Peak loads by time of day and by month
- Reactive energy exploration by time of day and by month
- Determining, if possible, the drivers of temperature in households with heat pumps.

5 Acknowledgements

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