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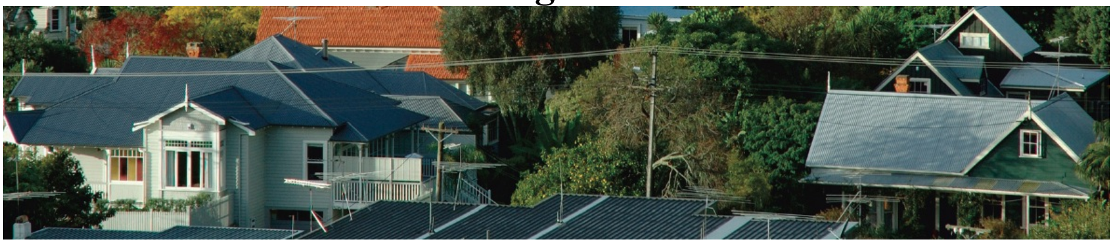

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Heat pumps in New Zealand houses

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Abstract

Heat pumps have grown rapidly in popularity – in 2009 approximately 21% of New Zealand houses had a heat pump compared to only 4% in 2005. It is important to understand how heat pumps are being used to ensure houses are heated in an effective and efficient way, and to update information on where electricity is being used in homes.

BRANZ is currently monitoring 85 homes with heat pumps throughout New Zealand. They are having their heat pump energy use, temperatures and humidity monitored, a house audit, and there is an extensive survey of heat pump users. Next year another 85 homes will be monitored.

This work allows us to understand how people are using them for both heating and cooling, if healthy conditions are being achieved, the future uptake of heat pumps, and the benefits, negatives and potential problems with them. Results are compared to the Household Energy End-Use Project (HEEP) data to see how heat pumps are changing the way we condition our houses and the expected increase in energy use.

Early results show extensive use of heat pumps during winter and warmer houses than in HEEP. There are health benefits to warmer houses, but electricity use from some of the houses is high. The potential exists for savings through thermal envelope improvements and improving the installation quality of the heat pumps.

Heat pump use is less during summer, but many houses are using them for cooling – a completely new energy use in New Zealand. Most heat pump users are very pleased and happy to recommend them to family and friends.

Early results of this work suggest heat pump usage in New Zealand will continue to grow in popularity as well as the energy use required to run them.

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 also be used to cool. The growth of heat pumps has been accelerated by clean heating programs, advertising by manufacturers and word of mouth from satisfied heat pump users.

The market change has been so quick that very little is known about how they are used. HEEP found solid fuel burners provided most of the heating in New Zealand houses (Isaacs et al, 2006). 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 170 houses with heat pumps and collects data on energy use, temperatures achieved, occupant attitudes and use, along with a house audit. Currently 85 houses are being monitored, with a further 85 to be monitored next year. Some clear patterns are coming through about how the heat pumps are being used which are reported on in this paper.

Monitoring project

The monitoring project has been designed to be nationally representative of houses with air source heat pumps for space heating (called air-to-air heat pumps). 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 (Statistics New Zealand, 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. Approximately one in five houses had a heat pump, which meant oversampling was necessary to recruit enough houses with heat pumps. Details of the project were given on the phone to the interested participants, as well as an information pack sent to the household.

So far, in the project there has been a high participation rate of around 50% (slightly above 50% at the phone call stage). However, some dropped out before the installation of equipment, which meant just under 50% participated. This is a high participation rate 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.

This year houses are being monitored in Northland, Auckland, Waikato, Manawatu-Whanganui, Wellington, Otago and Southland. Houses are picked randomly within each region, giving a spread across the region. For example in Otago there are houses in Wanaka, Ranfurly, Alexandra, Clyde, Cromwell, Oamaru as well as Dunedin. For a statically representative national sample of houses, selecting houses randomly throughout each region is the preferred method. This can also be an expensive way of monitoring as the sample can be quite spread out. However, the remote data monitoring equipment in this project has made it possible.

The remaining regions will be monitored once the first set is complete. 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) for one year. 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 switchboard 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 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 survey is carried out with the household. Surveying 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.

How heat pumps work

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.

In the external unit, the liquid refrigerant evaporates to become a gas, absorbing energy from the air. This gas is then pumped to the internal coil where the gas condenses to a liquid, giving up the heat. The opposite occurs when cooling – heat is extracted from the inside and moved to the outside air.

Heat pumps produce the most heat for a given amount of electricity of any commonly available electrical heating system. 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).

For heat pumps, the COP will reduce as the temperature difference between inside and outside increases. For heating in colder locations they are therefore less efficient than in warmer climates, with the opposite true for cooling. The advertised MEPS COP is determined under test conditions, but in actual use will change as the temperature difference between inside and outside changes. The Centre for Advanced Engineering New Zealand (CAENZ) has developed a simple model, based on outdoor temperatures, to evaluate the maximum annual effective mean COP for heat pumps in four locations (Duncan et al, 2007). CAENZ suggest heat pumps with a rated COP of 3.0 will average closer to 2.4 in the colder areas of New Zealand during winter.

Internationally there is evidence in-use heat pump performance can be significantly lower than the standardised test results due to poor installation and operation (Lubiner et al, 2005). Anecdotal evidence suggests this is also true in this country. Until now, no New Zealand work has been undertaken to explore the in-situ performance of heat pumps.

Early results from the monitoring project

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.

Change in the way we use 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 changes with our houses as well as how we use houses between the 1971/72 study and HEEP. In terms of heating appliances, electric heating has not changed a lot (4% of HEEP sample had heat pumps), but 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 done by solid fuel (56%) (Isaacs et al, 2010). Insulation requirements have been introduced and retrofitting insulation into houses is now becoming more common (New Zealand Standards, 1977, 1996, 2009; Williamson, 2010). The number of occupants per dwelling has decreased; there has been an increase in appliances and their energy use (28% to 47%).

A survey completed in late 2007 collected information on what type of heater the heat pump was replacing (if any). About 40% reported they were replacing an existing heater and the remaining reported they were installing a heat pump for additional heating and keeping their existing heaters (French, 2008). Figure 1 gives the breakdown of the heaters that were being replaced. Information on fuels was not collected, but it can be assumed night stores, heat pumps and the electric heaters all use electricity. This means 40-50% of heat pumps installed are replacing electric heaters. It is possible heaters in the central heating category and the underfloor are also electric, hence the range given. These consumers are likely to get a much better service with increased temperatures for possibly less cost (depends on temperature set point and hours of heating). About one-half 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.

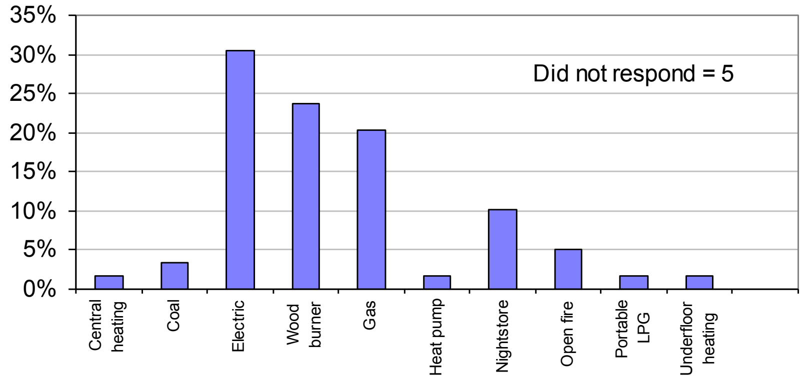

Figure 1: Heaters replaced by heat pumps (Source: French, 2008)

Between 1999 and 2005 HEEP monitored 400 households throughout New Zealand (Isaacs et al, 2010). HEEP collected information on all energy types as well as temperatures in each of the households monitored. HEEP gives us regional baseline data to be able to compare the electricity use for heating while heat pumps were reasonably uncommon (4% of the sample), with the data being collected now on heat pump energy use and temperatures in households. The HEEP sample was selected in a different way to how the heat pump sample was selected, so care is needed when making comparisons.

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 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).

Table gives the annual space heating use for heat pumps per house by region for houses in the heat pump study. Table will underestimate the total amount of electricity used in the house for space heating as other electric heaters are used in some houses. However, it will give a good indication of the space heating energy, as most houses report their heat pump(s) is their main source of heating. Manwatu-Whanganui has not been reported on due to the low sample size and high standard deviation.

Location	All energy types	Standard deviation	Electricity	Standard deviation
Overall	3,820	350	920	190
Auckland	3,190	840	1,630	720
Hamilton/Tauranga	2,830	530	280	80
Wellington	2,630	730	780	600
Christchurch	3,010	690	950	350
Dunedin/Invercargill	6,810	910	3,130	420
Clusters	4,370	560	420	110
Warm clusters	3,080	480	290	140
Cool clusters	5,860	830	550	180

Table i: HEEP – average annual space heating use per house (kWh)

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 (800 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.

Region	Electricity for heat pumps	Standard deviation	Sample size
Northland	620	240	3
Auckland	800	100	32
Waikato	2,320	1,080	12
Wellington	1,470	310	15
Otago	2,770	560	15
Southland	3,550	1,260	4

Table ii: Estimated annual electricity use for heat pumps per house per region – kWh (based on at least six months of monitoring for each house)

In Wellington the situation is reversed with the heat pump houses using almost double (1,470 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.

It is difficult to compare the lower South Island between the two studies, as the area for the sample is quite different. While HEEP had houses in the two cities, houses with heat pumps were selected from the Otago and Southland regions. Houses in Central Otago, which has quite a different climate to Dunedin, were therefore included. 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 1,600 kWh, whereas the median is approximately 1,100 kWh. The electricity use for the houses 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.

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 looked at.

Figure 2 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.

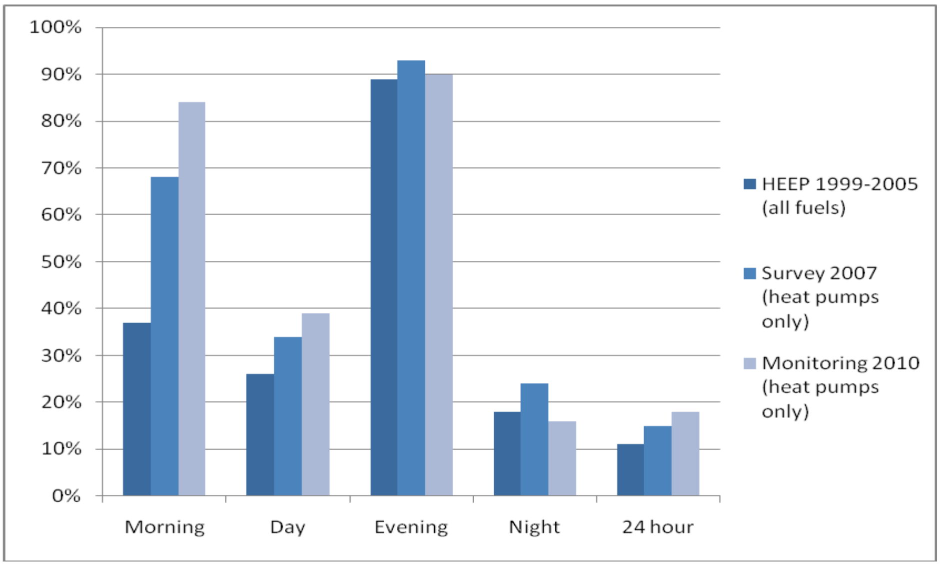

Figure 2: Heating schedules (Compiled from: Isaacs et al, 2010; French, 2008)

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 3 and Figure 4 are histograms of the mean living room evening (5pm to 11pm) temperatures during winter (June, July and August). Figure 3 is from HEEP (Isaacs et al, 2010) and Figure 4 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.

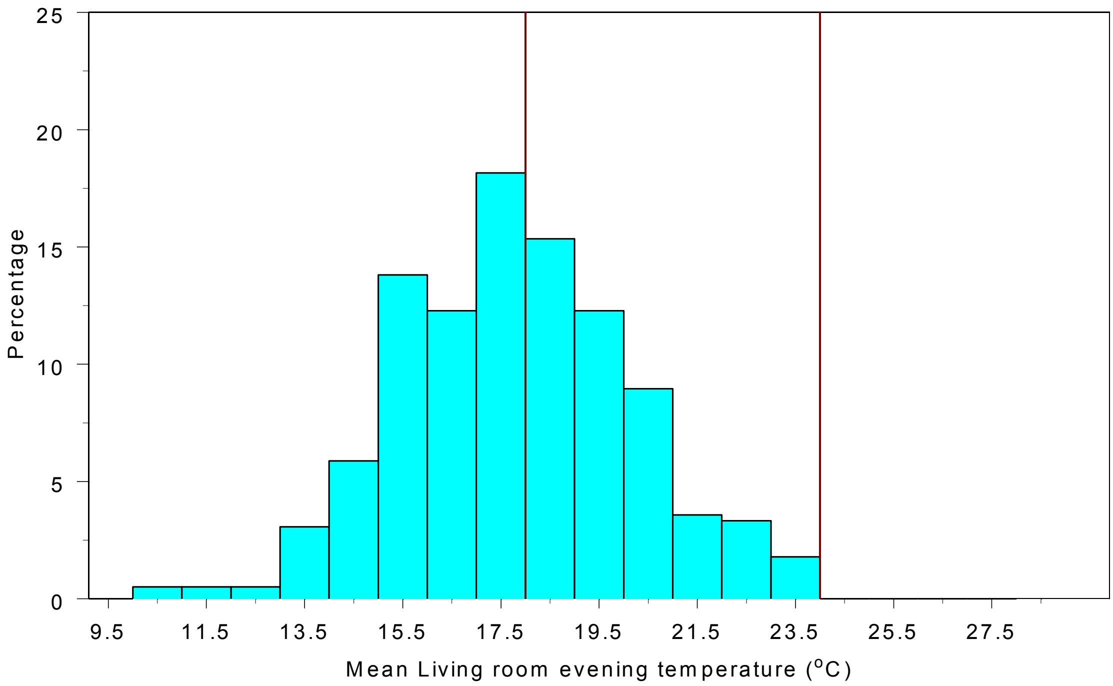

Figure 3: HEEP distribution of winter evening living room temperatures (Source: Isaacs et al, 2010)

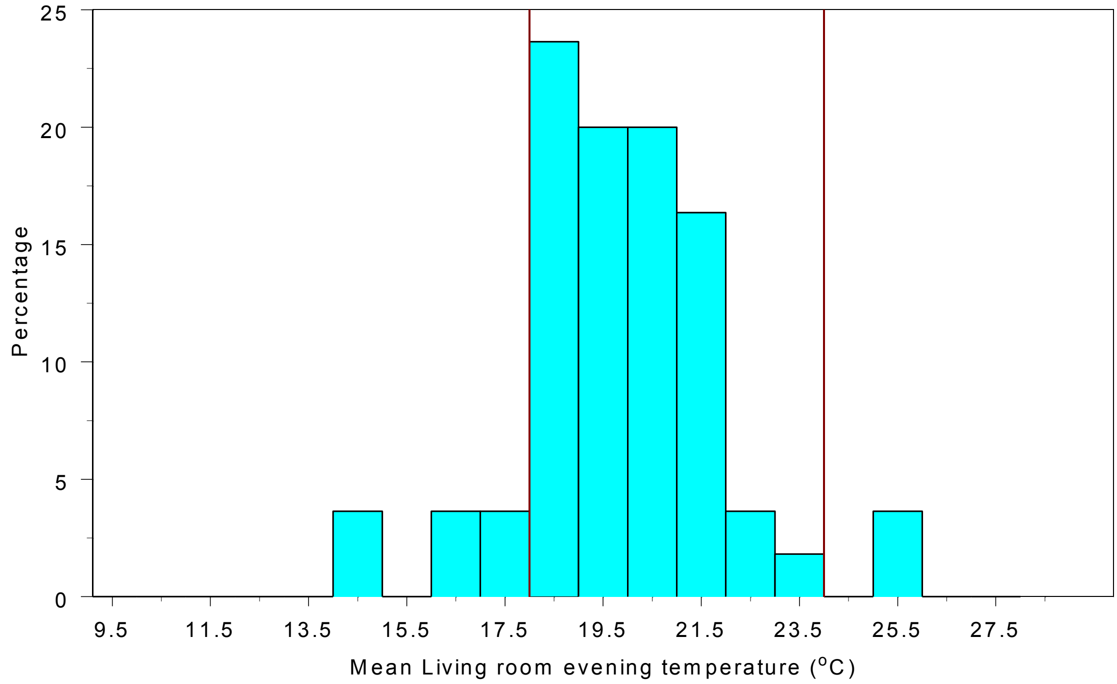

Figure 4: Heat pump houses* – distribution of winter evening living room temperatures (°C)

*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.

The warmer the temperature, the more moisture the air can hold, so as a result the relative humidity is lower. Although no national studies have been done before now on relative humidity levels within our houses, studies have found our houses are often damp and mouldy and display signs of high relative humidity (Phipps, 2007). In a study by Beacon Pathway Ltd of nine houses in a suburb of Porirua near Wellington, eight out of the nine houses failed to meet Beacon's High Standard of Sustainability® of relative humidity within 20-70% (Burgess et al, 2008). The Waitakere NOW Home® (Pollard et al, 2008) relative humidity was measured throughout the house for two years. The relative humidity after the first winter was 62%, which dropped to 58.7% in the second year. Two extraction fans were installed after the first year of monitoring, which may explain the decrease. The Waitakere NOW home® is well insulated and has good passive design. Cunningham et al (2001) monitored the indoor environment in an uninsulated house in Wellington, and then again when the floor, roof and walls were insulated. The relative humidity dropped from 68% to 60% during the winter.

This study is monitoring relative humidity in the room being heated by the heat pump (Figure 5). 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%.

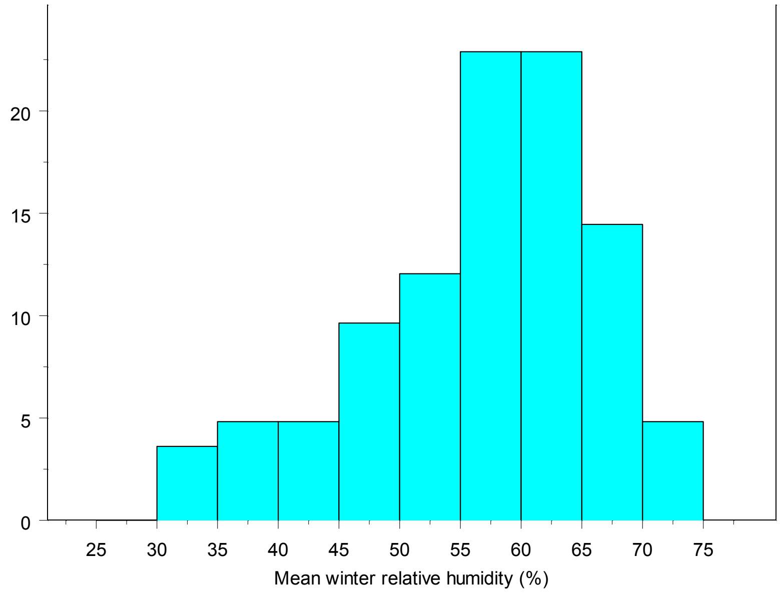

Figure 5: Mean winter relative humidity (%) in the heat pump houses*

* Includes 83 monitored houses during June, July and August 2010

Benefits of heat pumps

The World Health Organization (WHO 1987, 2003) suggests that comfortable conditions (above 18°C) should be maintained to ensure healthy conditions are achieved. 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.

Determining what temperature is appropriate for good health is very difficult as health depends on individuals' response as well as known risk factors such as age, diet, exercise and history of illnesses.

Raw et al (2001) have looked at a number of studies and reached the following conclusions. Below 16°C causes an increased risk of respiratory infection. Below 12°C can cause cardiovascular strain (rise in blood pressure). The lowest suggested temperature is 16°C for occupied living rooms and bedrooms, above 18°C is the minimum for thermal comfort. Given the variations in the population and houses, it is not possible to say that ill health will result from temperatures lower than suggested. They should however normally protect occupants from the ill health effects of cold conditions. Healthy temperatures should reduce heart attacks, strokes and respiratory illnesses that can be caused by cold temperatures (Raw et al, 2001).

With New Zealand's maritime climate and low heating levels our houses have often been reported as being damp or mouldy (Phipps, 2007) which suggests high relative humidity. To reduce relative humidity the first step is eliminating moisture sources (unflued gas heaters, drying washing inside) and extraction of moisture (range hoods, bathroom extraction fans). With this done adequate temperatures and ventilation are required to keep the relative humidity from getting too high and causing mould or fungi growth. Adequate temperatures are required, as the higher the temperature the more moisture the air can hold, which lowers the relative humidity. The warmer temperatures in the houses in the heat pump study are, therefore, also keeping the relative humidity lower than the same house heated to a lower temperature. Adequate ventilation is also important in controlling the relative humidity. However, if the ventilation is too high the space or house will require an increased amount of heating energy, as the warm air is lost through ventilation. The average relative humidity in the study is 56% during winter.

A safe range of 40-60% is recommended by Arundel et al (1986) and 30-70% by Raw et al (2001). Both examined risks with varying relative humidity levels and found there are risks at all levels of relative humidity. Arundel et al (1986) suggest that below 40% can cause excessive drying of the mucus membranes and can cause a point of entry for infection, and above 60% can cause mould and fungi growth. However, Raw et al (2001) suggest that below 30% is an issue for drying and above 70% an issue for mould and fungi.

Having 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). This benefits not only the household, but also New Zealand as a whole because of increased productivity and reduced cost of healthcare.

Reduce electricity use, but keep the benefits

Households using heat pumps have shown different patterns of use compared to those found in HEEP (Isaacs et al, 2010). Heat pump users tend to heat to higher temperatures and more frequently. As shown, there are benefits to having warmer houses, but it can also increase the electricity use for the household. 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.

To improve existing houses heat losses should be reduced as much as possible through floor, roof and wall insulation, and advanced window systems will help reduce losses through windows. Simple actions such as weather stripping your windows and doors and using thick curtains are worthwhile. In winter try and maximise solar gains as much as possible by letting the sun into the house (e.g. open curtains during the day and prune trees to let the sun through). There are many more options when building a new house, by maximising the gains in winter and reducing the losses in many of the warmer parts of New Zealand no heating will be needed at all (Pollard et al, 2008; Jaques & Mardon, 2008). There are many references available on how best to go about this. New Zealand references include: Level (2010), Smarterhomes (2010) and EcoDesignAdvisor (2010).

Overseas research has found the better the installation of the heat pump the better the performance (Lubiner et al, 2005). This project has found many heat pumps in New Zealand could be better installed (Burrough, 2010). Both the indoor and outdoor unit need to be well placed: the indoor unit so it can distribute heat evenly to the space(s) being heated; and the outdoor unit, so it is close by but ideally in a sunny warm place with no obstructions around its air intake. However, the outdoor units can be noisy and they do discharge cold air so this needs to be considered when installing. Capacity size is important so the unit is not switching on and off, but also does not require other heating to help heat the space. EECA have been working in this area and have produced a good practice installation guide (EECA, 2009).

There are reports of conflicting information being given to consumers on how best to operate their heat pump, for example, some participants reported that their installer told them the most efficient way to heat is leaving the heat pump on 24 hours a day. Others suggest to just heat when needed. This project will review how people are using their heat pumps and compare energy use, service and efficiency of the heat pump to help understand the best way to operate them. Heat pumps are very different to most heating appliances we have traditionally used in New Zealand in that they have a thermostat. In the USA, Kempton (1987) found that users often did not understand how a thermostat worked and would turn it to a higher temperature than what is desired so the heat pump would heat the room faster. This is not how a heat pump works and can lead to higher electricity use due to overheating (or cooling during the warmer months).

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.

Houses are being heated to a higher temperature and 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.

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.

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.

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