STUDY REPORT

No. SR 122 (2003)

Energy Use in New Zealand Households

Report on the Year 7 Analysis for the Household Energy End-use Project (HEEP)

Supported by:

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Energy Use in New Zealand Households – HEEP Year 7 Report
November 2003
Executive Summary

This is the seventh annual report on the Household Energy End-use Project (HEEP). Although data collection will not be completed until early 2005, the annual reports provide preliminary results from our research. Each report includes the increased house sample that becomes available when the previous year's monitoring is complete. This report includes data from 200 randomly selected houses, as well as non-random selections. Regional coverage includes the full Auckland sample, Hamilton, Wellington and Christchurch.

The funding highlight of the past year has been the allocation by the Foundation for Research Science and Technology under the 'Public Good Science & Technology' (PGST) 'Output Class 7: Research for Industry' for science funding to support the completion of the HEEP model by June 30, 2007. We also acknowledge the sponsors listed on the front cover.

Readers new to the HEEP work will find a wide range of analysis. In many cases, along with the mean, information is given on the range found in the HEEP houses. However, though such analysis can be informative, it is not necessarily applicable to all situations. For example, it will not provide guidance to aspects of

- household energy use in houses with high or low incomes
- temperatures found in older or newer houses
- behaviour and use of older or newer appliances.

Readers with interest in specific use of the HEEP data are invited to contact the HEEP team.

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New Zealand residential energy use

The domestic sector consumes 13% (60 PJ) of New Zealand's energy, and 33% of all electricity, with consumption growing at over 2% per annum. The domestic sector is a major contributor to peak demand which must be met by thermal generation, with a consequent impact on greenhouse gas emissions. The residential sector accounts for about 10% of CO_2 emissions (directly for 1.6% and indirectly at least 8% from thermal electricity generation).

As consumption grows, the negative economic, social and environmental effects increase, so finding ways to reduce energy demand, GHG emissions and use energy more efficiently becomes critical. However, if strategies to reduce energy demand result in lower indoor temperatures and increased damp the outcomes may be undesirable. Mould is associated with damp and low indoor temperatures, as are a number of health problems. The problems arising from inadequate indoor temperatures and damp within the residential sector can have significant costs for households, the government and the economy.

Each 1% improvement in the efficiency of energy use in New Zealand homes would result in a benefit of $17 million and reduce national CO_2 emissions by 0.1%.

For the residential sector the goal must be increased energy efficiency and minimising energy demand while also ensuring: (a) satisfactory perceived levels of comfort; and (b) healthy temperature and moisture levels in residential dwellings.

Designing and implementing interventions to achieve that goal is inhibited by our limited knowledge of the dynamics of residential energy demand. Energy supply (electricity, natural gas, LPG, wood, coal, oil etc) is well understood and documented, but this is not true for the residential energy demand. HEEP will assist in demand management of residential energy through improved understanding of energy end-use from a range of viewpoints, including the house construction, appliance use (including the hot water system) and the socio-economic and demographic characteristics of households.

During the past 30 years since the last household electricity survey, there have been major changes in the way NZ houses are built and used:

- materials (e.g. since the 1970s, particleboard has been the main flooring material)
- building code (e.g. thermal insulation required since 1978)
- appliances (e.g. microwave ovens widely available from the late 1970s)
- consumer expectations
- work practices
- the characteristics, size, age, configuration and cultural diversity of households.

All these factors affect the complex relationship between energy demand, indoor temperature, perceived comfort, household energy costs, and the local climate.

Household energy use by end-use

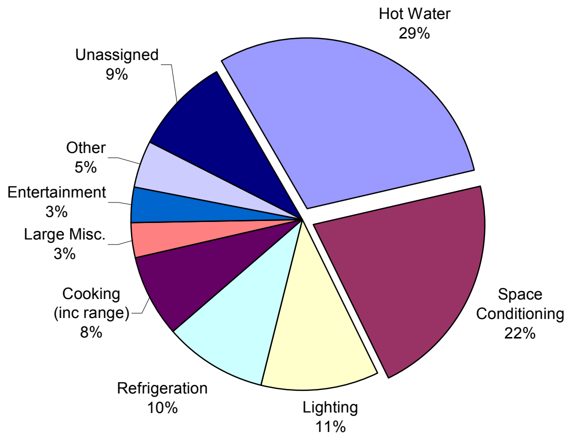

Figure i: Electricity & gas by end-use

The report provides a revised analysis of the energy used both at the total household and individual appliance levels (Figure i). No statistically significant difference has been found in total energy use between the four regions – with the strata-weighted average over the four HEEP locations for electricity and natural gas reported at 1154 ± 52 W. Note that this value currently excludes portable LPG heaters and solid fuel burners. Work is continuing on incorporating energy resulting from the use of these remaining fuels into the analysis.

As well as the strata-weighted average end-use breakdown given above, the report provides updated pie charts by region. On average, hot water is the biggest use of household electricity and gas at close to 30%, with space conditioning (heating and/or cooling) following at 22%. Lighting at 11% is one half of the energy used for space heating, while refrigeration follows in fourth place with 10%. The importance of lighting and refrigeration has not been well recognised, perhaps due to the comparatively small power load.

Indoor temperatures

Comparing the temperatures by region from the 1971/72 Household Electricity Survey with the current HEEP results does not appear to suggest that there has been any increase in average temperatures. There is a wide distribution of temperatures, and this will be subject to further investigation.

There is a significant difference in the start and finish of the heating season. Households in cooler climates, on average, start heating earlier in the year and finish heating later in the year than those in warmer climates. A similar pattern was found for the time-of-day heating pattern. The start of heating is progressively earlier going from warmer to cooler regions, being about 30 minutes earlier at each location going from Auckland at 5:50pm through to Christchurch at 4:20pm. The time of the maximum rate of increase of temperature is approximately the same in all regions, ranging from 6:20pm to 6:50pm, with no apparent pattern. The end of heating appears to be weakly related to the household bedtimes.

The temperature distribution continues the pattern reported last year, with nearly 30% of households having average winter (June through to August, 5pm to 11pm) evening temperatures below the World Health Organisation recommended minimum of 16°C. There are also significant correlations between mean winter evening temperatures and the house age, presence of insulation, and house floor area.

House age group	Average winter evening living room temperature	Average winter overnight bedroom temperature	Average winter evening energy use
Pre-1978	17.0 ± 0.2°C	13.8 ± 0.2°C	1680 ± 114 W
Post-1978	18.0 ± 0.3°C	14.9 ± 0.3°C	1590 ± 210 W

Table i: Winter temperatures and energy use by insulation level

There is a very strong relationship between the age of the house and the winter temperatures (Table i). Currently, we can conclude that post-1978 houses are 1.0°C warmer on average and that their winter evening energy use is not significantly different from the pre-1978 houses. This difference is slightly less than that given in the Year 6 report, and the reduction has been caused in part by pre- and post-1978 houses in Christchurch having no significant difference in winter evening temperatures.

Winter energy use

Out of the 280 houses, 93 (33%) reported that the main heating is by solid fuel – second only to the use of electric heating (42%); 14% of the households report their main heating fuel is LPG, and 11% use natural gas.

The HEEP methodology for analysing solid fuel energy-use continues to be developed, and thus the heating energy analysis includes only electricity, natural gas and LPG.

The mean space heating energy use is 3650 kWh per year, with a minimum of 253 kWh/yr and a maximum of 14,120 kWh/yr. Normalised to floor area, heating energy use ranges from a minimum of 0.8 kWh/m²/yr to a maximum of 42.9 kWh/m²/yr with an average of 13.5 kWh/m²/yr.

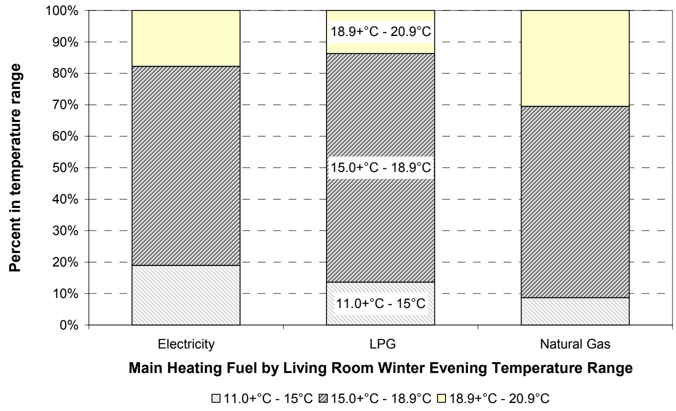

Figure ii: Temperature range by main heating fuel

There is a wide scatter of energy use by floor area and house age, neither of which show a strong relationship. Figure ii shows that houses heated by solid fuel heaters tend to have warmer winter evening living room temperatures than those heated by electricity, natural gas or LPG.

A preliminary 'heating index' has been developed to explore the impacts of different heating schedules. Houses that are heated for long hours have a higher mean winter evening living room temperature, although there is a very wide spread of temperatures for both the heating index and the energy use.

LPG heaters

30% of the HEEP sample have LPG heaters, averaging just over one per house. The operation of portable (unflued) LPG heaters also releases quantities of water vapour into the heated space. Just over one-third (35%) of the houses with LPG heaters have a dehumidifier, whereas the houses that do not have an LPG heater have about a 21% chance of having a dehumidifier – this is statistically significant at the 1% level.

The patterns of LPG heater use do not reflect their ability to provide larger amounts of heat – with the majority used at levels that are comparable with the heat that can be provided by portable, plug-in electric heaters. The heaters are predominantly operated on low setting (72%); 11% are operated on medium and 17% are predominantly operated on high setting. These settings are often not varied, with close to three-quarters of the heaters spending more than 80% of its use at the one setting. Most LPG heaters are not heavily used – over 50% of the LPG heating energy is used by only 20% of the heaters.

Health and Housing

Buildings protect the occupants from the excesses of the external climate. Although it is possible in many parts of New Zealand to achieve this through ‘passive’ solar design, which maximises the use of free solar energy, the majority of houses use purchased energy to ensure the indoor climate is acceptable to the occupants.

A review of international and New Zealand literature shows there is increasing evidence of a link between the consequences of energy efficiency and occupant health. Health, and other non-energy benefits of improved house energy efficiency can be of sizeable value, with one USA study suggesting they were close to being equal.

There is no simple measure of how the conditions within a building support the well-being and health of the occupants. One approach is to examine some health consequence, which should show minimum seasonality (variation across seasons) if the occupants are well-protected from the variation in the external climate.

The whole population seasonal mortality is examined for Japan, the United Kingdom, Australia, New Zealand, the United States of America and Sweden. The analysis found that over the 30 year period from 1970 to 2000 there has been a steady increase in the seasonality of mortality in the USA and Sweden, Japan and the UK have remained reasonably constant, and in both New Zealand and Australia it has been decreasing.

Age-specific monthly mortality data was obtained for New Zealand and Australia. It was found that between 1980 and 1999 in New Zealand only the 0 to 4-year age group was demonstrating a strong downward trend, although a small downward trend was apparent in the 5 to 64 and 65-plus age groups. However for all three Australian age groups, seasonality was decreasing. The reduction was greatest for the 0 to 4-year age group, but the other two groups were showing a greater decline than is the case for New Zealand.

Hot-water systems

An analysis is provided of the hot-water systems and temperatures found in the HEEP sample. Of the houses in the current HEEP database (including both random and non-random houses), 91% have one hot-water system, 8% have two systems and 1% have three systems. None have more than three hot-water systems.

The majority of the HEEP hot-water systems (79%) only have an electric storage water cylinder – an electric element is located inside an insulated tank of water, with the temperature controlled by a thermostat. Eight percent of the systems have an electric cylinder with some form of supplementary heating, either solar, wetback or a combination. Eight per cent of the water heating systems are gas storage system, 5% are instantaneous gas and less than 1% are solid-fuel-only.

Most cylinders (50%) are either 135 litres (30 gallons) or 180 litres (40 gallons) (40%), with the remainder being split almost equally between the small cylinders located close to their end-use (e.g. under the kitchen sink) and larger cylinders.

Cylinder size (volume) distribution varies by location. In the North Island sample (Auckland, Hamilton, Wellington and Wanganui) 52% of the sample cylinders are 135 litres and 37% are 180 litres or greater. In the South Island (Christchurch) the reverse is the case, with 24% of the cylinders at 135 litres and 66% at 180 litres or greater. These size distributions are likely to reflect historic energy-supplier policy, as there appears to be a shift to larger cylinders in newer homes.

The system water pressure has also changed in more recent years. More than three-quarters (79%) of the HEEP sample are low pressure and the rest (21%) are 'mains' pressure. Three percent of the cylinders from the 1960s are mains pressure, 9% in the 1970s, 17% in the 1980s and 26% in the 1990s.

Houses have a longer life than hot-water cylinders, and it is expected that as hot water cylinders fail they will be replaced, often with the same size but not necessarily with the same pressure. Even very old houses (which originally would have had low-pressure systems) are being retrofitted with mains pressure hot-water systems. About one-third (32%) of the houses, but two-thirds (65%) of the hot-water cylinders date from 1980. The oldest cylinder in the sample dates from the 1930s.

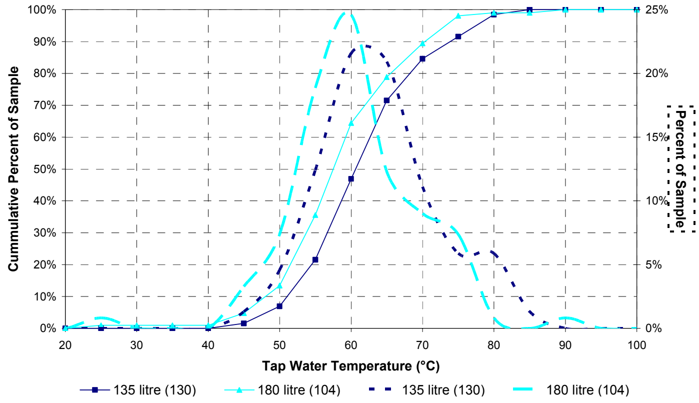

Figure iii: Tap temperature by cylinder volume (electric)

The analysis of the hot water temperatures and systems raises a number of energy, safety and health issues about the provision of hot water in homes:

- **Over 40% of the cylinders had UNSAFE delivered water temperatures:** 43% of the measured water temperatures were above 60°C, including 13% with delivered water over 70°C (see Figure iii).
- **One-third of the cylinders had INACCURATE thermostat control:** 67% of the delivered water temperatures are within ±10% of the thermostat setting. However, 25% of the delivered water temperatures are more than 20% higher than the thermostat setting. In other words, even if occupants set the thermostat to what they believe to be a 'safe temperature', the tap temperature may be unsafe.
- **Even when users set the thermostat at a safe temperature, one-third of these cylinders had UNSAFE hot water delivered :** 35% of the cylinders had the thermostat set at 60°C or under, but about one-third of these houses had water over 60°C being delivered at the tap (i.e. 11% of all the cylinders in the sample). Thus, even if the householder was attempting to ensure safe temperature water was delivered through correct setting of the thermostat, the thermostat was not providing it.

- **One out of seven houses with a tempering valve delivered hot water over 60°C**: Only 12% of the cylinders (for which thermostat and water temperature data was available) had tempering values to ensure water would be delivered at a ‘safe’ temperature. Of these systems, 45% were delivering water at less than 55°C, 40% between 55°C and 60°C, and 15% at a temperature above 60°C – although the maximum measured hot-water delivery temperature for a cylinder with a tempering valve was only 64°C, compared to the maximum of 87°C for one electric storage system without a tempering valve.

These results help to identify potentially important hot-water health and safety issues in New Zealand homes. The HEEP study will continue to monitor delivered and thermostat hot-water temperatures. HEEP will also work toward developing an appropriate methodology to assist in the identification of hot-water systems that are likely to have excessively high temperature water and tools to ameliorate the possible dangers.

Shower flows

The shift to mains pressure systems has a particular impact on water flow. The average shower flow of 8.2 litres per minute (l/m) measured in the HEEP shower sample – which is equivalent to a water-efficient AAA shower head – disguises the system water pressure.

The average shower flow for a low-pressure hot-water system is 7.2 l/m and for a mains pressure system is 10.6 l/m. The maximum recorded flow rates were 20 l/m for low pressure and 30 l/m for mains pressure. On average, 25% of low pressure systems had ‘warm’ shower flows over 9 l/m, while 60% of mains pressure system were above this threshold.

Thus, a house in Auckland that currently had a shower flow above 9 litres per minute which switched from a high flow to a low flow shower head (saving 7 litres per minute of water) and maintained a five-minute shower, could save around **11.5 cents per shower** for the costs of both the freshwater and waste water.

The energy savings from the reduced flow, based on heating the water from 14°C to 39°C and an electricity tariff of 13 cents per kWh would be **13.2 cents per shower**.

The total savings would be about **25 cents per shower** (46% due to reduced water and 53% due to reduced energy), or over a full year $90 assuming one shower per day. In this case the retrofitting of a low-flow shower head (product cost about $40), would have a payback of less than six months assuming only one shower per day – obviously the payback would be far faster for two or more showers per day.

Hot-water standing loss analysis

HEEP has regularly reported on the standing losses of hot-water systems. With the addition of the Christchurch houses and the second year of Auckland houses, the number of hot-water systems available for analysis has almost doubled. Unfortunately, with the increase in numbers there has been a large increase in exceptional and unusual cases, which have caused problems for the standing loss analysis methods.

The data currently coming in from the HEEP clusters (which are predominantly small towns and semi-rural areas) are even more unusual, as hot-water electric network load would appear to be controlled more tightly in many of these areas. As a consequence, the methods previously used to estimate standing losses have been replaced by a new method. Ideas for methods to maximise the opportunities to improve hot-water cylinder energy efficiency are also reviewed.

Year 7 Executive Summary

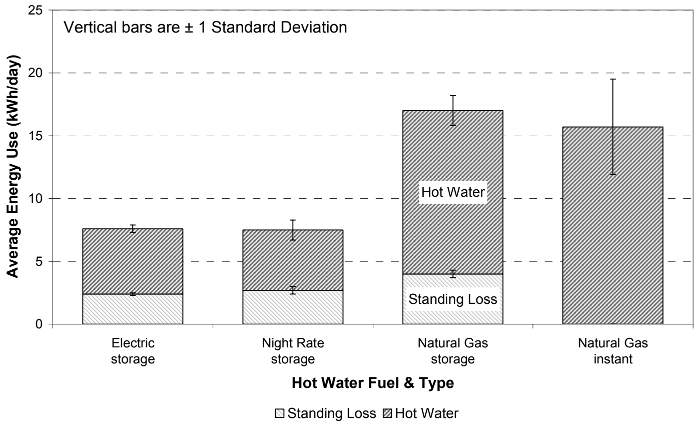

Figure iv: Energy consumption & standing losses by system type

Revised estimates of average total energy use and the standing losses are provided for four cylinder types: electric storage, electric night rate storage, natural gas storage and natural gas instant. Total energy use ranges from 7.5 (electric night rate storage) to 17 kWh/day (natural gas storage). Average standing losses range from 24% (natural gas storage) to 36% (electric night rate storage) of the total energy use. (see Figure iv)

Obtaining HEEP reports

The HEEP team has worked to ensure the results of the work are available to the widest possible range of stakeholders – including the public, special interest groups, government agencies and other researchers. References to previous HEEP reports, and other publications on the HEEP work, are given in the full report. Many of these are available for downloading from BRANZ website shop.

Copies of the full Year 7 report are available from BRANZ, using the order form below:

Postal address: BRANZ, Private Bag 50908, Porirua City, NZ.
Phone: +64 (04) 237 1170 Fax: +64 (04) 237 1171
E-mail: HEEP@branz.co.nz Web site: http://www.branz.co.nz

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ENERGY USE IN NEW ZEALAND HOUSEHOLDS

Report on Year Seven for the Household Energy End-use Project (HEEP) – November 2003, BRANZ Study Report SR 122

Authors:

Nigel Isaacs (Ed.), Lynda Amitrano, Michael Camilleri, Lisa French, Andrew Pollard, and Albrecht Stoecklein (BRANZ Ltd)

REFERENCE

Isaacs N., Amitrano L., Camilleri M., Pollard A. & Stoecklein A 2003 *'Energy Use in New Zealand Households, Report on the Year 7 Analysis for the Household Energy End-use Project (HEEP)'*, BRANZ Ltd: Judgeford, November 2003.

ABSTRACT

This report covers the activities of the seventh full year of the Household Energy End-use Project (HEEP) and is based on survey, house audit and monitored energy and temperature data from 200 randomly selected houses in Auckland, Hamilton, Wellington and Christchurch, and on survey data in these houses, plus additional non-random houses. Monitoring will be completed in early 2005.

Analysis includes examination of energy by end-use, indoor temperatures, space heating energy use, seasonal mortality, hot-water energy use, hot-water temperatures, shower flows and hot-water system standing losses.

The top four uses of electricity and natural gas are hot water (29%), space heating (22%), lighting (11%) and refrigeration (10%). Houses built after 1978 (mandatory thermal insulation requirements) are found to be on average 1 °C warmer with that same energy use. Winter evening temperatures in pre-1978 houses average 17°C in the living room and 14°C in the bedroom. There is a wide range of space heating energy use, but houses heated by solid fuel tend to have warmer temperatures than houses heated by electricity, natural gas or LPG. More than 40% of the hot water was delivered at unsafe temperatures (over 60°C).

The average shower flow for a low pressure hot-water system is 7.2 litres/minute and for a mains pressure system is 10.6 litres/minute – with increasing numbers of mains pressure systems being installed. Average hot-water system standing losses range from 24% (natural gas storage) to 36% (electric night rate storage) of the total energy use.

Acknowledgements

The funding support of the following organisations is gratefully acknowledged:

- BRANZ Inc., and the Building Research Levy
- Energy Efficiency and Conservation Authority (EECA)
- Fisher and Paykel New Zealand Ltd
- Foundation for Research, Science and Technology - Public Good Science & Technology fund
- Social Policy Agency, Ministry of Social Policy, Te Manatu mo nga Kaupapa Oranga Tangata (now Ministry of Social Development, Te Manatu whakahiato ora)
- Cement and Concrete Association of New Zealand
- PowerCo, Wanganui
- TransAlta New Zealand Ltd, Wellington
- TransPower New Zealand Ltd
- WEL Energy Trust, Hamilton

The HEEP team is also grateful to the house occupiers who responded to our questions and permitted us to monitor their homes for the best part of a year. Without their cooperation this research would not have been possible.

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1. INTRODUCTION

This is the seventh annual report on the Household Energy End Use Project (HEEP). It provides an overview of the monitoring programme, discusses the future monitoring and provides preliminary analysis from the HEEP database.

Of particular importance is the support to be given to the HEEP science component from the Foundation for Research Science and Technology under the 'Public Good Science & Technology' (PGST) 'Output Class 7: Research for Industry'. It has awarded funding until 30 June 2007.

As before, HEEP data collection, due to be completed in early 2005, is funded by a wide variety of other organisations.

This report includes analysis based on monitored data from 200 randomly selected houses from around New Zealand, and survey data from over 300 houses. Section 1.2 (page 2) discusses the coverage of earlier HEEP reports.

Readers new to the HEEP work will find a wide choice of analysis in this report. In many cases, along with the mean energy use or temperatures, information is given on the range and distribution. Although such analysis is informative, it is not necessarily applicable to all situations. For example, it will not provide guidance as to aspects of:

- household energy use in houses with high or low incomes
- temperatures found in older or newer houses
- behaviour and use of older or newer appliances

Readers with interest in specific use of the HEEP data are invited to contact the HEEP team by any of the methods given in Section 1.5 (see page 6).

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1.1 HEEP in action

HEEP has delivered new knowledge about energy use in houses for every year of its existence. It is recognised nationally and internationally as leading research into domestic energy end-use. As well as formal research outputs (conference papers, journal articles, reports) there has been a steady stream of industry and general public reporting. In the past year the results of HEEP research have appeared in a wide range of media:

- in electricity and construction industry trade magazines
- as presentations to service clubs (including Lions and Rotary) and industry organisations (including M-co staff, Office of the Electricity Complaints Commissioner, IPENZ, Royal Society of New Zealand, Energy Management Association)
- in lectures to Auckland, Victoria and Otago universities
- in the NZ Official Yearbook 2002
- on television in the consumer programme 'Fair Go'
- in newspapers
- on radio and television news
- as a major component of National Radio's 'Insight' documentary on 'Energy Efficiency in NZ houses' (25 May 2003)

- as part of two National Radio series - '**Understanding Your Home**' each Wednesday morning in 'Nine to Noon' from April 11 to June 26, 2002, and '**Energy Efficiency Moments**' each Friday afternoon in 'In touch with New Zealand' from May 23 to August 1, 2003.

HEEP has even found its way into at least two national advertising campaigns – both in their own way working to promote energy saving - Figure 1 due to the hydro-electricity shortage, and Figure 2 due to the shortage of refreshments.

If you sing in the shower, choose shorter songs.

Water heating can amount to almost half your power bill, so having shorter showers will save you heaps of power. Call 0800 55 00 55 or visit www.target10.co.nz

TARGET 10%

Figure 1: Target10 advertisement, May 2003

Figure 2: Tui Beer billboard, June 2003

1.2 Coverage of HEEP annual reports

The HEEP Year 7 report provides more extensive coverage of New Zealand houses than previous reports (see Table 1).

Early reports (Years 1 – 4) reported on the pilot study, which used houses that were *not* randomly selected, and therefore their results are not representative of New Zealand, in part or as a whole.

From Year 5 onward, the HEEP reports contained analyses that were representative of parts of NZ, depending on how many regions had been completed.

The current coverage of randomly selected houses includes: Auckland, Hamilton, Tauranga, Wellington, Dunedin, Christchurch, Invercargill, and all the clusters that have been or are currently monitored (299 randomly selected houses in total). This report (Year 7) is representative of 47% of NZ for the analysis based on the energy and temperature monitoring, and about 75% for the results based on the HEEP survey questionnaire.

Results from Years 1 – 4 reports should now be regarded as case studies only, and used with careful regard to the data from which they were drawn. For analysis reported from Year 5 and later, only the most up-to-date results should be used.

Status	*Report Year*	*Regions covered in report analyses*	*House count*	*Number of houses used for report*	*Percentage coverage of NZ*
Pilot	1	Wanganui, Christchurch	18	10 Wanganui, 8 Christchurch	Not a random, representative sample
Pilot	2	Wanganui, Christchurch	37	29 Wanganui, 8 Christchurch	
Pilot	3	Wanganui, Wellington	40	29 Wanganui, 11 Wellington non-random	
Pilot	4	Wanganui, Wellington	81	As Year 3 plus 41 random Wellington. Varied by analysis.	
Full	5	Wanganui, Wellington, Hamilton	109	As Year 4 plus 17 random Hamilton, 11 non-random Hamilton. Varied by analysis.	**13%** for analyses based on random sample. Still much non-representative analysis.
Full	6	Auckland, Hamilton, Wellington	160	As Year 5 plus 50 random Auckland	**37%** for analyses based on random sample. Some non-representative analysis
Full	7	Auckland, Hamilton, Wellington, Christchurch + other areas by questionnaire only	260	As Year 6 plus 47 random Auckland, 36 random houses Christchurch, 10 random houses Waikanae.	**47%** for analyses of temperatures and energy based on random sample. About 75% for analysis based on HEEP survey. Most analysis are representative, though the coverage varies
Full	8	As above plus half of the 'rest of NZ' sample	~300	As Year 7 plus half of the 'rest of NZ' sample	**75%** for analyses of temperatures and energy based on random sample. 100% for analyses based on HEEP survey. Most analysis will be representative, though the coverage will vary
Full	9	Complete	~400	Complete	**100%** monitoring and survey

Table 1: Coverage of HEEP annual reports

1.3 Locations

Previous HEEP reports have provided detailed background to the location and house selection procedures (see Section 2 in Stoecklein et al. (2002), and Section 1.8 in Isaacs et al. (2002)). Table 2 allocates each monitored location into a region and the NZS 4218 :1996 'climate zone'. It also provides a representative latitude and longitude, based on the named location, except where a nearby location has been used as noted. Location latitude and longitude have been taken from the 'New Zealand Atlas' (Ward 1976). Degree days to 15°C base for the months May to August (inclusive) are from the ALF documentation.

Island	Location	Latitude S	Longitude E	NZS4218 Zone	Degree Days Base 15°C (May-Aug)
Bottom NI	Arapuni	38.07	175.65	3	716
Bottom NI	Western Heights	38.13	176.22	2	798
Bottom NI	Ngakuru	38.33	176.18	2	798
Bottom NI	Mangapapa	38.65	178.02	2	592
Bottom NI	Rangatira	38.68	176.08	3	905
Bottom NI	Wairoa	39.05	177.43	2	612
Bottom NI	Tamatea North	39.50	176.87	2	612
Bottom NI	Wanganui	39.93	175.03	2	630
Bottom NI	Foxton Beach	40.47	175.23	2	701
Bottom NI	Waikanae	40.88	175.07	2	701
Bottom NI	Wellington	41.28	174.77	2	705
Top NI	Kaikohe	35.40	173.80	1	306
Top NI	Kamo West	35.68	174.28	1	372
Top NI	Sherwood Rise	35.75	174.37	1	372
Top NI	Orewa	36.58	174.70	1	510
Top NI	North Shore	36.80	174.78	1	510
Top NI	Waitakere	36.85	174.55	1	510
Top NI	Auckland	36.87	174.75	1	510
Top NI	Manukau	36.93	174.93	1	510
Top NI	Awhitu	37.08	174.63	1	369
Top NI	Parawai	37.13	175.55	1	460
Top NI	Minden	37.70	176.17	2	560
Top NI	Tauranga	37.70	176.17	2	560
Top NI	Hamilton	37.78	175.28	2	685
South I	Wai-Iti	41.43	173.00	3	907
South I	Seddon	41.67	174.07	3	836
South I	Christchurch	43.53	172.62	3	965
South I	Oamaru	45.08	170.98	3	947
South I	Dunedin	45.88	170.52	3	944
South I	Invercargill	46.42	168.35	3	1113

Table 2: Monitored locations by region

1.4 Research team

The HEEP research team will be considerably expanded in the coming year, so it is opportune to provide brief background details.

The research team is led by Mr Nigel Isaacs, with Dr Michael Camilleri, Mr Andrew Pollard and Ms Lynda Amitrano (BRANZ). Ms Kay Saville-Smith (will lead the social science component from 1 July 2003) and Ms Ruth Fraser (CRESA), Dr Pieter Rossouw (CRL Energy Ltd) (development of the national residential sector stock model), and Mr John Jowett (consultant statistician) will provide experimental design and analysis support.

- Nigel Isaacs (programme manager) has an extensive career researching building-related environmental and energy issues, including energy use in housing, offices, schools, hotels and hospitals. He has worked on renewable energy and the barriers to its use, the in-situ measurement of thermal insulation and a range of building evaluations of offices and hospitals, including the development of the Building Quality Assessment methodology for office and retail buildings. He led the technical work for the 1996 revision of the NZBC Clause H1 Energy Efficiency, and participated in the resulting three Standards NZ committees. He continues to advise both the BIA and EECA on energy use in buildings. He has worked on this project since 1996, and was previously a member of the EECA Advisory Board developing the concept.

- Andrew Pollard and Dr Michael Camilleri have worked on HEEP for the past eight and six years respectively. Andrew has particular interest in house temperatures and measurement methodology. Michael has investigated baseload and standby electricity. They have made numerous public and professional presentations on their work, and are both co-authors for all the HEEP annual reports.

- Lynda Amitrano has worked on HEEP since 2000, and manages the monitoring programme. Lynda has previously managed the implementation of two house energy assessment models (HERO and EnergyAssist) which BRANZ developed for ECNZ and is in wide use by electricity supply companies. The HEEP monitoring programme has employed and trained field staff (currently in Auckland, Waikanae and Christchurch) to ensure data quality; and university students, including a two-year appointment part-time worker to assist with monitoring and data pre-processing.

- Albrecht Stoecklein has research experience in a variety of fields - including research in nuclear physics, ground-water pollution and renewable energies. He has specialised in energy in houses over the past nine years. Recent publications include numerous reports for BRANZ projects, EECA, commercial clients and conferences. His work on the Annual Loss Factor (ALF) received a 'Highly Commended' award in the 2001 Energywise Awards. He is expected to rejoin in Objective 3 in July 2004, after completion of his current work investigation into Zero and Low Energy Houses (ZALEH).

- Ms Kay Saville-Smith will be undertaking the analysis of the determinants and relationship between household practices, the consumption of energy and comfort expectations. A social researcher and director of the Centre for Research, Evaluation and Social Assessment (CRESA), she has considerable research and policy experience in both housing and in the determinants of household decision-making. She leads two FRST funded programmes, notably *Sustainable Housing in Disadvantaged Communities* programme (RESX0202). She is a team member for the Health Research Council funded programme *Healthy Housing*. She undertook the social research around home maintenance practices for the BRANZ House Condition Survey and research into climate change and the construction industry (BRA805). She is the chair for the Home Ownership Working Party for the Social Housing Strategy being developed by HNZC. Her work on sub-standard and overcrowded housing in the Eastern Bay of Plenty was a key driver in the development of the Government's Low-deposit Rural Lending programme, the Kapa Hanga Kainga self-build housing policy and Rural Housing Programme.

- Ruth Fraser and Joe Cook will be working on the social science component of HEEP. Ruth is of Ngai Tahu descent. In addition to her role as co-ordinator across CRESA's research programmes, she also undertakes research in the area of justice and court processes, resource management, local government and service responsiveness. Joe will support the data analysis.
- John Jowett has over 20 years experience as a general statistical consultant, first in the Town and Country Planning Division of the Ministry of Works, then in the Applied Statistics (formerly Biometrics) Section of the Ministry of Agriculture and Fisheries. He has specialised in the design and analysis of sample surveys and field trials, and has been responsible for the design and analysis of several major national surveys. He has provided statistical design and support for HEEP since 1998.
- Dr Pieter Rossouw has been principal investigator, consultant and model developer for the Joint Venture Agreement on the Energy Efficiency Resource Assessment (EERA) Project, New Zealand, since 1995. Before coming to New Zealand he was with the Atomic Energy Corporation (Republic of South Africa) initially as a scientist (1969) and finishing as senior consulting engineer and head of the Division of Structural Analysis (1991). Dr Rossouw developed the EERA bottom-up energy end-use, energy efficiency and greenhouse gas model and database of the New Zealand economy. It has been used for a wide range of activities and clients (both commercial and government), including HEEP. Uses include the construction and analysis of energy-use and greenhouse gas scenarios and quantifying the impact of energy efficiency options on energy demand, energy supply and GHG emissions. Dr Rossouw has presented widely on this work, and is an internationally recognised expert on the development and use of such models.

1.5 Further information

In addition to the annual reports, members of the HEEP team regularly publish results from the work, speak at conferences in New Zealand and overseas, and provide presentations, radio and television interviews.

Section 12 (page 88) provides full references for a range of HEEP written material:

- HEEP Reports
- HEEP *BUILD* articles
- HEEP Conference Papers
- Other references.

The results from the HEEP analysis are readily available to full financial partners, who have access to published reports before they are released to the general market, and direct access to the HEEP research team. They can also discuss their specific needs with the team and discuss how the monitoring programme can best meet their needs.

HEEP analysis is also available to other interested groups. Please contact us and we will work with you to define your question and work out how HEEP analysis could best assist you. On request, your name can be included in our e-mail list providing HEEP results several times a year.

If you are interested in participating in any part of the HEEP work or would like further information about obtaining outputs customised to your specific needs, please contact the HEEP team at BRANZ:

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1.6 Acknowledgements

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- *Energy Efficiency and Conservation Authority (EECA)*
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- Jean Simpson, **Injury Prevention Research Unit, University of Otago**
- Peter Faase, **Rheem N.Z. Ltd**
- Ann Weaver & John Wren, **Safekids**, Auckland
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- Prof. Arthur Williamson, **Thermocell Ltd**
- Rob Westcott, Water Demand Management, **UK Environment Agency**
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2. RESEARCH OVERVIEW

Each HEEP annual report has included a discussion of future plans. Each year these plans have been contingent on the availability of funding to ensure not only the data collection could be carried out, but also the necessary science support, analysis and model development could occur. The funding situation remains uncertain for data collection, with support continuing from the Building Research Levy, EECA and Transpower. The New Zealand government agency responsible for allocation of research funds, the Foundation for Research Science and Technology, has agreed to fund the essential science for the next four years – with completion due by 30 June 2007[i]. This will ensure that the HEEP planned work can be completed. The following section provides a more detailed outline of the HEEP research plan for the coming four years.

2.1 National overview

The domestic sector consumes 13% (60 PJ) of New Zealand's energy (MED 2002a), and 33% of all electricity, with consumption growing at over 2% p.a. The domestic sector is a major contributor to peak demand which must be met by thermal generation, with a consequent impact on greenhouse gas (GHG) emissions. The residential sector accounts for about 10% of New Zealand's CO_2 emissions (MED 2002b) (directly for 1.6% and indirectly for at least 8% from thermal electricity generation).

As consumption grows, the negative economic, social and environmental effects increase, so finding ways to reduce energy demand, GHG emissions, and use energy more efficiently becomes critical. However, if strategies to reduce energy demand result in lower indoor temperatures and increased damp the outcomes may be undesirable. Mould is associated with damp and low indoor temperatures, as are a number of health problems. The problems arising from inadequate indoor temperatures and damp within the residential sector can have significant costs for households, the government and the economy.

Understanding the residential sector is critical to improving the national energy efficiency and reducing greenhouse gas emissions. Despite that, HEEP is the only research establishing a model of energy use in domestic dwellings and the only program to collect the data fundamental to understanding and promoting energy efficiency in the home. The other sectors of the economy (commercial, industry, agriculture and transport) also require this fundamental data, but work has yet to commence.

For the residential sector, then, the goal must be increased energy efficiency and minimising energy demand while also ensuring: (a) satisfactory perceived levels of comfort; and (b) healthy temperature and moisture levels in residential dwellings.

Designing and implementing interventions to achieve that goal is inhibited by our limited knowledge of the dynamics of residential demand for energy. The energy supply (electricity, natural gas, LPG, wood, coal, oil etc) is well understood and documented, but the same is not true for the residential demand for energy.

HEEP will assist in the management of residential demand by improving the utilisation of residential energy through improved understanding of energy end-use from a range of

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[i] Further information on the funding process and structure can be found on www.frst.govt.nz

viewpoints, including the house construction, appliance use (including the hot water system) and the socio-economic and demographic characteristics of households.

Each 1% improvement in the efficiency of energy use in New Zealand homes would result in a benefit of $17 million (Statistics NZ 2001) and reduce national CO_2 emissions by 0.1% (MED 2002b). The attained benefit will depend on the policy decisions taken. The HEEP Energy Model will provide clear guidance on the 'best' areas for action and the likely consequences, thereby maximising the potential benefits. It will also lead to improvements in the design, construction and utilisation of New Zealand houses to enable them to meet the comfort expectations of all classes of occupants in the most energy-efficient way.

2.2 Background

Residential heating energy demand is a complex function of technical, economic and social issues. The energy use is related, in part, to the thermal efficiency of dwellings (technical), and, in part, to the occupant's expectations and desires about, and ability to manage, indoor temperature levels (social). But this is complex dynamic mediated by a number of cultural, social and economic factors.

The clearest evidence of the importance of social practice is found in the decline of the whare in the post-colonial period. Māori traditionally constructed their dwellings of "raupo walls and [a] nikau roof" (see Figure 3) . The resultant thermal resistance of about R 2.1 would even today meet the 2000 energy efficiency requirements of the New Zealand Building Code. Early European bush settlers copied the same method to create a 'warm, weatherproof dwelling' (Allen 1883). The subsequent replacement of raupo reeds by timber-slab and then timber-framed construction arose out of socio-cultural factors, not because the timber technology was any more thermally efficient.

Figure 3: Raupo reed hut

Sealed cavity, timber-frame wall construction provided a thermal resistance of only about R 0.6. After 1945, economic factors drove the use of wet timber with a vented cavity and the thermal resistance of the typical New Zealand dwelling wall declined further to R 0.3 (Bastings & Benseman 1950). There were dramatic increases in mould and moisture problems (Bastings 1947). Thermal insulation was suggested to combat those problems, but it was not until the oil and electricity crises in the 1970s that building energy efficiency became of general interest. Legislation requiring thermal insulation only started in 1978 (Isaacs 1993), and was updated in 2000 (Isaacs 2001) - requiring a wall thermal resistance which had been achieved a 150 years before by the tangata whenua.

Thermal insulation is now required in all new homes, and retrofitted to many older houses. Underpinning this requirement for all new homes are two important assumptions:
(a) That higher thermal resistance will lead to higher energy efficiency and positive energy consequences (i.e. little or no "takeback"[ii]); and,
(b) That higher thermal resistance will lead to increased comfort and indoor living temperatures.

The reality is that we have little understanding of the energy consequences or takeback.

Previously, the only national data on conditions in New Zealand homes came from the 1971/2 'Household Electricity Survey' which found mean temperatures of 16.3°C in kitchens, 15.8°C in lounges and 14.4°C in main bedrooms (Statistics 1976). These are below those recommended by the World Health Organisation (WHO). WHO advises that living area temperatures below 16°C increases the risk of respiratory diseases (WHO 1987).

NZ has not had the same depth of discussion on the health consequences of such low indoor temperatures as countries with cooler climates (Boardman 1991), but it has been suggested that higher winter (seasonal) mortality may be associated with low indoor temperatures (Sakamoto-Momiyama 1977). NZ has higher seasonal mortality than in other developed countries (Isaacs & Donn 1993). The preliminary findings of this research indicate that indoor temperatures are persistently low in New Zealand houses, but are higher in newer, insulated houses (Isaacs et al. 2002).

2.3 Research design

The HEEP database will be a robust, statistically sound sample of New Zealand houses that will provide both a critical energy use database and a platform for modelling the energy performance of New Zealanders in their domestic dwellings. The FRST funded research consists of three objectives:

Objective 1: Energy use in residential buildings
Objective 2: Energy demand
Objective 3: Promotion of residential energy efficiency (to commence 1 July 2005)

A brief overview of each objective is now provided:

Objective 1: Energy use in residential buildings – this provides science support to the separately funded monitoring and data collection from 100 houses per year. This includes experimental and statistical design and review, sensor calibration, data validation and checking and database design. There is a critical social research component in this objective which involves the collection and analysis of household characteristics, behaviours and practices in relation to the main components of household energy use: perceived comfort, the maintenance of the dwellings thermal

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[ii] 'Takeback' occurs when the same energy is used but a different benefit is taken – a warmer building, perhaps.

resistance, and energy use. The HEEP database of energy use, construction, air and water temperatures from 400 randomly selected houses from around New Zealand, will be completed in mid-2005.

Objective 2: Energy demand model – the HEEP model will build on best international practice, and HEEP-monitored data to create a model of domestic energy demand. As shown in Figure 6 two key components of this model are the:

- House energy model: the ALF[iii] calculation engine (Stoecklein & Bassett 1999) will be tested against monitored data from 100 houses and then modified for alternative temperatures and heating regimes. The resulting engine will be developed to work with the EERA model;
- NZ Housing sector model: based on the residential sector of the EERA model (for example, see Rossouw 1999, Rossouw et al. 2000). This will link to the ALF engine, and include sub-models for 'hot water' and a limited number of different 'appliance' energy uses. As additional data comes available from the HEEP monitoring, it will be included in the EERA model.

The social analysis will establish (using Objective 1 data and additional investigations) variations between households, perceived comfort and behaviours that can increase or decrease dwelling energy-use. The focus will be on establishing whether and why variations arise systematically in relation to household characteristics (e.g. stage in the life cycle, household composition, the age, sex, or ethnicity of household members, size, location, income, employment status, etc), and the results used to underpin the model and user options.

Objective 3: Promotion of residential energy efficiency – this will involve:

- preparing a 'report of record' on the monitoring and database
- testing options for development of the HEEP model with stakeholders, such as the organisations that are already engaged with the program as outlined in Figure 4, to ensure that it is accessible to a wide range of end-users
- further scoping of the range of key stakeholder interests in energy-use models. Emphasis will be placed on extending the knowledge pathway beyond the end-users already engaged to: community based end-users (such as Energy Trusts and communities looking to increase household disposable incomes through energy efficiency); government agencies with an interest in intersection between dwelling comfort, health and the well-being of households (such as the Housing New Zealand Corporation, Ministry of Social Development, the District Health Boards and local government)
- Developing a range of other analysis and reports, as well as international publication of the results
- Preparing a 'report of record' on the background, methodology and use of the 'HEEP Residential Sector Energy Model'

Those strategies will ensure that the results of the HEEP Residential Sector Energy Model will be widely disseminated, and the feedback used to improve its functionality.

[iii] ALF is a tool accepted by BIA as a verification method for assessing the compliance of building designs with the energy efficiency requirements of the NZ Building Code.

2.4 Science priorities

HEEP fits well in the NZ Government's current science priorities. It will provide the knowledge platform critical to the 'sustainable use of natural resources' and wealth creation through 'improving the efficiency of New Zealand's resource utilisation', as well 'reducing greenhouse gas emissions from energy production' - issues at the heart of the 'Energy Strategic Portfolio Outline (SPO)'[iv]. It builds on links to research programmes being undertaken within the Built Environment and Construction SPO and the construction industry's strategic research plans set out in 'The Built Environment Research Agenda' (Construction Liaison Group 2002).

The research programme demonstrates a strong fit with the portfolio change messages in the Energy SPO. These seek reduced CO_2 levels, more efficient use of energy, partnerships and co-funding with industry.

- **Economic Horizons**: The program is working at the H1 (value recovery) and H2 (value addition) as it seeks to both understand the current energy end-use situation and develop new business opportunities through improved fundamental knowledge. It also seeks to provide knowledge to assist house occupants to improve their efficiency of energy use.

- **Infrastructure profiling**: In 1978, the guest editor of the first study of house energy use could note they knew more about 'the thermal and environmental behaviour of a spaceship than … about a domestic dwelling' (Tuttle 1978). This is still true in New Zealand. This research is concerned with **fundamental knowledge generation** as to the use of energy in New Zealand homes, e.g. the work on standby power quantified a previously unconsidered issue. Such knowledge is available for energy supply but not energy demand. It is involved with identifying **socio-economic impacts** – a complex interaction of the occupants, their house, the appliances and the climate.

- **Māori responsiveness**: Māori households have particular concerns with the energy efficiency of their homes for three reasons. Firstly, Māori are bearing the health burden of housing-related poor health. This is connected with myriad problems, such as over-crowding, but more particularly the apparently high incidence of damp and mould in Māori occupied dwellings. Second, because Māori households tend to be the most economically disadvantaged in NZ, the burden of high energy costs and the benefits of energy savings may have significant impacts on the disposable incomes of Māori households. Third, Māori are particularly exposed to housing in poor condition and/or with poor thermal resistance. Understanding the dynamics between the dwelling, household practices and energy use will provide Māori with critical information to assist them to target energy efficiency strategies to either changing household practice or to addressing poor housing conditions (or a mixture of both).

- **Social knowledge themes**: This program will make a critical contribution to our understanding of the way in which households relate to the built environment and, in doing so, make decisions about energy consumption. It will build on the work that CRESA has already developed through collaborative arrangements with BRANZ in the area of house condition surveying, home maintenance and environmental risk management and environmental prioritisation. The integration of social research with

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[iv] See http://www.frst.govt.nz/about/spo/Energy.pdf.

> technical research in the performance of dwellings, other buildings, energy consumption and household practice is generating real interdisciplinary research capabilities. In doing so, this program will be a critical contributor to providing the evidence platform necessary to designing and implementing interventions to increase energy efficiency and minimise energy demand while also ensuring: (a) satisfactory perceived levels of comfort; and (b) healthy temperature and moisture levels in residential dwellings.

The value of the HEEP research was recognised by the 1996 Official Review of Energy Statistics, which found 'there is a strong case for gathering more information' on household energy use, and supported the HEEP research approach (by name) with a focus on how to 'determine a suitable segmentation pattern.' (Statistics NZ 1996) HEEP was recognised in the development of the 2006 Census as an additional data source on household heating fuels (Statistics 2003). HEEP will also address the inadequacies of energy end-use data sets in NZ which have inhibited the development of targeted and effective policy responses (Schipper et al. 2000).

Since its implementation in 1994/5, the HEEP programme has developed strong links with key policy agencies. The Parliamentary Commissioner for the Environment's 2000 review of progress on energy efficiency and renewable energy initiatives (PCE 2000) recommended to the Minister for Energy that the level of funding for HEEP needed to be reviewed to ensure that the program could continue to meet the critical need for comprehensive household energy end-use data and analysis.

Figure 4 illustrates the range of uses to which the data, modelling and analysis from this program can be put. Because the program allows on-going, incremental data analysis, end-users are already integrating early findings and data into their policy and operational planning.

They include the **National Energy Efficiency & Conservation Strategy (NEECS) (EECA 2001)** which lists HEEP as a specific output activity, noting that the 'most realisable energy efficiency gains over the next five to 10 years will come from improving the existing stock' and EECA's **Residential Grants Scheme** administrators in applying their allocation methods.

The HEEP research matches with main priorities identified by the **National Science Strategy Committee on Climate Change** including 'behavioural issues affecting energy supply and use' and 'development of building codes that improve the long-term performance of buildings' (NSSCCC 2001). It will thus support the government's **Climate Change Policy** development and implementation of Kyoto Protocol greenhouse gas emission control strategies.

Figure 4: Users of HEEP results

Other end-uses to which the program outcomes will be critical inputs include: **Building Industry Authority's** (BIA) future development of New Zealand Building Code Clause H1: Energy Efficiency. The 1996 revision of Clause H1 identified a number of issues for future consideration, including a need for measured information on how and why energy is used in homes (Isaacs et al. 1996); **BRANZ** and the **construction industry** for the future development of ALF (Stoecklein & Bassett 2000), the Green Home Scheme and other energy or environmental design or assessment tools, which in turn lead to improved guidance to architects, property developers, major rental organisations etc.; those in the **electricity marketplace** interested in the user of time-of-day 'profiles'; suppliers and users of residential **distributed generation technologies** – the preliminary results are already being used to investigate opportunities under the portfolio 'New and Emerging Energy Technologies' to develop a 'Zero Energy House'[v]; **appliance developers, suppliers and government regulators** interested in either voluntarily improving the energy performance of their products, or the application of mandatory Minimum Energy Performance Standards (MEPS) or energy labelling; and policy developers working on **health and housing.**

The results will also provide essential baseline data for other activities, e.g. for the HRC-funded research examining links between health and housing, or for policy development, e.g. local government and central government agencies interested in reducing localised pollution due to household energy use. The research team is regularly in discussion with such a wide range of research users and stakeholders.

2.5 Research programme

Figure 5 provides a programme overview, with the current position indicated by the dotted line. HEEP started in 1994/95 with the development of a conceptual model of house energy-use based on the 1971/72 household electricity study and international research. An experimental design and a pilot monitoring study followed, using innovative monitoring equipment. Some of this, designed and built specifically for this program, is now used in other BRANZ research. The monitoring programme is generating required energy-use data and analytic tools. In 2001 monitoring increased from 40 to 100 houses per year.

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[v] For further information, see the BRANZ web site www.branz.co.nz/main.php?page=ZALEH

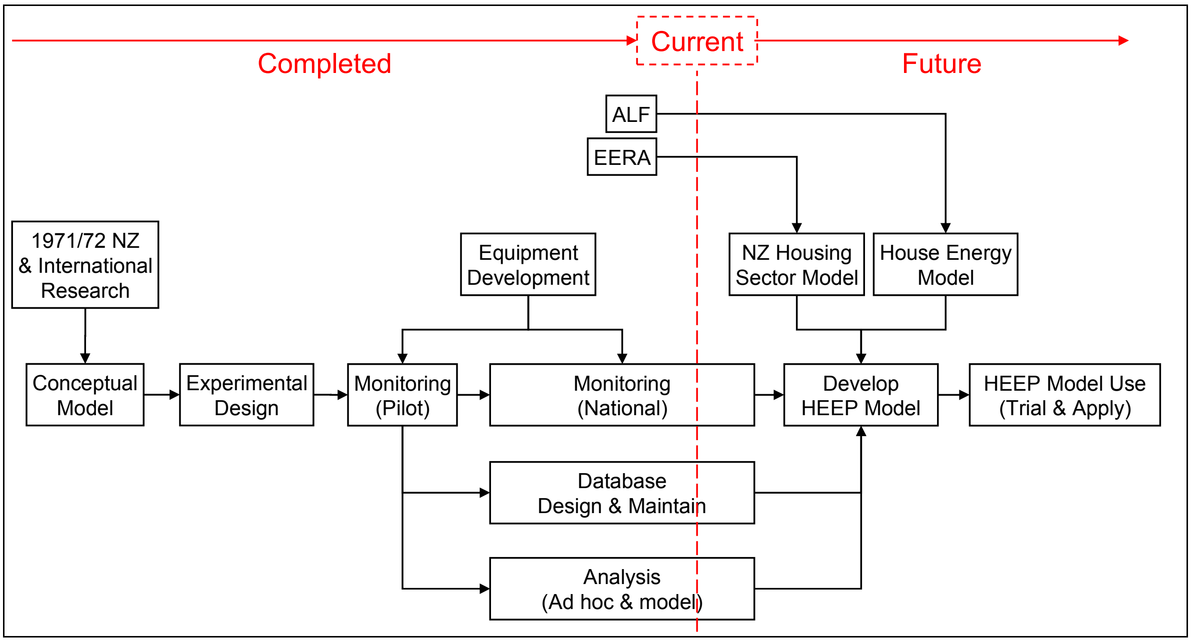


Figure 5: HEEP overview

The next innovative step is to integrate the calculation engine from the Annual Loss Factor (ALF) tool as the house energy model, with the Energy End-use Resource Assessment (EERA) model of the NZ energy economy to provide a basis for the development of the residential sector model. EERA is already being used by CRL Energy Ltd, Transpower and EECA to provide computational energy management policy and research services to the energy supply and distribution industry, energy policymakers and other customers.

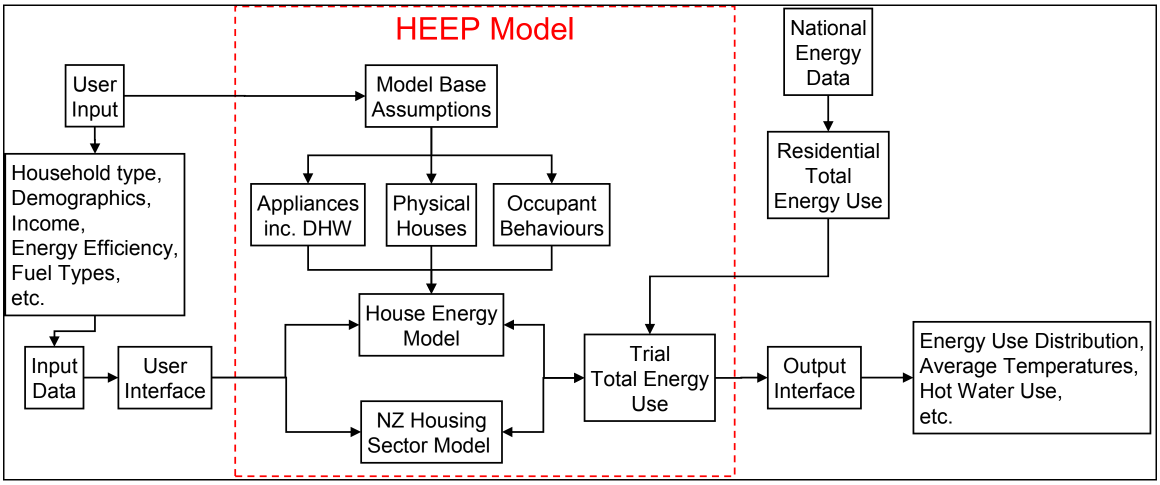
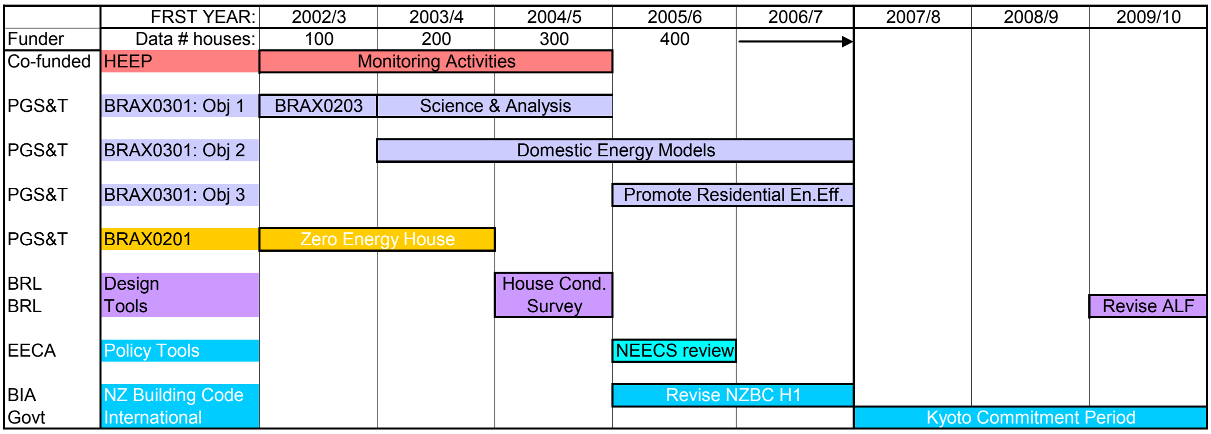


Figure 6: HEEP Residential Sector Energy Model – Overview

Figure 6 illustrates the expected use and structure of the currently proposed HEEP model. The intention is for the user to enter key base data, including household socio-economic and demographic data (such as household and family types, income), the fuel types available (e.g. natural gas, electricity), etc. This data is fed into the model through the user interface. Based on the results of the HEEP data collection and monitoring, and the stock model, a wide range of base assumptions are built into the HEEP model, but the user is able to adjust them as appropriate.

The HEEP model is expected to include both a house energy sub-model and a NZ housing sector sub-model, both of which will be used inter-actively within the overall model to balance with the residential total energy use sourced from national energy data. The output interface will provide the results, which could include an estimate of average temperatures for different housing classes, the energy use distribution, the hot water energy use etc, in an appropriate format.



	FRST YEAR:	2002/3	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10
Funder	Data # houses:	100	200	300	400	→			
Co-funded	HEEP	Monitoring Activities							
PGS&T	BRAX0301: Obj 1	BRAX0203	Science & Analysis						
PGS&T	BRAX0301: Obj 2		Domestic Energy Models						
PGS&T	BRAX0301: Obj 3				Promote Residential En.Eff.				
PGS&T	BRAX0201	Zero Energy House							
BRL BRL	Design Tools			House Cond. Survey					Revise ALF
EECA	Policy Tools				NEECS review				
BIA	NZ Building Code				Revise NZBC H1				
Govt	International						Kyoto Commitment Period		

Figure 7: Timetable overview

Figure 7 provides an overview of the work program. HEEP monitoring (100 houses per year) will be completed in early 2005, with the next three years building on the analysis undertaken during the monitoring years to develop the two key parts of the HEEP model. The final year is concerned with demonstration and knowledge transfer, ensuring the benefits of the work and model are made available to the widest possible range of users.

3. HEALTH AND HOUSING

Buildings play a critical role in the provision of indoor environments to support the well-being and health of the occupants. This has been recognised throughout the various legislative systems established to control buildings. This section reviews the different aspects of health covered internationally by building control legislations, and then describes one seasonality method of examining the impact of climate on the public health. This method is applied, and the results reported for a number of selected countries, as well as age-specific results for the east coast of Australia and all of New Zealand. To conclude, a brief review of international and NZ work on linkages between health and housing is provided.

3.1 Building controls and health

Table 3 gives the 'Purposes' of the current New Zealand Building Act 1991, and Table 4 provides an extract from the proposed Building Bill (introduced to Parliament on August 29, 2003)[vi]. A similar philosophy supports the Building Code of Australia (BCA) 1996 edition, as given in Table 5 (ABCB 1996), and the UK Building Act 1984, given in Table 6.

6. Purposes and principles

(1) The purposes of this Act are to provide for—

(a) Necessary controls relating to building work and the use of buildings, and for ensuring that buildings are safe and sanitary and have means of escape from fire; and

(b) The co-ordination of those controls with other controls relating to building use and the management of natural and physical resources.

Table 3: NZ Building Act 1991 – Purpose

3 Purpose

The purpose of this Act is to provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings, to ensure that—

(a) people who use buildings can do so safely and without endangering their health; and

(b) buildings provide an appropriate level of amenity for people who use them; and

(c) people who use a building can escape from the building if it is on fire; and

(d) buildings are constructed and used in ways that promote sustainable development.

Table 4: NZ Building Bill 2003 – Purpose

The goals of the BCA are to enable the achievement and maintenance of acceptable standards of structural sufficiency, safety (including safety from fire), health and amenity for the benefit of the community now and in the future.

Table 5: Building Code of Australia - Goals[vii]

1 – (1) The Secretary of State may, for any of the purposes of:

(a) securing the health, safety, welfare and convenience of persons in or about buildings and of others who may be affected by buildings or matters connected with buildings,

(b) furthering the conservation of fuel and power, and

(c) preventing waste, undue consumption, misuse or contamination of water,

make regulations with respect to the design and construction of buildings and the provision of services, fittings and equipment in or in connection with buildings

Table 6: UK Building Act 1984 - Purpose[viii]

[vi] Available from: http://www.med.govt.nz/buslt/bus_pol/building/review/bill/index.html (October 2003)

[vii] Source: www.abcb.gov.au

[viii] Source: Building Act 1984

The topics considered by building controls tend to be limited to those having immediate, or at least short-to-medium term, impacts. Raw & Hamilton (1995) reviewed, from a UK perspective, the issues of health that a building can affect or control. They developed a summary table of the health hazards, ranked in order of risk – summarised in Table 7 for housing. It is important to note that not all of these risks apply equally to all countries or locations, and that many of the risks are minimised by the controls and standards that are in use today.

Highest risk
Hygrothermal conditions Radon (not NZ issue) House dust mites Environmental tobacco smoke Carbon monoxide
Second level of risk
Fungal growth Smoke Security and the effects of crime Noise Lead
Third level of risk
Sanitary accommodation Other sources of infection Space Volatile organic compounds Particulates
Fourth level of risk
Sulphur dioxide and smoke Landfill gas Pesticides
No clear basis for risk assessment
Lighting Electromagnetic fields

Table 7: Health risks and housing

The risk assessment attempts to rank the various health hazards, based on the number of severity of health outcomes, with a greater weight given to the numbers of deaths or where the evidence is stronger. A common theme is the complex interactions between health and buildings – people experience the whole environment rather than just one part. For example, a poorly insulated home with inadequate heating might not only be cold, but also give rise to damp conditions that facilitate the survival of airborne pathogens and the growth of moulds and other fungi. This would probably be made worse if the household introduced unflued gas heaters, which would also increase the risk of ill effects of combustion products. Each of these conditions has direct health consequences, and in isolation may have no negative health effects. It is the combination that is less well understood, and offers perhaps the greatest challenge to future research and practice.

Ranking top of Raw & Hamilton's list are 'hygrothermal conditions' – temperature and relative humidity. Relative humidity (RH) is closely tied to temperature. Colder air can hold less moisture, so for a given amount of water the RH will be higher than if the air was warmer.

Detailed information on the conditions in a random selection of New Zealand homes is limited in the main to the results of the HEEP research. This evidence suggests temperatures are lower than would be expected in other developed countries. Other research would suggest that such lower temperatures are likely to impact on the health of the occupants.

3.2 Seasonal mortality

After examination of the patterns of death across the year in a number of countries, the Japanese medico-geographer, Sakamoto-Momiyama (1977), noted that in countries with severe winter conditions, e.g. Sweden, winter deaths were no more prevalent that deaths occurring in other seasons of the year. She hypothesised that this was due to warmer indoor winter temperatures resulting in a decrease in the numbers of winter deaths – a reduction in the 'seasonal mortality'.

In 1993 Isaacs & Donn reported on an investigation into New Zealand's seasonal mortality, and found it higher that the five other countries investigated – Australia, the UK, the USA, Sweden and Japan. This seasonality was particularly pronounced for the very young (0 to four years of age) and the elderly (over 65). They reported that only limited data was available on the winter temperatures maintained inside New Zealand homes, with only three research sources being available:

- **1971 nationwide survey of 1,651 houses** found during the two-month period August to September 1971, mean temperatures were 16.3°C for the kitchen, 15.8°C for the lounge and 14.4°C for the main bedroom (Department of Statistics 1976)

- **1986 nationwide study of 28 houses** found average winter internal temperatures ranging from 13.7°C to 16.3°C (Breuer 1988)

- **1989 study of 36 units for the elderly** in Blenheim found that more than one-third of the minimum daily temperatures for the year were below 16°C (Isaacs & Donn 1990).

HEEP, in conjunction with other research projects, is now providing temperature data on a range of New Zealand homes. HEEP also provides an opportunity to update the seasonal mortality analysis for New Zealand.

A number of methods for examination of the seasonality of mortality are available (e.g. Sakamoto-Momiyama 1977, Freedman 1979, Edwards 1961). Edwards' method, as modified by Walter and Elwood to allow for unequal lengths of time sectors of a cycle of seasons, has been used (Walter & Elwood 1975).

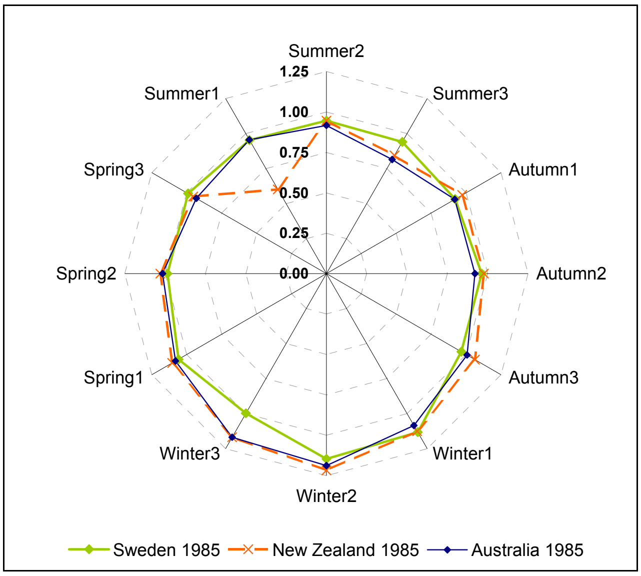


Figure 8: New Zealand, Australia and Sweden – 1985 mortality distribution

In outline, the modified Edwards method represents monthly data as weights placed at 12 equally-spaced points around a circle of unit radius. If the number of deaths is spread evenly across the year, then the centre of gravity of the 'weights' is the centre of the circle. A 'D' parameter is generated which measures the shift in the centre of gravity from the centre. The greater the value of 'd', the greater the seasonality of mortality.

The method has been programmed using the SAS© statistical analysis system, including the generation of a Chi-squared test of the significance of the value of the 'D' parameter. A 1% significance level was selected.

Monthly data for use in the analysis was kindly provided in electronic form by the Demographic Statistics Section of the UN Statistics Division, New York (United Nations 2003)

Figure 8 provides, as an example, the monthly mortality proportions for the New Zealand, Australia and Sweden for the five years from 1985 to 1989 (inclusive). To match seasons, June in the northern hemisphere has been matched with December in the southern hemisphere, and named 'Summer1', and so on for the other months.

The 'D' values for Figure 8 are 0.046 for New Zealand, 0.032 for Australia and 0.023 for Sweden. The 'dip' in monthly mortality for New Zealand in the Summer1 (December) has been a feature for many years, as shown in Table 8. Table 8 reports monthly mortality in thousands of deaths per month, averaged for the five years following the given year. Examination of the individual years revealed this December 'dip' stops in 1991.

Average '000/mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	1.9	1.7	1.9	1.9	2.1	2.2	2.5	2.4	2.2	2.1	1.8	1.4
1975	1.9	1.7	1.9	1.9	2.2	2.3	2.5	2.4	2.2	2.1	2.0	1.2
1980	2.0	1.8	2.0	2.0	2.2	2.3	2.5	2.5	2.2	2.2	2.0	1.3
1985	2.1	1.9	2.1	2.1	2.3	2.5	2.7	2.6	2.4	2.3	2.1	1.3
1990	2.0	1.8	2.0	2.1	2.3	2.4	2.6	2.6	2.4	2.3	2.1	2.0
1995	2.1	1.9	2.2	2.1	2.3	2.5	2.9	2.7	2.5	2.3	2.2	2.2

Table 8: NZ average monthly mortality 1970 to 2000

3.3 International comparison

Figure 9 plots the 'd' parameter for total mortality for Japan, the UK, Australia, New Zealand, the USA and Sweden. This has been calculated using the monthly mortality data provided by the Demographic Statistics Section of the UN Statistics Division. To minimise the year-on-year fluctuations, the monthly mortality has been averaged over the five years commencing with the year reported on the graph, i.e. the seasonality of mortality 1970 through 1974 (year starting January) is reported under '1970'. To assist interpretation, lines have been used to link points representing a single country.

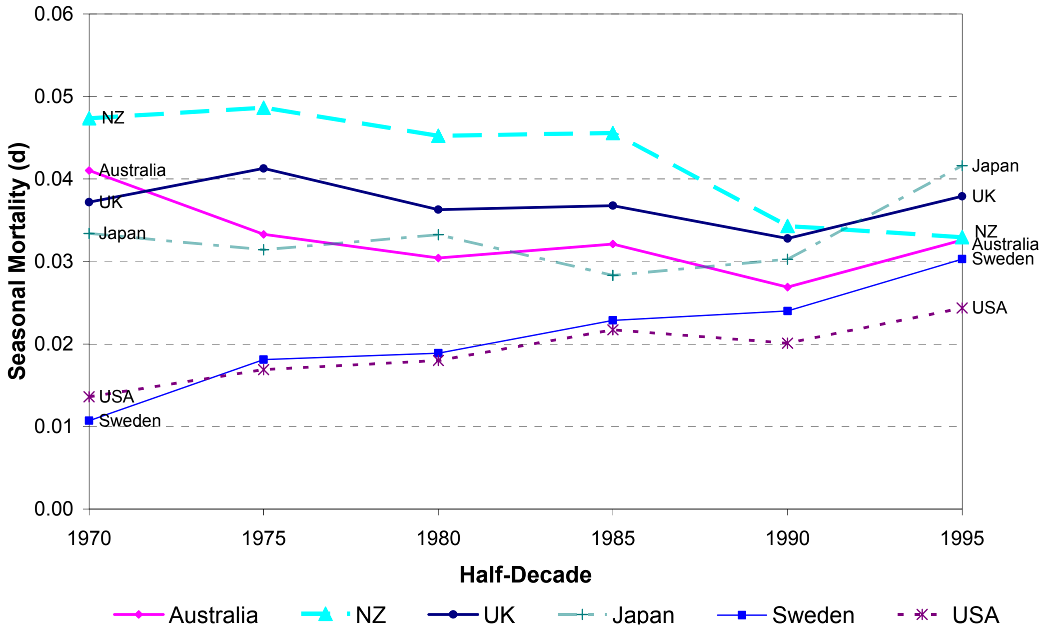


Figure 9: Seasonal mortality 'd' parameter 1970 to 2000 by country

Figure 9 shows that over the 30-year period from 1970 to 2000 there has been a steady increase in the seasonality of mortality in the USA and Sweden, Japan and the UK have remained reasonably constant, and in both New Zealand and Australia it has been decreasing. All 'd' values are significantly different from the hypothesised null value, implying that all these countries have some degree of seasonality of mortality.

3.4 Australia and New Zealand comparison

The steady reduction in seasonality for Australian and New Zealand in Figure 9 will now be examined in greater detail. Figure 10 (based on the UN data) plots the 'd' parameter for these two countries on an annual basis, based on the calendar year i.e. January to December. A linear regression line has been fitted to illuminate the trends, which in both countries is towards a reduction in the seasonality of mortality.

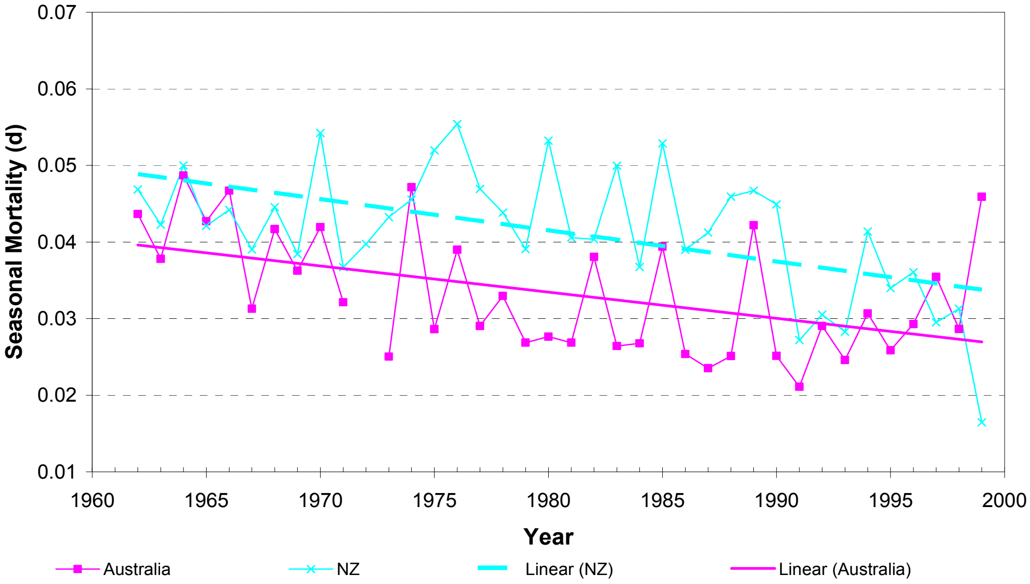


Figure 10: Seasonal mortality 'd' parameter, Australia and New Zealand 1962-1999

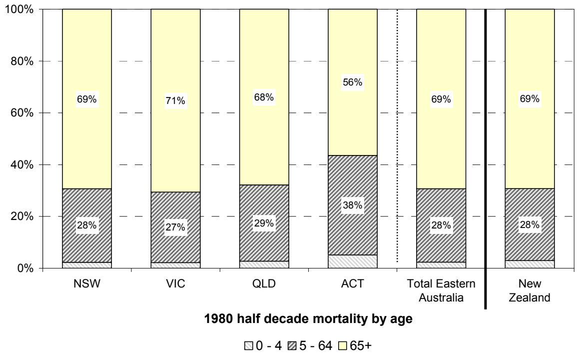
To further investigate this pattern in both Australia and New Zealand, age-specific monthly mortality data was obtained. New Zealand data was provided by the Public Health Directorate of the NZ Ministry of Health (data provided 24 July 2001), and Australian data by the Information Consultancy Service of the Australian Bureau of Statistics (24 June 2003).

As Australia has a wide range of climate zones, to provide maximum compatibility the eastern coast was selected for comparison – New South Wales (NSW), Australian Capital Territory (ACT), Victoria (VIC) and Queensland (QLD). The data shows wide fluctuations, year-on-year, and thus it was amalgamated into half decades, named by the first year – i.e. **1980** = 1980-1984 inclusive, **1985** = 1985-1989, **1990** = 1990-1994, **1995** = 1995-1999.

About 45% of the deaths in any given half decade occurred in NSW, 33% in Victoria, 20% in Queensland and 1% in ACT. The total mortality for these eastern Australia states is about 3½ times the total mortality of New Zealand.

Three age groups were selected – 0 to four; five to 64-years and 65 plus. The proportion of deaths in each of the age groupings for the 1980 and 1995 half decades are given in Figure 11 and Figure 12. The figures give the age-specific proportions for the individual states and territory, total eastern Australia and total New Zealand

As would be expected, the greatest proportion of deaths is in the 65-plus age group – in the 1995 half decade ranging from 70% in ACT to 79% in Victoria. The low number of deaths in the 0-four age group (e.g. in 1995 half decade there were only 130 deaths in the 0-four age group in ACT, and 6267 in the ACT and the selected states) leads to variations in the proportions. The different, and changing, age demographic of the states, territory and country are also reflected in the differing age group mortality proportions.



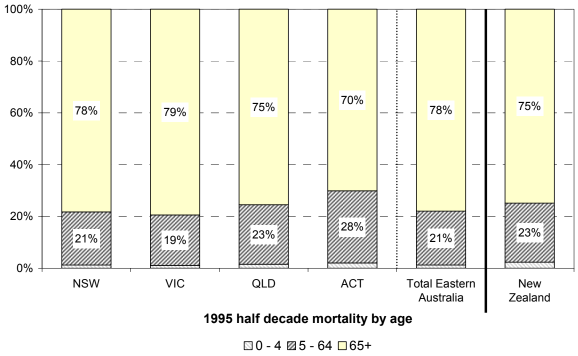


Figure 11: 1980 half decade mortality by age group and state / country

Figure 12: 1995 half decade mortality by age group and state / country

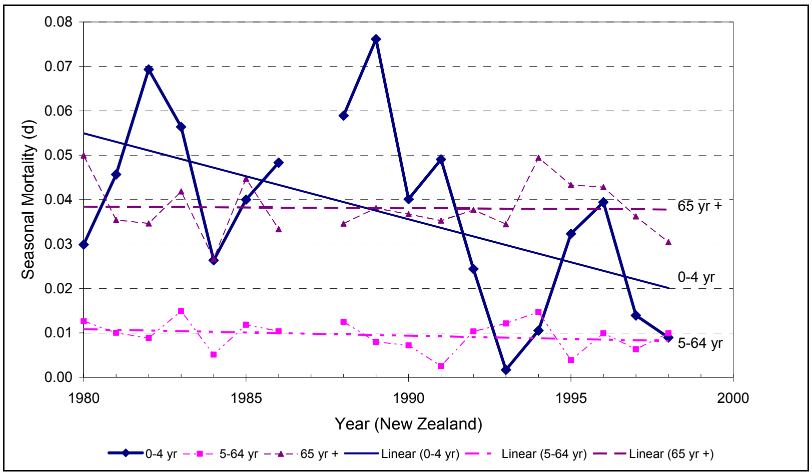


Figure 13: New Zealand age-specific ‘d’ parameter

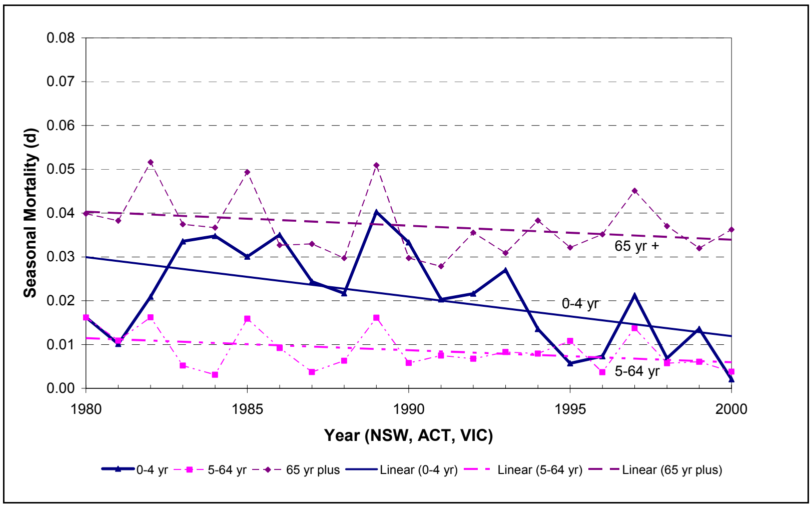


Figure 14: Eastern Australia age-specific ‘d’ parameter

Figure 13 (New Zealand) and Figure 14 (Australia) plot the age specific seasonal mortality ‘d’ parameter. There are fluctuations from year-to-year, and a linear regression line has been fitted to draw attention to the overall trend. For both graphs, the greatest fluctuations are in the 0-four age group, which as noted above is also the lowest mortality.

Figure 13 shows that for New Zealand only the 0-four age group is demonstrating a strong downward trend, although a small downward trend is apparent in the other age groups.

Figure 14 shows that for all three Australian age groups, seasonality is decreasing. The reduction is greatest for the 0-four age group, but the other two groups are showing a greater decline than is the case for New Zealand.

It should be noted that the reduction in seasonal mortality has occurred at a time of increasing total mortality – for eastern Australia from 93,163 in 1962 to 122,730 in 1999, while for New Zealand the total deaths increased from 21,496 in 1962 to 28,122 in 1999 – in both countries a 31% increase in total mortality.

3.5 Role of energy efficiency

The laws of physics establish the potential for improved household energy efficiency – increasing the levels of thermal insulation will improve the thermal performance of the house, and in turn result in higher indoor temperatures for the same amount of energy (see Section 5.3.4). In addition to the obvious energy benefits, there are a range of other benefits from improved energy efficiency.

There is now an increasing number of international and New Zealand research projects investigating the wider benefits of energy efficiency.

3.5.1 International

Schweizer & Tonn (2002) undertook a literature review that examined the non-energy benefits of improved energy efficiency retrofits for the USA. They found that these benefits included:

- reduced water consumption, water and sewer fees, and an increase in property values
- reduced costs for bill collection and service shut-offs, as well as fewer emergency calls
- improved comfort and health
- local home service industry employment
- improved national security through reduced need to produce or import energy
- less emissions and use of fossil fuels

They found that for each dollar invested in improving the energy performance of low-income households, there was US$1.83 of energy benefits and US$1.88 of non-energy benefits – giving a US$3.71 return for each US$ investment.

Included in this value is monetary benefit for improved health (no monetary benefit was allocated to improved comfort). Schweizer & Tonn (2002) report that the net present values in the literature for fewer illnesses range from a low of $US 0 to a high of $US 2191. They use a point estimate of $US 55. This was calculated using the method described in Skumatz (2001). Skumatz developed a point estimate for the benefit of fewer illnesses associated with low-income weatherisation efforts, based on survey findings regarding the number of lost workdays avoided and an assumed average wage earned by the affected workers.

Levy et al. (2003) focused on the health benefits associated with the marginal energy use reduction which could be expected from insulation retrofits in single-family homes in the USA. They found that the reduction in energy use would lead to reduced pollution – either directly from the direct use of natural gas or fuel oil, or indirectly through reduced electric generation. The reduction in energy use in turn would result in reductions in emission of particulates, nitrogen oxides (NO_x) and sulphur dioxide (SO_2), which in turn would lead to fewer air pollution related deaths, fewer asthma attacks and fewer ‘restricted activity days’. Over the entire US they found the health benefits correspond to US$1.3 billion per year in externalities averted compared with the US$5.9 billion in economic savings.

Wilkinson et al (2001) (quoted in Ferriman 2001) examined the situation in the UK, and found that housing that is older (and intrinsically more draughty and less well-insulated than more modern housing) is more strongly associated with excess winter deaths, particularly among elderly people. They discovered that the amount of seasonal fluctuation was much bigger in people living in the coldest homes than it was for people living in the warmest homes. The risk of death relative to the summer minimum was about 1.5:1.00 in the coldest homes and about 1.3:1.00 in the warmest homes.

3.5.2 New Zealand

In the HEEP Year 6 report (Isaacs et al. 2002 - Section 1.3.1) background information was provided on the ‘Te Kainga Oranga - Housing and Health Research Programme’ being carried out at the Wellington School of Medicine and Health Sciences, investigating the links between health and housing with different research projects.

The ‘Insulation and Mould Study’ is a longitudinal study investigating the relationship between cold houses and poor health among people with existing respiratory problems. It measured the impact of improved thermal insulation in terms of temperature, humidity, mould growth and energy use and, over two winters, it will examine the impact on household health, well-being and comfort. Fourteen hundred households and almost 5,000 people took part in the study. Baseline interviews were carried out after the 2001 winter, and then a randomly selected half of the houses were retrofitted with insulation. After the 2002 winter a further set of interviews were undertaken.

The preliminary results from this study were released in October 2003[ix]. These suggest that the improved insulation resulted in:

- a small, statistically significant drop in energy use
- drier, and slightly warmer, houses
- a significant improvement in the 'self-reported' health of adults and children
- reduced numbers of visits to the doctor (GP)
- reduced hospital admissions for respiratory conditions
- less sick children (and hence less need for the adults to take off 'sick days')
- less reported mould (although mould measurements did not find a change)

The data analysis is still being completed, and further results are expected.

The 'Pacific Islands Families' study is currently being undertaken at the Faculty of Health Studies, Auckland University of Technology[x]. 1376 mothers were interviewed when their infants were six weeks old, and the interviews will be continued into childhood. One part of the 'First Two Years of Life Study' questioned the mothers with regard to problems with dampness or mould and cold housing, facets of maternal health (assessed using the Edinburgh Postnatal Depression Scale), and asthma (Butler et al. 2003). It was found that more than one-third of the mothers (37%) reported that their homes had dampness/mould problems, and more than half reported problems with cold housing (53.8%). Damp and cold housing were significantly associated with a number of variables, including large household size, state rental housing, and financial difficulty with housing costs. Damp and cold housing were also both significantly related to maternal depression and incidence of asthma.

[ix] see www.wnmeds.ac.nz/academic/dph/research/housing/insulation.html. Accessed November 2003

[x] see www.aut.ac.nz/research_showcase/research_activity_areas/pacific_islands_families/who_are_we/index.shtml

4. APPLIANCE ENERGY USE

This section provides an update of HEEP summary data on household appliance energy use – electricity, natural gas and a limited analysis of LPG and solid fuel. An estimated national household breakdown of electricity and natural gas use is provided as a pie chart, as well as charts for the areas thus far monitored – Auckland, Hamilton, Wellington and Christchurch.

4.1 Appliance energy use

Mean annual power consumption has been calculated for the various appliance groups for Auckland, Hamilton, Wellington and Christchurch, and their weighted average.

Appliance Group	Auckland, Wellington, Hamilton	Christchurch
Refrigeration	Freezer	Freezer
	Fridge/freezer	Fridge/freezer
	Refrigerator	Refrigerator
Range	Hobs / oven / range	Hobs / oven / range
Other cooking	-	Bench top mini-oven
	Breadmaker / crockpot	Breadmaker / crockpot
	Electric coffee maker	Electric coffee maker
	Electric frying pan	Electric frying pan
	Electric jug	(moved to ‘Electric Jug’)
	Electric juicer	Electric juicer
	Microwave	(moved to ‘Microwave’)
	Rangehood	(moved to ‘Other climate control’)
	Toaster	Toaster
Microwave	see ‘Other cooking’	Microwave
Electric Jug	see ‘Other cooking’	Electric jug
Heating (all fuels)	Air conditioner	Air conditioner
	Central heating	Central heating
	Electric resistance heating	Electric resistance heating
		Dehumidifier with or w/out heater
	Gas heater	Gas heater
Other climate control	Dehumidifier	(moved to ‘Heating Electricity’)
	Electric blanket	Electric blanket
	-	Extractor fan
	Fan (internal)	Fan (internal)
	Heated towel rail	Heated towel rail
	-	Rangehood
	-	Waterbed
Lighting	Compact fluorescent - portable	Compact fluorescent - portable
	Halogen or similar - portable	Halogen or similar - portable
	Incandescent - portable	Incandescent - portable
Washing machines	Washing machine	Washing machine
Dryers	Dryer	Dryer
Dishwasher		Dishwasher
Entertainment	Computer/games	Computer/games
	-	Cable / Digital TV decoder
	-	Stereo
	TV	TV
	-	Video
Large miscellaneous	Pool pump / spa	Pool pump / spa
	Water pump	Water pump
Small miscellaneous	Dishwasher	(moved to ‘Dishwasher’)
	Electric fence	Electric fence
		Electric lawnmower or mulcher
	Electric power tools	Electric power tools
	Guitar amplifier	Guitar amplifier
	Iron or iron press	Iron or iron press
		Security alarm
	Sewing machine	Sewing machine
	Vacuum cleaner	Vacuum cleaner
Hot water (all fuels)	Storage, instant	Storage, instant

Table 9: Appliance group coverage by region

The data analysis was performed by consultant statistician John Jowett. The methods used for the analysis are described in separate unpublished documents, which will be incorporated in a later HEEP report.

These methods are under continuous development as the sample size, and hence appliance coverage, increases. The combinations of different appliances used for each appliance ‘group’ are given in Table 9.

There have been changes in the appliance group allocations, and these have been applied only for the Christchurch data reported here. Next year’s HEEP report will reallocate appliances to the revised groups for all locations.

Table 10 gives for selected appliance groups and total household the average power estimates by location, along with the standard deviation (SD) (given as ± 1 SD)

Table 10 shows that there are no significant differences between the total electricity and natural gas energy use for Auckland (1156±85 W), Hamilton (1280±162 W), Wellington (1172±105 W) and Christchurch (1075±65 W). Note these totals **exclude** solid fuel in all locations, and LPG in Wellington and Hamilton.

Hot water energy-use now shows no significant variation between regions – Auckland (386±29 W), Hamilton (428±93 W), Wellington (462±43 W) or Christchurch (343±26 W).

Appliance	Estimated Watts per	Auckland (2001/2)	Hamilton (2000)	Wellington (1999)	Christchurch (2002)	Strata weighted
Refrigeration	Appliance	75±5	69±7	68±6	71±15	72±4
	House	128±16	113±17	146±33	108±29	126±12
Range, oven, hobs	House	51±9	80±27	67±24	85±16	64±8
All other cooking	Appliance		6±2			
	House	42±8	29±10			
Microwave	Appliance	10±3			10±2	
	House	9±3			8±2	
Electric jug	Appliance	22±6			20±3	
	House	22±6			20±3	
All cooking	House	93±12	109±29		117±16	
Heaters & air conditioners	House	382±203	177±72		109±36	
Other climate control	House	38±129	12±7		18±13	
Lighting	House (Plug)	21±6	9±8		2±1	
	House (Fixed)	170±48	95±19	109±31	59±15	130±26
	House (All)	192±50	105±21		61±15	
Washing machines	Appliance	4±1	10±2		6±4	
	House	4±1	10±2	6±3	6±4	
Dryers	Appliance	42±15	14±5	37±19	3±1	31±9
	House	42±15	11±4	32±17		29±8
TV/computer	Appliance	10±2	19±3			
	House	43±11	49±9			
Entertainment	Appliance				15±3	
(inc TV/computer)	House				96±42	
Large miscellaneous	House	49±45	7±5		-	
Small miscellaneous	House	6±5	7±5		1±1	
Dishwasher	Appliance	36±10		22±12	45±8	
	House	22±8		16±9	22±8	
Hot water, electric	Per system	324±23			337±25	
Hot water, gas	Per system	529±80				
Hot water (All)	House	386±29	428±93	462±43	343±26	396±20
Total (inc. nat. gas & LPG Auckland & Christchurch)	House	1156±85	1280±162	1172±105	1075±65	1154±52

Table 10: Appliance average power estimate by location

Data is not reported in Table 10 for energy use by Christchurch dryers, as the sample included the energy use of only four dryers, each monitored for one or two months. The result is not a reliable estimate of dryer energy use in Christchurch. Dryer use will also be further investigated in detail using the survey responses.

Table 10 also does not include an estimate for 'Hot water, gas' in Christchurch as only one LPG based system was monitored.

The Entertainment group is interesting, as the energy-use for Christchurch was 96±42 W, which is comparable to the energy use for Lighting or All Cooking. As appliances in this group (TV, VCR, stereo, computer, decoders) become more common, and new types of appliances emerge (e.g. DVD, home theatre) there is the potential for importance of the energy used in this group to increase.

4.2 Energy end-use proportions by location

Figures 8, 9, 10 and 11 provide the proportions of energy (electricity and natural gas only, except Auckland and Christchurch which include LPG) by end use for Auckland, Hamilton, Wellington and Christchurch, using the appliance groupings in Table 9. Figure 19 provides a strata-weighted average over the four locations. Percentages reported as ‘0’ are less than 1%, and thus the total sum may be less than 100%. Note that in Figure 17 for Wellington, space heating energy was not separately collected. and it is included in the ‘unassigned’ category.

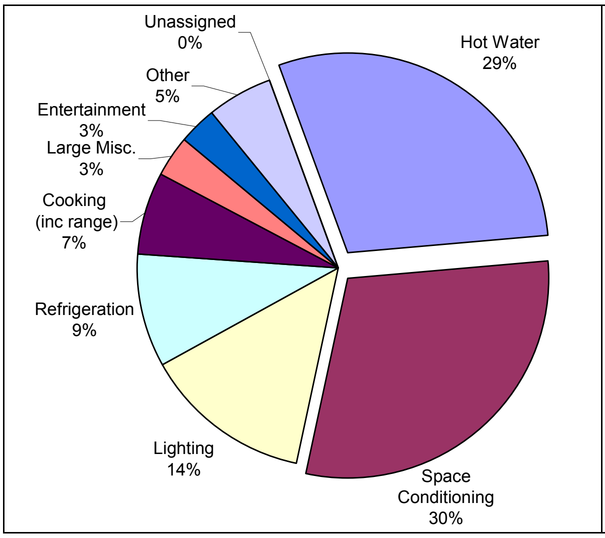


Figure 15: Auckland elect. & gas by end-use

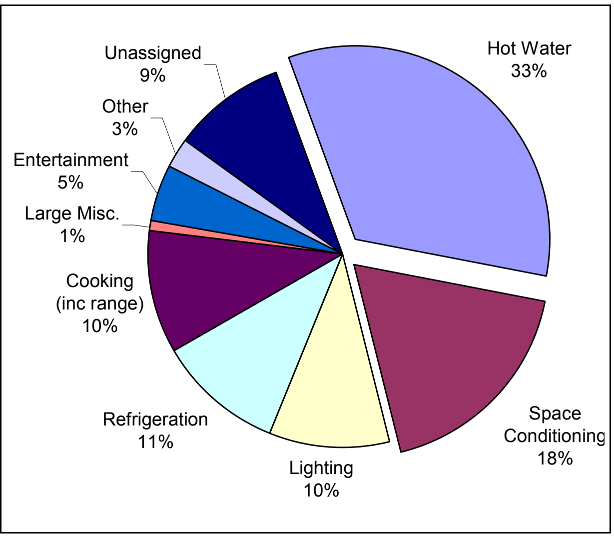


Figure 16: Hamilton elect. & gas by end-use

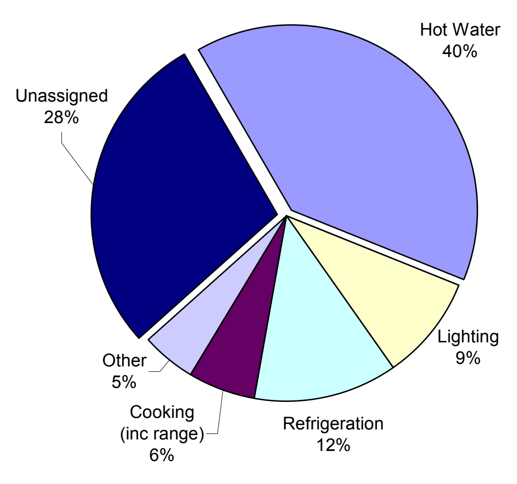


Figure 17: Wellington elect. & gas by end-use

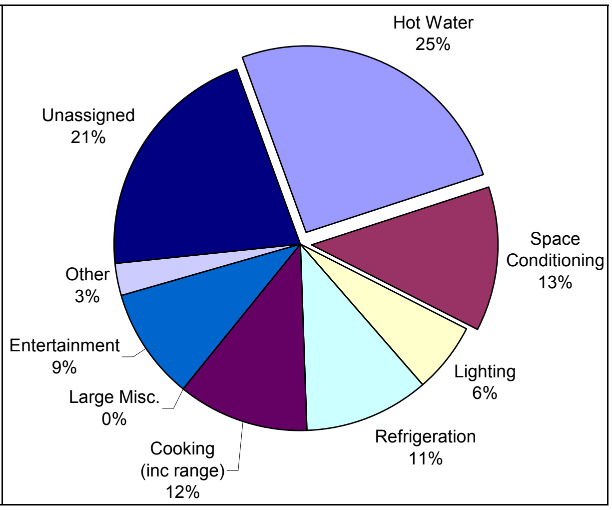


Figure 18: Christchurch elect. & gas by end-use

There are likely to be a range of reasons for the differences in the proportions for each appliance group between regions. For example, as shown in Table 10, there are no significant differences in the absolute energy used for water heating between the four regions. Thus if the total electricity and gas energy use is lower in any given region, the proportion of the energy used by water heating will be higher.

Figure 19 (a strata-weighted average over the four areas) shows that on average hot water is the biggest use of household electricity and gas at close to 30%, with space conditioning following at 22%. Lighting at 11% is half the energy used for space heating, while refrigeration follows in fourth place with 10%. The importance of lighting and refrigeration has not been well recognised, perhaps because of the comparatively small power load. However, a small load turned on and used for a long time (e.g. a heated towel rail operating all day, all year) uses as much energy as a large load turned on for a comparatively short time (e.g. electric clothes dryer uses for 90 minutes every day).

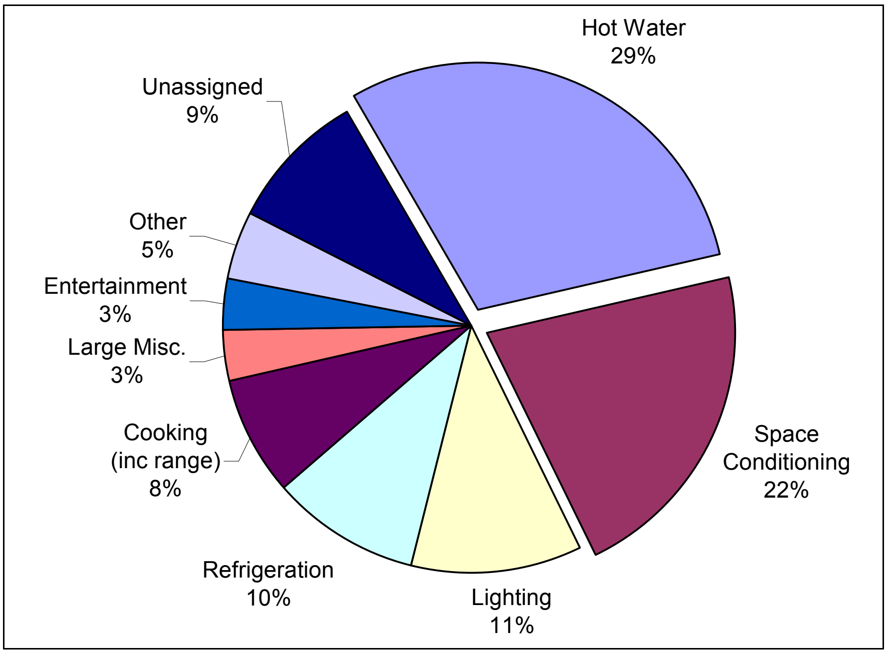


Figure 19: Mean annual electricity & gas - strata weighted average

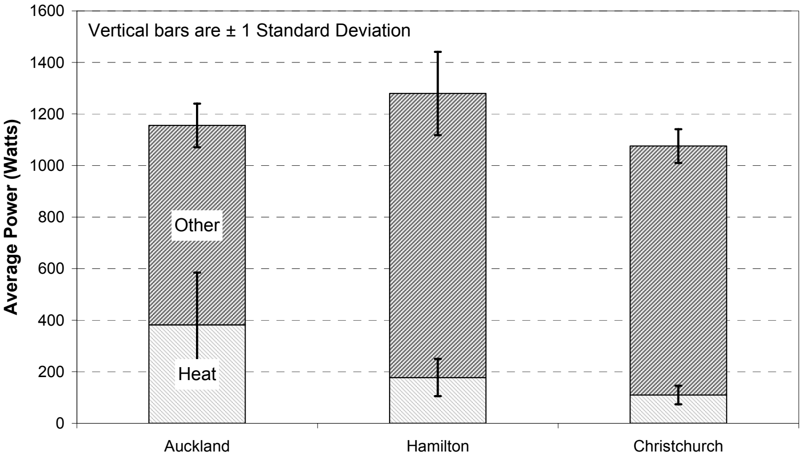


Figure 20: Heating energy as part of total energy use

Figure 20 plots the electricity and gas energy used for heating in relation to the total electricity and gas energy use by region. The vertical bars indicate one standard deviation for each of the heating and total energy use. About one-third of electricity and gas is used for space heating in Auckland, one-seventh in Hamilton and one-tenth in Christchurch. The apparently low proportion in Christchurch is possibly due to a greater proportion of houses reporting the use of solid fuel as the main method of heating (33% of houses in Christchurch compared to 18% in Auckland), and this will be further investigated.

5. INDOOR TEMPERATURES

This section compares the results of the HEEP monitoring with previous New Zealand research, examines the patterns of indoor temperatures and then compares the temperatures with selected physical attributes of the house.

For the analysis in this section, the HEEP database contained the ‘year’ of data from the households in Auckland, Wellington, Hamilton, and Christchurch, and survey data only from Dunedin, Invercargill, and the cluster samples from Northland (30 houses), Waikato/Bay of Plenty (30 houses) and Oamaru (10 houses). Some of the analysis was conducted on all available houses and some on a sub-set containing only the randomly selected houses.

5.1 Historical comparison

What temperatures are found inside New Zealand houses, and what are the drivers? Earlier HEEP reports have investigated this area and have found indoor temperatures to be somewhat lower than would be expected. Table 11 compares the results of the HEEP monitoring with the ‘lounge’ temperatures for the August-September months by region from the 1971/72 Household Electricity Survey (Statistics 1976).

Aug-Sep Temperatures °C	**HEEP Wellington 1999**	**Southern North Island 1971**	**HEEP Hamilton 2000**	**HEEP Auckland 2001/02**	**Northern North Island 1971**	**Christchurch**	
						HEEP 2002	**1971**
Living room:							
Mean temperature	15.7	16.6	16.7	16.5	17.7	16.0	15.2
Standard deviation	1.2	-	1.2	1.5	-	2.0	-
95% Conf. Interval	15.3 – 16.1	-	16.2 – 17.2	16.2 – 16.7	-	15.4 – 16.5	-
External:							
Mean temperature	10.4	11.0	11.2	12.2	12.0	10.3	9.3
Mean temperature difference	5.3	5.6	5.5	4.3	5.7	5.7	5.9
Sample size	33	64	17	95	98	35	69

Table 11: HEEP & 1971 descriptive temperatures by region

Figure 21 shows the temperature distribution (each point is one house) and the mean temperature with 95% confidence interval for Wellington, Hamilton, Auckland and Christchurch. Figure 21 can be compared with the standard deviation and confidence intervals in Table 11.

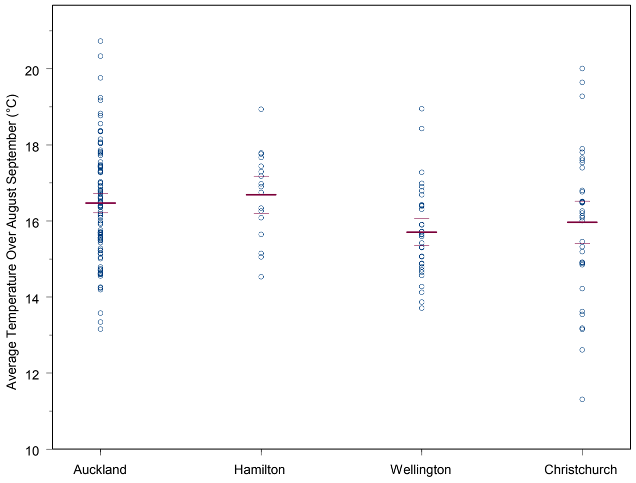


Figure 21: Mean temperatures Aug – Sept by location

5.2 Heating patterns

The first step to evaluating winter evening temperatures was to determine the most common heating season based on the occupant survey response to questions about the first and the last month when heating is used. Table 12 and Figure 22 give the number of houses reporting the given start or finish month.

Month		Number start	Number end
1	January	5	
2	February		
3	March	13	
4	April	82	
5	May	97	
6	June	44	1
7	July	15	7
8	August	2	35
9	September	1	111
10	October		81
11	November		17
12	December		6

Table 12: Reported heating season

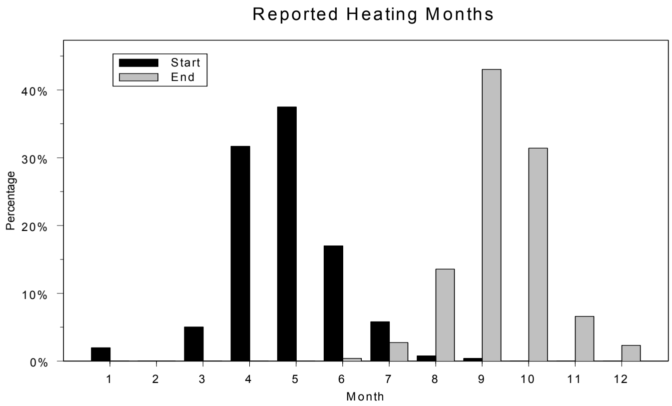


Figure 22: Reported heating season start and finish

Figure 23 (also based on survey data) gives the length of the reported heating session, with the number of houses in each band given in brackets on the y-axis. It shows that households that start heating early in the season also finish later in the season.

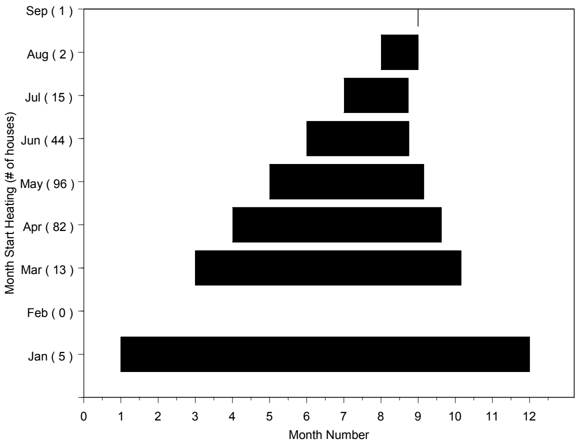


Figure 23: Length of reported heating season

Region	Start month	End month	Length	Length SD
Auckland	5.1	9.1	4.0	0.2
Cluster	5.0	9.1	4.2	0.3
Hamilton	4.9	9.8	4.9	0.6
Wellington	4.8	9.4	4.6	0.2
Christchurch	4.4	9.4	5.0	0.2
Dunedin	3.4	10.5	7.0	0.7
Invercargill	4.0	10.2	6.2	0.2

Table 13: Average heating season by region

Table 13 shows that the average starting and finishing heating seasons show statistically significant variations by region – households in cooler climates, on average, start heating earlier and finish heating later than those in warmer climates.

The starting month of the heating season is weakly related to the average winter evening living room temperatures, thus houses with warmer winter temperatures tend to start heating earlier in the season.

Based on the reported heating seasons it was decided to consider the period between June and August (inclusive) as the winter heating season. The evening period was taken to be the time between 17:00 and 22:50. The average winter evening temperatures were then calculated for each household using the winter season and the evening periods. If multiple loggers were present in the family room then the averages of the logger readings were calculated, although no account was taken of logger heights or consistency between different households. As loggers are generally installed at two different heights, i.e. at about 0.4m and about 2.0m, the average temperature should be representative of temperatures at around 1.2m height.

Figure 24 gives the winter temperature profiles for Auckland, Hamilton, Wellington, Christchurch and the average of all four regions. It reveals some interesting patterns:

- Hamilton houses are the warmest, followed by the Auckland houses. Christchurch houses are the coolest of the sample, though only very slightly cooler than Wellington houses during the evening.
- Peak living room temperatures occur at 8:20pm in Auckland, 8:10pm in Hamilton, 9:40pm in Wellington, and 8:50pm in Christchurch. This effect may be related to the house occupants' schedules, as the average bedtimes are 11:10pm, 10:00pm, 11:00pm, and 10:30pm respectively. The HEEP survey does not request information on the time that people come home each day, but it seems possible that Auckland commuters would arrive home later, on average, than Hamilton commuters.

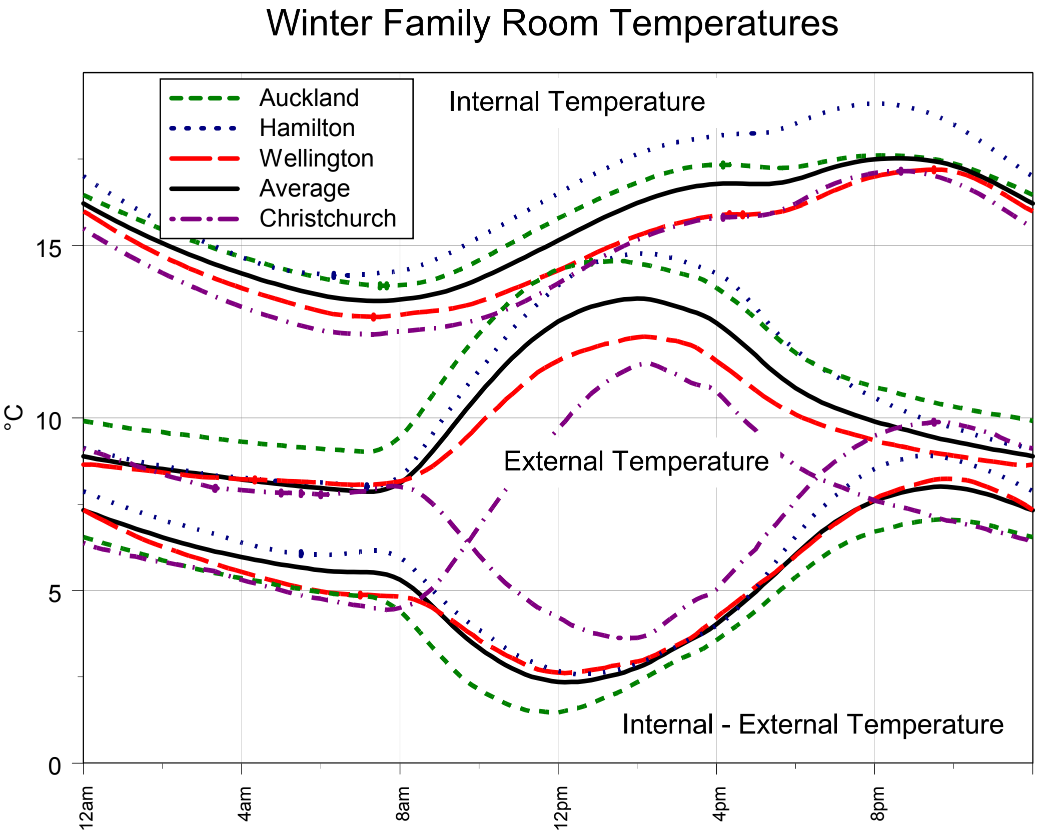


Figure 24: Winter temperature profiles

The temperature profiles were examined to determine the times that heating was applied. Four parameters were examined, and are reported in Table 14:

- **start of heating** was defined as the time when the temperature starts to rise in the evening. Without heating, houses will cool off in the evening, so when the profile begins to rise it indicates that, on average, houses are being heated.
- **time of the maximum rate of temperature increase** indicates that most houses are being heated.
- **time of maximum temperature** indicates when the comfort temperature has been reached, or when some households begin to stop heating.
- **end of heating** was determined by finding the point at which the difference between the outside and inside temperature decreases.

Region	Start	Max rate	Peak	End	Bedtime
Auckland	5:50	6:40	8:20	9:50	11:00
Hamilton	5:20	6:20	8:20	9:30	10:05
Wellington	5:00	6:50	9:50	10:10	11:00
Christchurch	4:20	6:30	8:50	9:50	10:30

Table 14: Estimated heating times by region

The start of heating is progressively earlier going from warmer to cooler regions, being about 30 minutes earlier at each location going from Auckland at 5:50pm through to Christchurch at 4:20pm. The time of the maximum rate of increase of temperature is approximately the same in all regions, ranging from 6:20 to 6:50pm, with no apparent pattern. The end of heating appears to be weakly related to the household bedtimes.

5.3 Temperature correlations

As discussed in Section 5.2, New Zealanders do not maintain constant indoor temperatures 24 hours a day. For the purpose of the following analysis, the ‘winter evening’ (between 17:00 and 22:50 from June to August inclusive) is used as the baseline. Unless otherwise specified, the temperatures reported are for the living room (the part of the house most commonly heated).

Figure 25 provides an overview of the winter (June through August) evening (5 pm to 11 pm) living room average temperatures in the randomly selected houses in Auckland, Hamilton, Wellington and Christchurch. As the curve shows, this follows the normal (bell shaped) distribution, with an average temperature of 17.3°C and a standard deviation of 0.16°C. Figure 25 shows that nearly 30% of the average winter evening living room temperatures are below the WHO recommended healthy minimum of 16°C (WHO 1987).

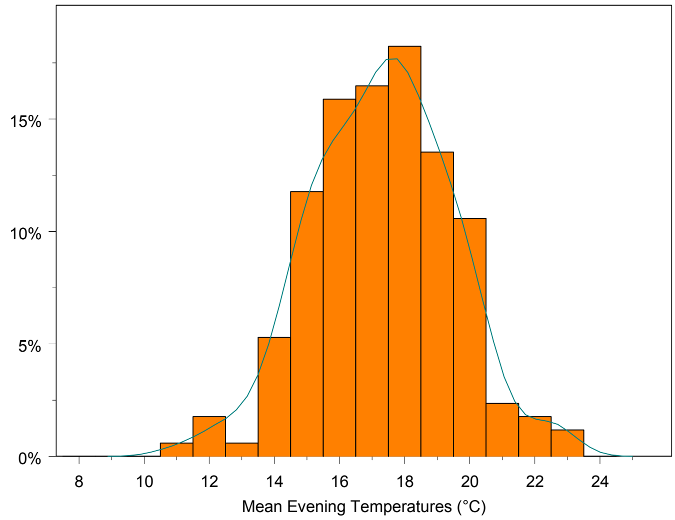


Figure 25: Winter evening living room average temperature distribution

There are significant correlations between mean winter evening temperatures and:

- heating fuel (Section 5.3.2)
- house age (Section 5.3.3)
- presence of insulation (Section 5.3.4)
- house floor area (Section 5.3.5).

There is a significant correlation between mean winter evening temperatures and the region (Section 5.3.1), but this is largely due to the temperatures in one particular region. There is a significant correlation between mean winter evening temperatures and the presence of floor insulation, but the correlation is not significant for roof insulation (Section 5.3.6). This will be further investigated.

5.3.1 Region

Figure 26, a box plot, shows that the Hamilton temperatures are significantly higher than all other regions. The median temperature for each region is indicated by the horizontal line across the box, while the 75th and 25th percentiles (upper and lower quartiles) are indicated by the top and bottom respectively of the box. The vertical lines end at the minimum and maximum temperatures, while the free-floating horizontal line(s) represent outliers.

There are no significant differences between the Auckland, Wellington or Christchurch average temperatures. There is a significant difference between the regions at the 95% confidence level (ANOVA model: F statistic 3.6 on 3 and 171 degrees of freedom, Pr (F) = 0.014), but this is primarily due to the warmer temperatures measured in the 17 Hamilton houses.

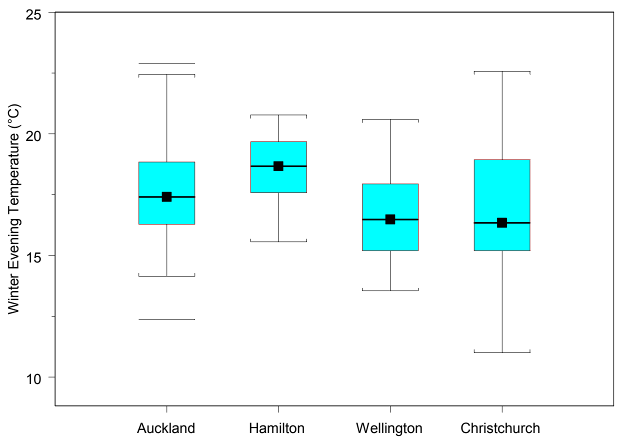


Figure 26: Mean winter evening living room temperatures by region

At least part of the lack of difference in average temperatures between regions is due to the wide range of temperatures within each region. The Christchurch living room winter evening temperatures show the greatest range and variation, ranging from 12°C to 23°C. Examination of temperatures by region, combined with some other key variable - for example the type of heating system - may reveal significant correlations.

5.3.2 Heater type and heater fuel

There are major variations in space temperatures with different main heater types and/or main heater fuels. Figure 27 and Table 15 illustrate that houses heated with gas or solid fuel are significantly warmer than electric and LPG-heated houses. Table 16 and Figure 28 show that houses with gas central heating or solid fuel burners are the warmest group with an average evening temperature of 18.2°C. Gas heated houses (e.g. stand alone gas heater) and fixed electric heaters (including night store heaters and other large, fixed-wired electric heaters) are significantly cooler, at an average of 17.7°C. Houses heated by plug-in electric heaters or LPG heaters are significantly cooler again, at 16.5°C. The drivers for these differences have yet to be established.

Fuel	Temperature °C	Standard deviation	Sample count
Electricity	16.7	0.2	79
LPG	16.8	0.4	22
Natural gas	17.9	0.4	23
Solid fuel	18.2	0.4	41

Table 15: Winter living room evening temperatures by heating fuel

Heater type	Temperature °C	Standard deviation	Sample count
Electric	16.4	0.3	58
LPG	16.8	0.4	22
Fixed electric	17.6	0.5	17
Gas	17.8	0.5	16
Solid fuel	18.2	0.4	41
Gas central	18.3	0.7	7

Table 16: Winter living room evening temperatures by heater type

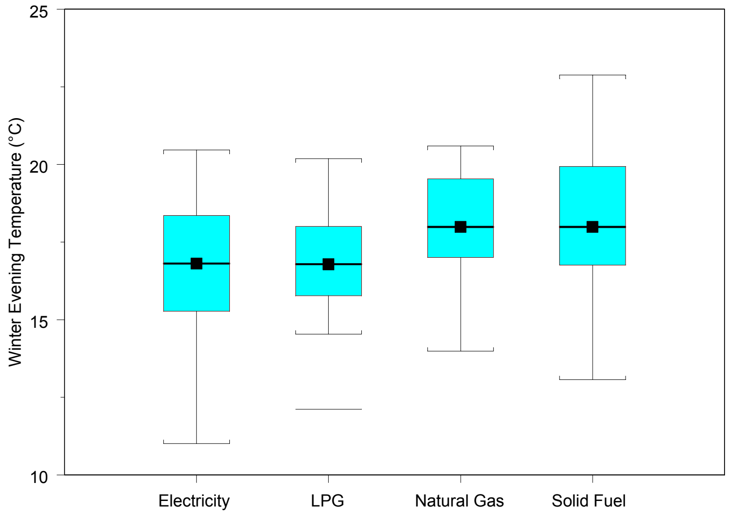


Figure 27: Living room winter evening temperatures by heating fuel

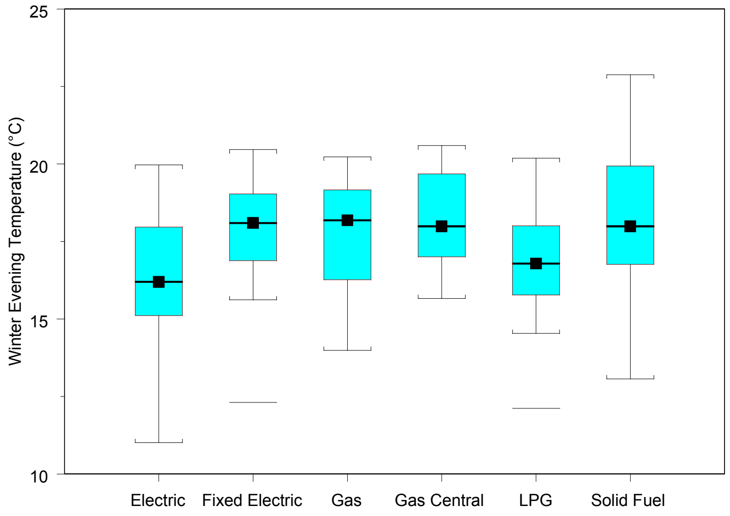


Figure 28: Living room winter evening temperatures by heater type

5.3.3 House age

There is a very strong relationship between the age of the house and the winter temperatures. Currently, we can conclude that post-1978 houses are 1.0°C warmer on average and that their winter evening energy use is not significantly different from the pre-1978 houses. This difference is slightly less than that given in the Year 6 report, and the reduction has been caused in part by pre- and post-1978 houses in Christchurch having no significant difference in winter evening temperatures.

Figure 29 plots this relationship by the decade the house was built, and shows that older houses tend to be colder. There is an average rate fall of 0.26 ± 0.07°C per decade. This result has a very high statistical significance (ANOVA F-statistic: 12.1 on 1 and 133 DOF, p-value 0.0006).

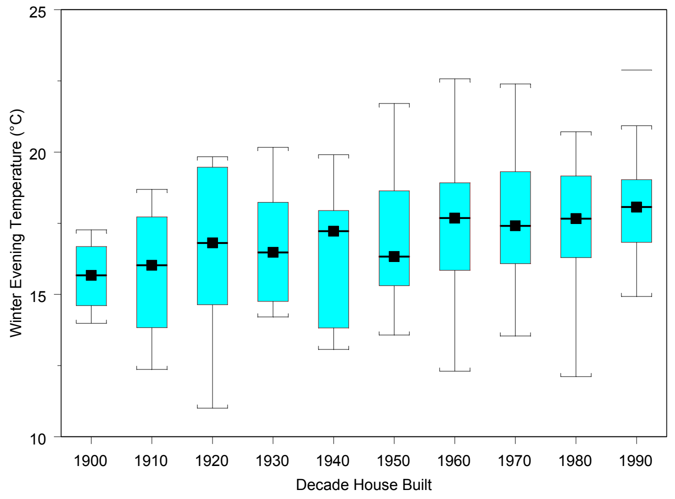


Figure 29: Winter evening living room temperatures by year house built

5.3.4 Thermal insulation

Houses built after 1 April 1978 were required to exceed a minimum level of thermal insulation, whereas older houses were not required to have any insulation at all. Figure 30 shows how the winter evening living room and bedroom overnight temperatures vary in houses built between the pre-1978 (no insulation), and post-1978 (insulated) requirements.

The same pattern is present for bedrooms (Figure 31), even though bedrooms are seldom heated. The reason for this would relate to the insulated bedrooms having a lower heat loss, and hence even the heat from the occupants is enough to result in an increase in the bedroom temperature.

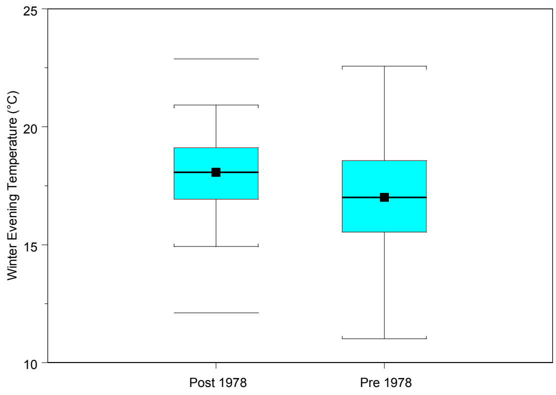


Figure 30: Living room winter evening temp by insulation requirements

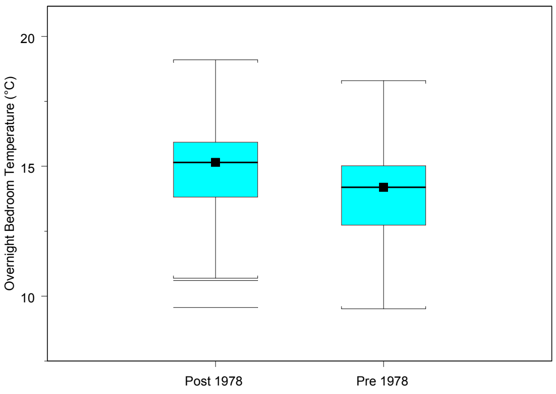


Figure 31: Bedroom overnight winter temp by insulation requirements

The temperature, energy (excluding solid fuels) means and population standard deviations are tabulated in Table 17, Table 18 and Table 19. Table 17 indicates that there is a highly significant difference between the temperatures in pre-1978 and post-1978 houses, with the older houses being on average 1.0°C colder.

House age group	Average winter evening living room temperature	Average winter overnight bedroom temperature	Average winter evening energy use
Pre-1978	17.0 ± 0.2°C	13.8 ± 0.2°C	1680 ± 114 W
Post-1978	18.0 ± 0.3°C	14.9 ± 0.3°C	1590 ± 210 W

Table 17: Winter temperatures and energy use by insulation level

Construction	Fuel	Total (Watts)	Z-score
Post 1978	Electricity	1431±161	0.96
Pre 1978	Electricity	1638±143	
Post 1978	Gas	3922±830	0.95
Pre 1978	Gas	2978±545	
Post 1978	LPG	825±240	1.51
Pre 1978	LPG	1265±164	
Post 1978	Solid fuel	960±264	1.42
Pre 1978	Solid fuel	1397±155	

Table 18: Heating energy use by house age & fuel type

The average energy use is slightly lower for the post-1978 group, but the differences are not statistically significant. This is confounded at the moment by the exclusion of the solid fuel energy estimates, and the much wider range of energy-use than average temperature. When examined by main heating fuel type (Table 18), all but the gas-heated houses (many of which use central heating systems, or use heaters to heat the whole house) show slightly less energy use for the post-1978 group, though the differences are only statistically significant at the 10% level for houses heated primarily by LPG or solid fuel.

Construction	Region	°C
Post 1978	Auckland	18.2±0.3
Pre 1978	Auckland	17.1±0.3
Post 1978	Hamilton	20.2±0.5
Pre 1978	Hamilton	18.6±0.8
Post 1978	Wellington	18.3±1.3
Pre 1978	Wellington	16.4±0.4
Post 1978	Christchurch	16.7±0.8
Pre 1978	Christchurch	16.6±0.8

Table 19: Winter evening temperatures by age & region

Table 19 shows that in Auckland, Hamilton, and Wellington the post-1978 houses are significantly warmer on winter evenings. However, there is no significant difference in Christchurch. A plausible explanation for this is the high proportion of solid fuel-heated houses in the Christchurch pre-1978 group (45%), compared to only 20% in the post-1978 group. As discussed in Section 5.3.2, solid fuel-heated houses are usually heated to much higher temperatures than houses using electricity or LPG (there is no reticulated gas heating in Christchurch).

5.3.5 Floor area

There was a weak correlation found between floor area and winter evening temperatures, with larger houses tending to be slightly warmer (Figure 32). Note that there appears to also be a correlation between household income and house floor area, with higher income households tending to have larger houses. On the basis of house thermal performance, a large house needs more energy to maintain the same temperature as a small house, which would suggest that small houses might be warmer than large houses. However, households with higher incomes may find heating more affordable, and so heat to higher temperatures. These issues will be further investigated.

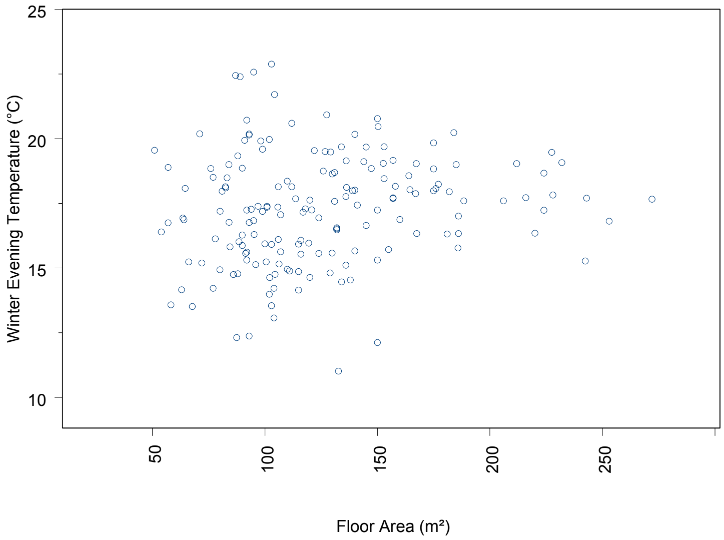
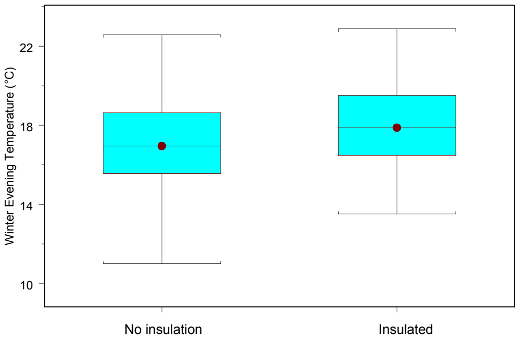


Figure 32: Winter evening temperatures vs. floor area

5.3.6 Presence of insulation

Houses with floor insulation are 1.0°C warmer than those without (Figure 33), and this is statistically significant. Houses with roof insulation are 0.4°C warmer than those without (Figure 34), but this is not statistically significant at the 90% confidence level.



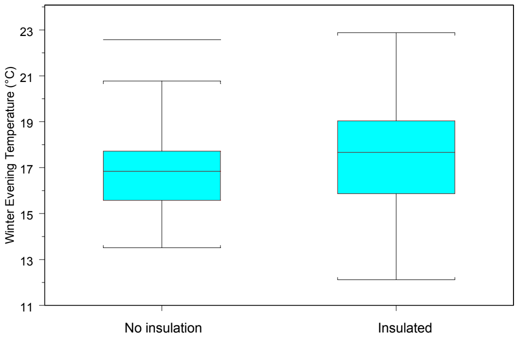


Figure 33: Winter evening temperatures by presence of floor insulation

Figure 34: Winter evening temperatures by presence of roof insulation

6. WINTER ENERGY USE

The use of energy for space heating in New Zealand homes is dependent not only on the technical aspects of the house construction (e.g. thermal insulation, orientation, construction materials, etc.) but also on the behaviour of the occupants (e.g. use of curtains, hours of heating). This section provides some preliminary analysis of the energy use, linking it to some of the user-established behaviours.

For the purposes of HEEP, the winter evening period has already been defined (Section 5.2) as the period from the start of June to the end of August from 5 pm till 11 pm. The energy used during this period by a HEEP house will include space heating, water heating and other end-uses. For the purpose of the analysis reported in this section, it has been assumed that all energy used for space heating and other non-water heating use ultimately ends up providing space heat. That is, the energy used for hot water has been excluded from the analysis. This will be an underestimation in some houses – notably those with a poorly insulated, interior hot-water cylinder, but this approach provides a first step towards a more comprehensive analysis as the HEEP work progresses.

Please note, as discussed in Section 6.1, this winter energy use analysis excludes houses that report their 'main heating fuel' as solid fuel.

6.1 Heating fuels

Table 20 provides an analysis of the *main heating fuel* for all the houses in the HEEP database. Ninety three out of the 280 houses (33%) for which this data is held, are principally heated by solid fuel – second only to the use of electric heating (42%). Fourteen percent of the households report their main heating fuel is LPG, and 11% by natural gas.

Table 20 also shows the distribution by decade of construction and reported main heating fuel type. It can be seen that for 14 houses for which the reported main heating fuel type was available, it was not possible to allocate a decade of construction. Figure 35 presents the same data, summed into groups of three-decades (except for 1990-onwards which is limited to houses built up to the time of the actual survey).

Reported main heating fuel	Decade of construction											Sub-total	Total sample
	1900	**1910**	**1920**	**1930**	**1940**	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**		
Electricity	6	1	12	8	4	9	24	17	12	15	1	109	117
LPG	0	1	1	1	2	7	6	6	8	4	0	36	39
Natural gas	2	2	2	3	1	2	1	9	7	1	1	31	31
Solid fuel	2	2	6	4	9	20	19	10	5	13	0	90	93
TOTAL	**10**	**6**	**21**	**16**	**16**	**38**	**50**	**42**	**32**	**33**	**2**	**266**	**280**

Table 20: Reported main heating fuel by house decade of construction

Figure 35 and Table 20 show that natural gas is reported as the principal heating fuel, even in houses built well before natural gas was available, although natural gas could have continued the in place of the use of the obsolete 'town gas' (coal gas). Similarly, the use of solid fuel as the main mains of heating is well spread throughout the different house age groups.

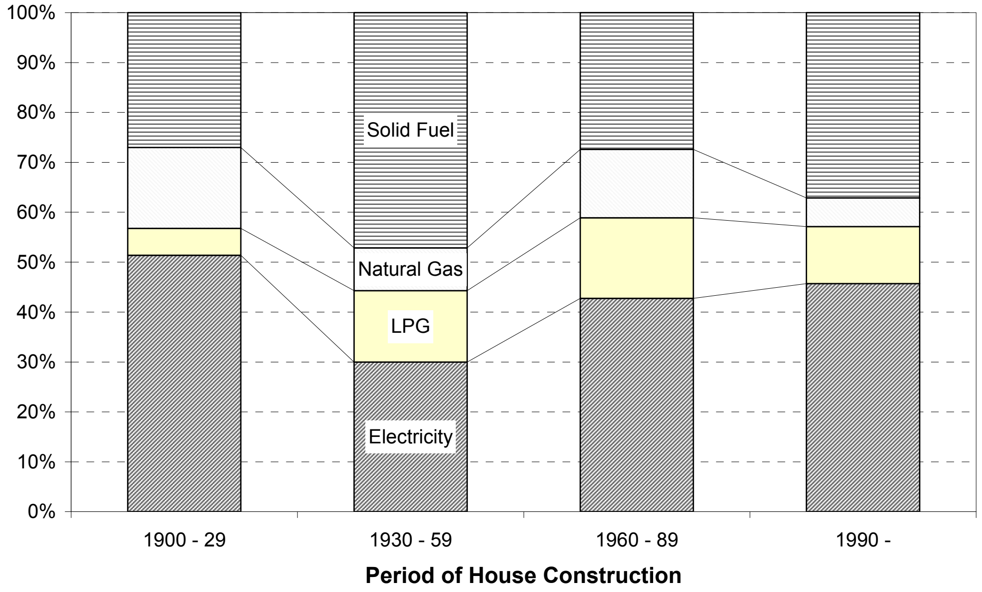


Figure 35: Main heating fuel by house period of construction

Work is continuing on the development of appropriate methodology to incorporate the energy used for space heating and hot water supplies from solid fuels – both enclosed burners and open fireplaces – in the HEEP database. As shown in Figure 27, a preliminary examination of the house temperatures shows that households that reported the use solid fuel burners as their primary heating source have, on average, warmer temperatures.

In the interim, the following winter energy use analysis excludes houses that report their *main heating fuel* as solid fuel.

6.2 Winter energy use distribution

Figure 36 and Figure 37 give the winter energy use distribution – Figure 36 the total winter energy use (kWh) and Figure 37 normalised by the household floor area (kWh/m^2). Both total and normalised distributions are skewed to the lower energy use, though each has a small but noticeable number of high energy-use cases. Table 21 provides some descriptive statistics on the distributions.

	Mean	Standard deviation	Minimum	Median	Skewness	Maximum	Available count	Missing count
Total (kWh)	3,652	192.3	253	3,055	1.8	14,120	168	132
Normalised (kWh/m^2)	13.5	0.6	0.8	11.9	1.3	42.9	166	134

Table 21: Winter energy use – descriptive statistics

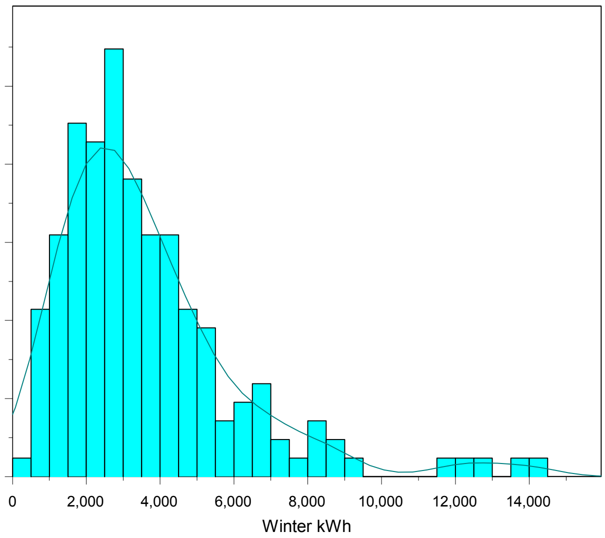


Figure 36: Heating energy use distribution

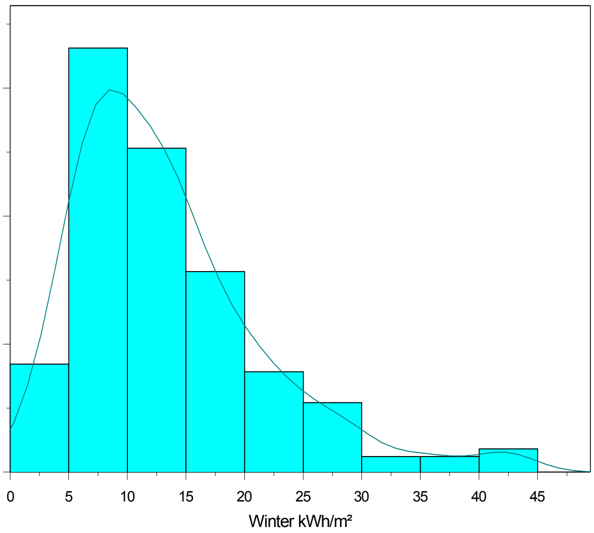


Figure 37: Normalised heating energy distribution

6.3 Winter energy use and house floor area

The lack of a strong link between floor area and winter evening temperatures has already been discussed (see Section 5.3.5 and Figure 32). Figure 38 (for winter energy) and Figure 39 (for winter energy normalised by floor area) display the relationships for heating energy use.

In neither case is a strong trend apparent. Figure 38 (kWh) could be taken to suggest that larger houses use more energy than smaller houses, but there is a very wide distribution of winter energy use for all house sizes. Figure 39 (kWh/m²) shows no obvious link between floor area and the winter energy used per unit floor area.

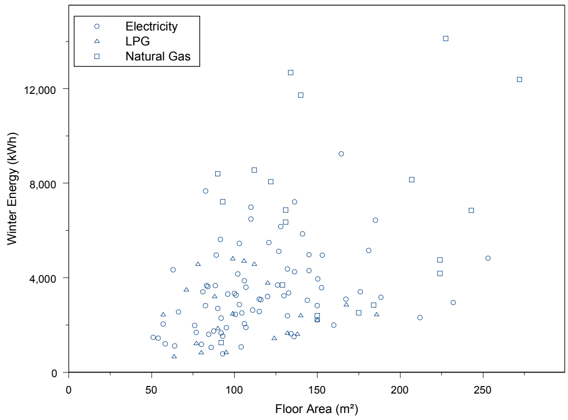


Figure 38: Winter energy use vs floor area

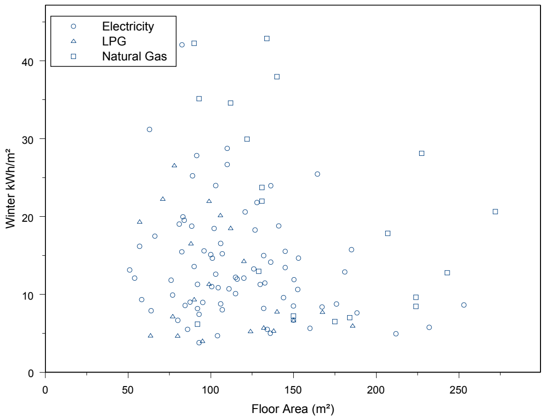


Figure 39: Normalised winter energy vs floor area

6.4 Winter energy use by house age

Figure 40 (for winter energy use) and Figure 41 (for winter energy use normalised by floor area) examine the distribution of energy use by decade of house construction. Neither the total, nor the normalised, winter energy use shows a strong relationship with the house age. However, the wide range in many of the decade groupings suggests that further investigation is required.

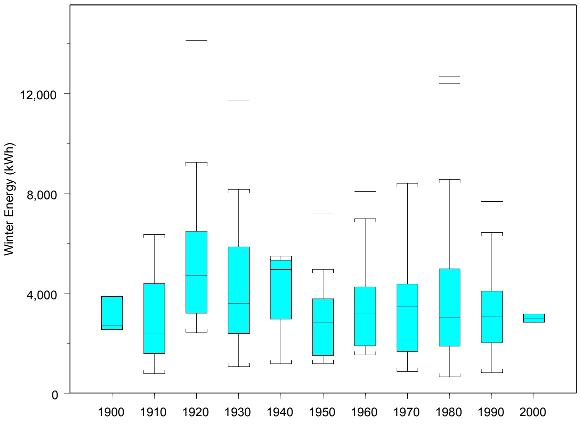


Figure 40: House age vs heating energy

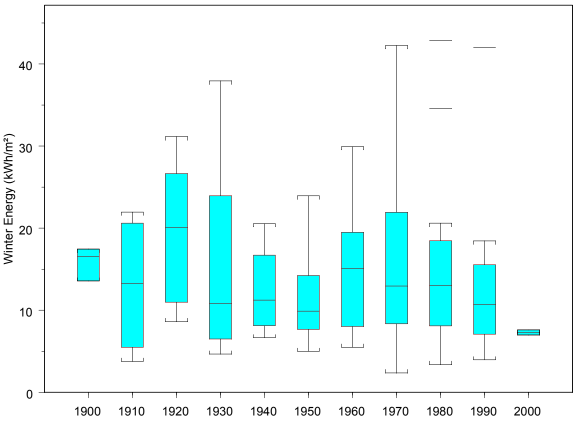


Figure 41: House age vs normalised heating energy

6.5 Heating energy use by heating schedule

The HEEP survey asks house occupants about their patterns of space heating. Table 22 provides the question as asked, with the different coding alternatives. Any combination of heating schedules is possible for each 'room type', from no heating at all through to all-day heating. Given that many households have the occupants at work during the week, the survey differentiates between the weekday and weekend heating schedules.

Heating In the winter season (usually May to August) what times of the day do you usually heat each of the three thermal zones? (put each relevant time period on the table below as **bold code**)		
1: 7am to 9am (morning)	**2:** 9am to 5pm (day)	**3:** 5pm to 11 pm (evening)
4: 11pm to 7am (night)	**5:** no heating	

Room types	**Weekdays**	**Weekends**
Bedrooms: e.g. Bedrooms or rooms used as bedrooms inc. sleep out		
Living areas/rooms: e.g. lounge/family room etc/ kitchen with sitting area/dining room/ rumpus room		
Utility rooms: e.g. kitchen, studies, hobby room, sewing room, garages used for hobbies etc		

Table 22: 'Heating schedule' HEEP survey question

A method was required to take account of the many different heating regimes – both with respect to time of day as well as the spaces heated. An ad hoc preliminary 'Heating Index' has been developed, and Table 23 provides the index weights. This index has been developed to provide a way of differentiating house heating regimes, including zoning, in a way suitable for numeric evaluation. The 'Heating Index' report here should be treated as work-in-progress, as it will be subject to evaluation and development as the HEEP analysis proceeds.

Heating schedule	Weight
None	0
Morning	0.5
Evening	1.0
Morning/evening	1.5
Overnight	1.5
Day/evening	2.0
Overnight/morning	2.0
All day	2.5
Not daytime	2.5
Evening/overnight	3.0
Not morning	3.5
24-Hour heating	4.0

Table 23: 'Heating Index' weights

Each of the three 'room types' (or heating zone) given in Table 22 is allocated the schedule weight from Table 23, and then summed for the appropriate number of days.

For example, if the 'Living area' is the only part of the house that is heated and it is only heated in the evening, then the 'heating index' will be '7' (1 area x 1 weight x 7 days). If the whole house is heated for 24 hours then the 'heating index' will be '84' (3 areas x 4 weight x 7 days).

Figure 43 and Figure 44 compare winter heating energy use to the heating index, categorising by the mean winter evening living room temperature. The 'main heating fuel', as reported by the house occupants, has been used for the plotting symbol. Both figures include vertical lines for a heating index of '7' – i.e. the house only heats one area every evening, most likely the living area). Figure 43 uses the total winter energy, while Figure 44 normalises this by floor area. There are no data points in shown in the top-right category (20.9°C to 22.9°C), as mean winter evening temperatures over 20.9°C have only been found solid fuel heated houses.

As would be expected, both Figure 43 (kWh total) and Figure 44 (kWh/m²) suggest that houses that heat long hours (i.e. a higher heating index) have a higher mean winter evening living room temperature, although there is a very wide spread of temperatures for both the heating index and the energy use.

Of all the houses shown in Figure 43 and Figure 44, about one-sixth are in the under 15°C category, about one-third of the houses are in the 15.0°C to 16.9°C category, one-third in the 16.9°C to 18.9°C category, and the remaining houses are in the 18.9°C to 20.9°C category.

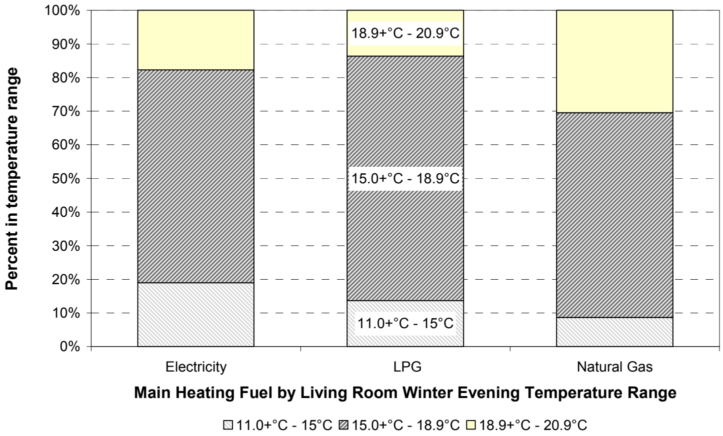


Figure 42: Temperature range by main heating fuel

Figure 42 provides a breakdown by winter evening mean living room temperature range category for each main heating fuel type.

A higher proportion of houses that use electricity as their main heating fuel are in the 11°C to 15°C category than for the other two fuels, while more natural gas houses are in the 18.9°C to 20.9°C range category than for the two other fuels.

This analysis based on the 'Heating Index', as note above, is preliminary. It does not yet consider aspects of the house construction that are likely to be critical – most notably the levels of thermal insulation. This work will be continued during the coming year.

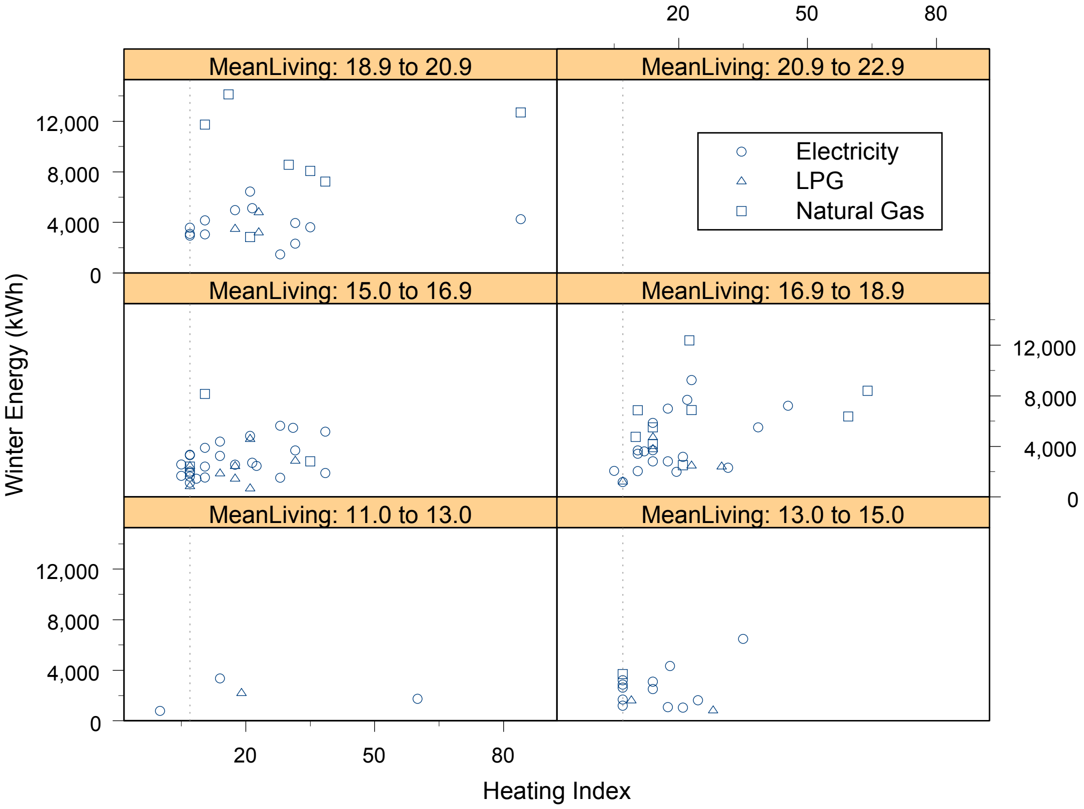


Figure 43: Heating index by heating energy & winter-evening living room temp.

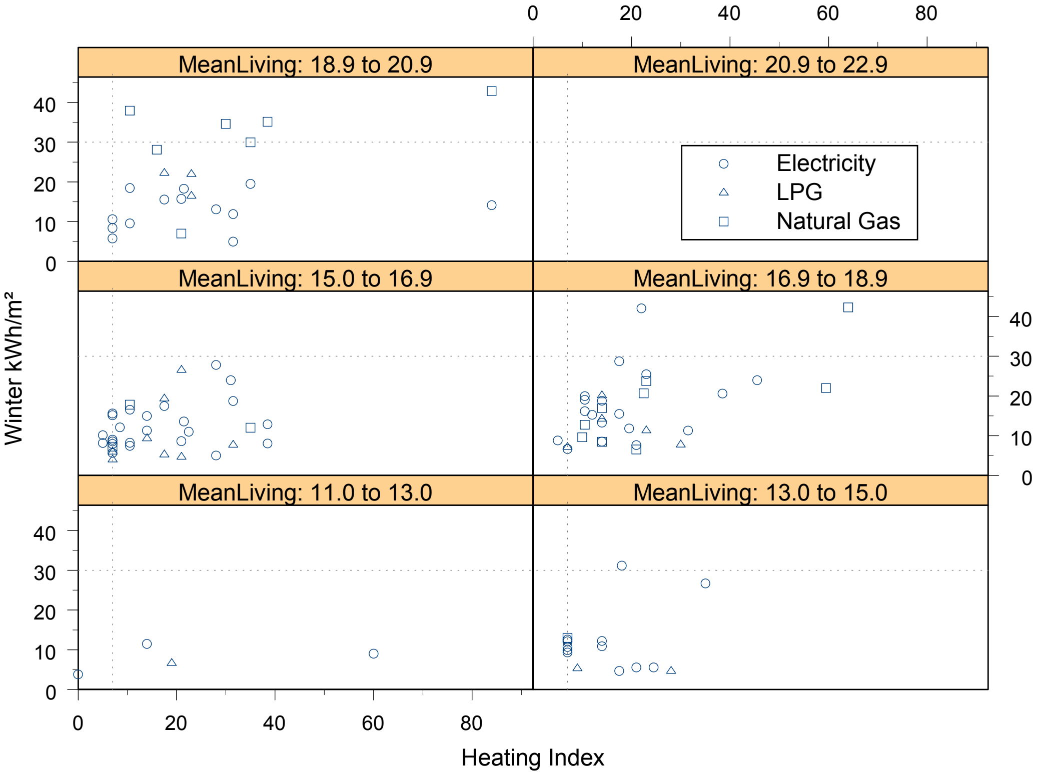


Figure 44: Heating index by energy per m² & winter-evening living room temp.

7. LPG HEATERS

This section presents an update on the use of portable LPG heaters, provided in the HEEP Year 4 (Camilleri, et al. 2000) and Year 6 (Isaacs, et al. 2002) reports.

7.1 LPG heater ownership

LPG is a common method of space heating in New Zealand. The 2001 Household Economic Survey (Statistics NZ 2002) reported that 33% of households had portable gas heaters. Table 24 provides analysis of the HEEP sample of the reported ownership of LPG heaters.

		Households in random HEEP sample			LPG heaters in random HEEP sample	
Region	**HEEP Monitoring period**	**Number**	**with portable LPG heaters**	**with portable LPG heaters (%)**	**Number**	**Average number per household**
Wellington	1999 (not measured)	47	17	36%	17	0.36
Hamilton	2000	17	7	35%	8	0.41
Auckland	2001/2002	97	27	28%	28	0.29
Waikanae	2002	10	1	10%	1	0.10
Christchurch	2002 (being processing)	37	9	24%	10	0.27
	Current monitoring	99	30	30%	30	0.30
Total		307	91	30%	94	0.31

Table 24: Ownership of LPG heaters in the current HEEP sample

7.2 LPG heater and dehumidifier ownership

The operation of portable LPG heaters also releases quantities of water vapour into the heated space. Dehumidifiers are becoming an increasingly popular method to reduce moisture levels so the ownership of both the source of moisture creating (LPG) heaters and moisture removing dehumidifiers is of interest. Table 25 provides a cross-tabulation of the reported ownership of dehumidifiers with the reported ownerships of LPG heaters. It shows that 35% of houses with LPG heaters have a dehumidifier, whereas the houses that do not have an LPG heater have about a 21% chance of having a dehumidifier. The difference in the proportion of houses with dehumidifiers in houses owning LPG heaters and those not owning LPG heaters is significant at the 1% level (p-value of 0.0004).

	No LPG	LPG	TOTAL
No dehumidifier	171	59	230
Dehumidifier	45	32	77
	217	91	307

Table 25: Ownership of LPG heater and dehumidifier

7.3 Data availability

To measure the energy use of an LPG heater, each heater has to be instrumented with a data logger and a number of thermocouples. Each heater is run through a series of burns for each of the heater's settings at the time of installation. The information from the data logger is collected at each visit to the house. The HEEP year 4 report (Camilleri et al 2000) provides a detailed description of the data collection methods used for LPG heaters.

The data collection methods were developed while the HEEP study was collecting data from Wellington (1999 monitoring year). Consequently there is no usage information for the 17 heaters in the Wellington sample.

Although an LPG heater may be present in a house, it may not be used at all during the year. Table 26 gives the number and percentage of LPG heaters in the measured sample which were reported by the occupants as being used. It shows that the overall percentage of LPG heaters that are reported as used is 81% – that is one in five LPG heaters is not expected to be used.

Not all of the 'reported as used' LPG heaters will have data available over the winter (June, July, August) period due to the heater not being used (or being present) in the house. The reasons for this missing data are generally occupant-driven and include such items as the heater being sold, the occupants moving out, heaters being borrowed temporarily or the heater developing a fault. The number of heaters that don't have such 'occupant'-related issues is given in Table 26.

Additionally, faults with the monitoring equipment (thermocouple wires shorting out or loss of data from the data logger) will also reduce the number of heaters that have valid data over the winter period, and these numbers are also shown in Table 26.

Finally, Table 26 also shows the number of LPG heaters in each region that have measured (non-zero) energy use. The difference between the number of heaters with measured data and the number of heaters with usage (non-zero) data recorded are the number of heaters that were reported as being used (including those reported as being used only very rarely) but did not report any usage during the year. The proportion of heaters that were either reported as not being used or had zero usage recorded was 26%. However, a proportion of those heaters that could not be measured would have also not been used, so this proportion may be lower than the overall figure.

	Number of LPG heaters					
Region	**Owned**	**Reported as used**	**With data (no occupant issues)**	**With data *(no monitoring issues)***	**Use recorded**	**Examples of reasons for missing measured data**
Wellington	17	14 (82%)	14	0	0	Methodology being developed
Hamilton	8	6 (75%)	5	5	5	Borrowed heater for 'short-term' use only
Auckland	28	24 (86%)	19	17	13	Occupants moved Sold heater Heater developed fault *Thermocouples shorted out*
Waikanae	1	0 (0%)	0	0	0	-
Total	54	44 (81%)	38	22	18	

Table 26: Usage of LPG heaters from the processed HEEP LPG sample

7.4 LPG heater use

Figure 45 and Figure 46 give histograms of the average weekly hours of use and the average weekly energy use over the winter period for the 22 LPG heaters (including the four heaters that had zero usage). The heaters are used on average over winter for 9.8 hours per week using on average 19.7 kWh of energy. Both histograms display some positive skewness, with two or three heaters showing much higher usage than the others.

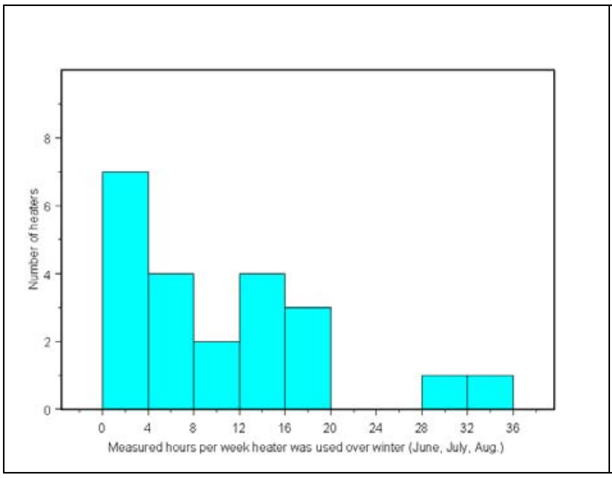


Figure 45: LPG heater time use distribution

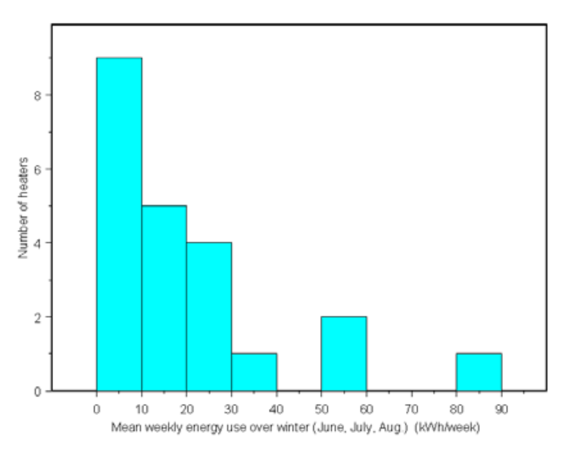


Figure 46: LPG heater energy use distribution

Figure 47 shows a plot of the cumulative energy use for the LPG heaters. It can be seen that over 50% of the energy was used by only 20% of the heaters. Once a representative number of heaters have been measured, a graph like Figure 47 will be useful for estimating how practical targeting energy reduction measures will be for LPG heaters and whether large reductions in energy are possible from a practical number of heaters.

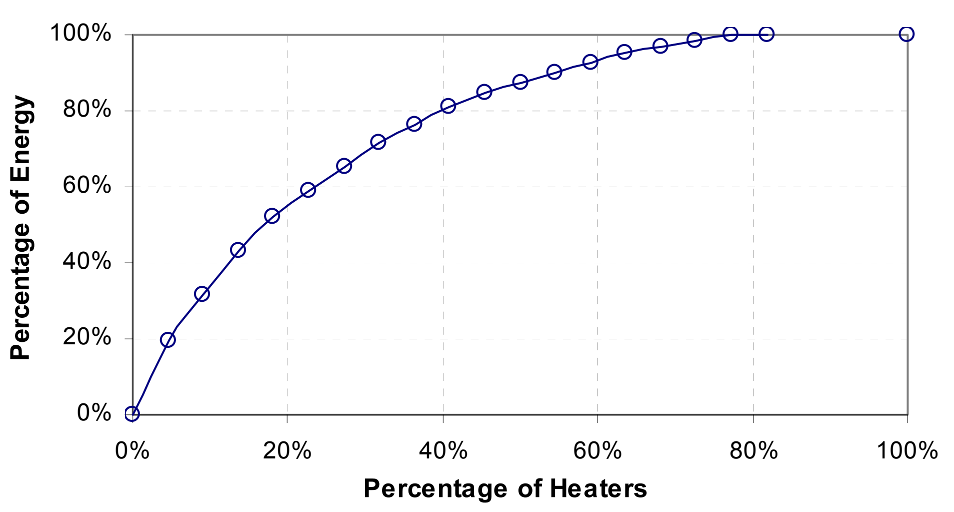


Figure 47: Cumulative plot of the energy used by each LPG heater

As part of the survey undertaken for HEEP, the occupants are asked to estimate their winter (hours per week) usage of each of their heaters. Figure 48 provides a comparison of the occupant's surveyed estimate of their use of their LPG heater with the measured hours per week calculated from the logger records. Note that two of the surveys did not report an estimate of the usage of their LPG heater so only 20 points are given in Figure 48. The majority of cases are above the one-to-one dotted line, indicating most people were over-estimating their usage of their LPG heater. There is also a high degree of scatter in the data, suggesting that people's estimates of their heater use are, in general, poor.

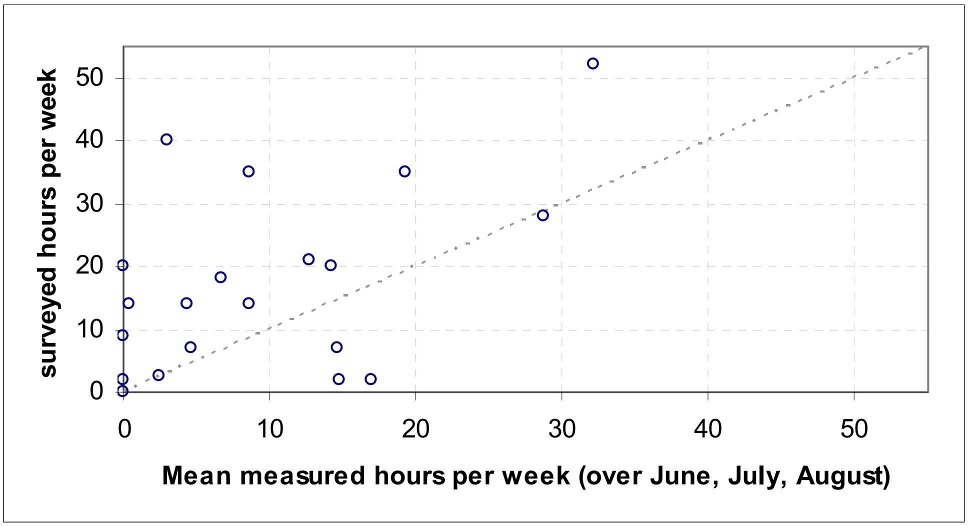


Figure 48: Comparison of the surveyed and measured hours per week use

The relationship between the measured hours per week and the energy use per week for each of the LPG heaters is shown in Figure 49. It suggests that a reasonable estimate of the weekly energy use can be made if the weekly hours-of-use are known.

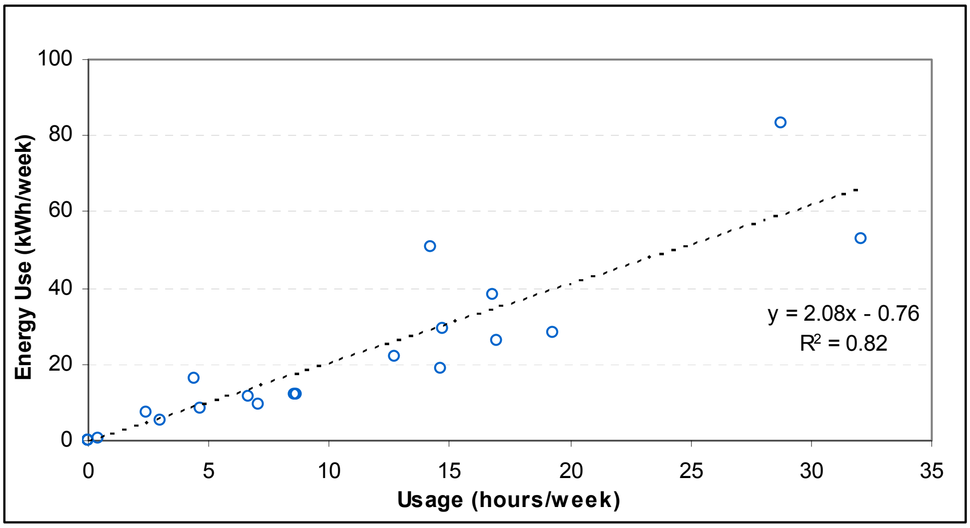


Figure 49: Comparison of hours of use and energy use

7.5 Heater settings used

LPG heaters generally have three settings covering low (1200-2300 W), medium (2300-3200 W) and high (3200-4300 W) ranges.

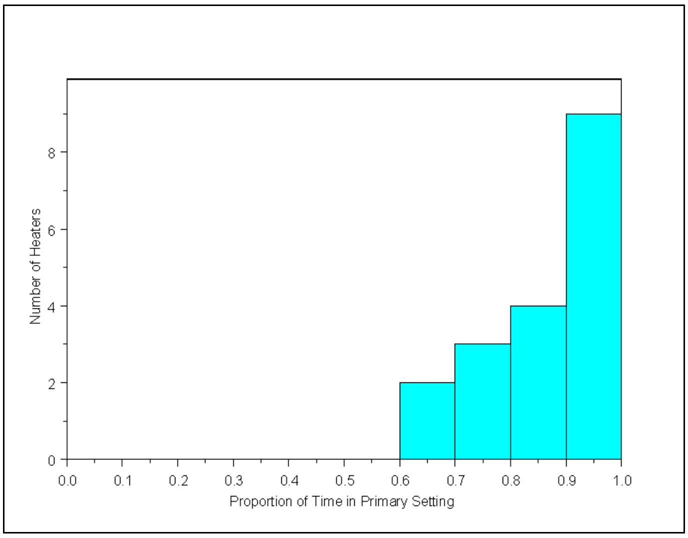


Figure 50: Proportion of time at the heater's most popular setting

Of the 18 heaters reporting usage, 16 had three settings, one heater had four settings (the additional setting being 'Economy' 0-1200W) and the remaining heater, which was a smaller sized heater had only low- and medium-ranged settings.

Of the 18 heaters, 13 (72%) are predominantly operated on low setting, 2 (11%) are operated on medium and 3 (17%) are operated on high setting.

Figure 50 gives a histogram of the proportions of time each LPG heater is in its most popular setting. Only one setting was used for seven of the 18 heaters and close to three-quarters of the heaters spent more than 80% of their time in their most popular setting.

Figure 51 shows the overall breakdown of the average weekly and mean weekly energy use by the LPG heaters by setting. On average, the low settings contribute about half of the total energy used by LPG heaters, with the medium setting contributing about one-third. The high setting accounted for about one-sixth, while the uncommon 'economy' setting made only a small contribution to the overall energy used by LPG heaters.

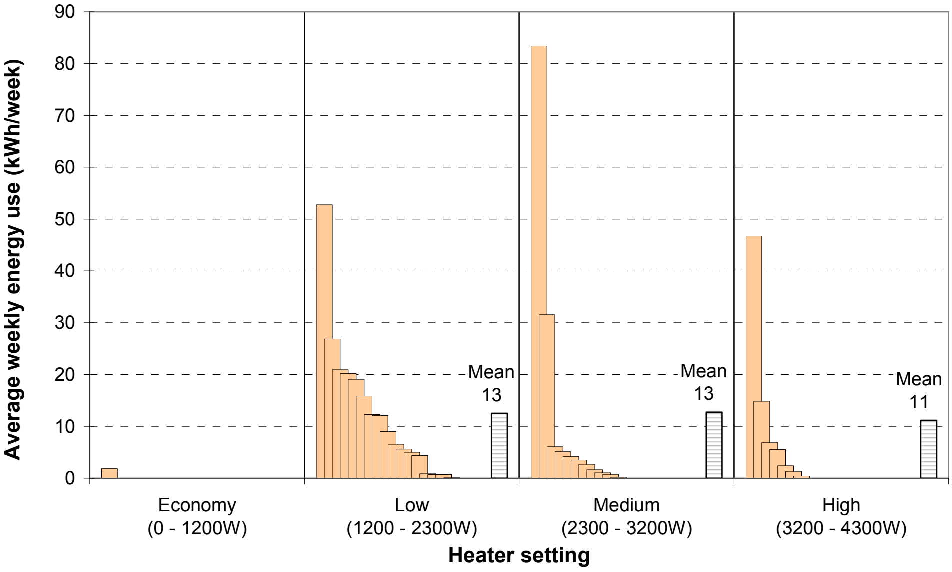


Figure 51: Average weekly LPG energy use by heater setting

Table 27 gives the means and standard deviations (as the plus or minus figure) of the non-zero (i.e. those settings that were used) settings from the 22 heaters that were measured. Overall there is a high variation in the energy and time use between the settings of the heaters, reflected in the large standard deviations in comparison to the means. An interesting comparison between the settings is that the mean energy use for the heaters, which varies by 12% from highest to lowest, is more consistent than the mean hours of use which varies by 64% from its highest to lowest values.

Setting	**n**	**Duration (hours/week)** (± 1 SD)	**Energy (kWh/week)** (± 1 SD)
Economy	1	1.8	1.9
Low	17	8.4 ± 8.3	12.5 ± 13.2
Medium	11	4.6 ± 8.7	12.7 ± 25.0
High	7	3.0 ± 4.4	11.2 ± 16.4
Overall	18	12.0 ± 8.7	24.1 ± 21.0

Table 27: Average energy and hours of use

8. HOT-WATER SYSTEMS

The analysis in this section, unless otherwise stated, refers to proportions of individual cylinders i.e. if a house has more than one cylinder, all the cylinders will be included in the analysis. The database used for this analysis includes houses that were installed during the current round of monitoring, and for these systems the energy use will not be available until completion of the monitoring in the 2004 year.

Of the houses in the current HEEP database (including both random and non-random houses), 91% have one hot-water system, 8% have two systems and 1% have three systems. None have more than three hot-water systems.

The energy used by hot-water systems relates to two key performance issues:

- **technical** – the system thermal efficiency, which is largely under the control of the
    - cylinder manufacture (e.g. cylinder insulation, appliance efficiency, type of thermostat, etc)
    - designer (e.g. type of system, distance to principal use, size of cylinder, size of 'element', shower mixer, shower head, etc)
    - installer (e.g. pipe insulation, type of pipe, quality of installation, interactions with other user, etc)
- **behavioural** – the usage of hot water which is primarily driven by the users e.g. thermostat setting, length of use, type of use (showers, baths, washing, etc), time-of-day use, etc.

The HEEP work has been concerned with separating these performance issues and investigating their relative importance in determining not only water energy use, but also their relevance to hot-water use in specific appliances and hot-water safety.

8.1 NZ Building Code requirements

Table 28 gives the Objective of **Clause G12 : Water supplies** as set out in Schedule 1 of the Building Regulations 1992 (New Zealand Building Code).

Objective
G12.1 The objective of this provision is to-
(a) safeguard people from illness caused by contaminated water:
(b) safeguard people from injury caused by hot water system explosion, or from contact with excessively hot water:
(c) safeguard people from loss of amenity arising from-
    (i) a lack of hot water for personal hygiene; or
    (ii) water for human consumption that is offensive in appearance, odour, or taste
(d) ensure that people with disabilities are able to carry out normal activities and functions within buildings.

Table 28: Building Regulations 1992 – extract from "Clause G12 : Water supplies"

These objectives are in turn met by the requirements of the Acceptable Solution and Verification Method. Table 29 sets out the portion of the Acceptable Solution to **Clause G12: Water supplies** which deals with 'Temperature Control Devices' and 'Safe Water Temperatures'. In broad terms, the Acceptable Solution requires thermostats to be of a quality set out in the appropriate Standards, safety cut-outs to control dangerous temperatures, appropriate temperature limiting mechanisms (to a level depending on the type of users) and a storage temperature to limit possibility of infection from Legionella pneumophila (Legionnaires' disease) bacteria.

6.4 Temperature control devices

6.4.1 Electric thermostats shall comply with NZS 6214 or AS 1308.

6.4.2 Energy cut-off devices shall be designed to:
a) Be reset manually, and
b) Disconnect the energy supply before the water temperature exceeds 95°C.

6.13 Safe water temperatures

6.13.1 Maximum temperatures

The delivered hot water temperature at any sanitary fixture used for personal hygiene shall not exceed:
a) 45°C for early childhood centres, schools, old people's homes, institutions for people with psychiatric or physical disabilities, hospitals, and
b) 55°C for all other buildings.

COMMENT:
1. At greatest risk from scalding are children, the elderly, and people with physical or intellectual disabilities, particularly those in institutional care.
2. Sanitary fixtures used for personal hygiene include showers, baths, hand basins and bidets.

6.13.2 Hot water delivered from storage water heaters

a) An acceptable method of limiting hot water temperature delivered from storage water heaters is to install a mixing device between the outlet of the water heater and the sanitary fixture.
b) Tempering valves shall comply with NZS 4617 or AS 1357.2.

6.13.3 Legionella bacteria

Irrespective of whether a mixing device is installed, the storage water heater control thermostat shall be capable of being set at a temperature of not less than 60°C to prevent the growth of Legionella bacteria.

6.13.4 Where loop systems are used temperature is to be greater than 60°C.

Table 29: NZBC Acceptable Solution G12/AS1 – Water Temperature & Control

When hot water cylinders are replaced on a like-for-like basis e.g. when a cylinder fails it is replaced by a new one of the same size and pressure, then if no tempering valve was present then a new is not required.

8.2 House and cylinder age

The age of the hot-water system and the age of the house appear to be of particular importance in understanding the thermal performance of the hot-water system.

House age is not always easily established. In some cases full house plans are available, while in others the house occupants may know the year of construction. In many cases it is necessary to rely on a combination of information, including the design style. The result of this is that although in some cases the exact year of construction can be established, in the majority of cases it has only been possible to allocate a decade of construction.

DHW cylinder age is also not easily established without manufacturer's documentation. Establishing the year of manufacture is based on a combination of on-site observations, notably labels giving one or more of: cylinder guarantee; date-of-manufacture; date of installation; or warranty expiry. In some cases an attached tag or card provides this information, but often the installation date (and hence warranty expiration) has not been noted on the cylinder during installation.

If the exact year of house construction has not been determined, for the purposes of comparison the mid-year of the decade has been used. This can lead, in a small number of cases (less than 10 for the current sample) to cylinders appearing to be older than the house e.g. if the house was built ‘in the early 1970s the decade of construction would be recorded as ‘1970-79’, and the apparent year of construction would be calculated as ‘1975’, but the cylinder year of construction may be labelled ‘1968’ – making it apparently seven years older than the house. The cylinder date would suggest that the house was actually built in 1968 or 1969, but to ensure valid comparisons, the cylinder has not been used to age the house. However, the difference between the house and hot-water cylinder age have been used to check for obvious errors, either in data recording or data entry.

8.3 Water temperatures

Previous research has found that New Zealand home hot-water temperatures are higher than in other countries (Waller, Clarke & Langley 1993). To begin to understand the factors that determine hot-water temperatures in New Zealand houses, a wide range of data collected by the HEEP study has been analysed, and is reported in this section.

8.3.1 System types

All houses in the sample have one or more hot-water systems, although not all systems are fully operational. Table 30 lists the HEEP codes for the various types of hot-water systems, and the number of houses reporting each type in the survey. The number of systems is greater than the number of houses, as some houses have more than one type of hot-water system.

Hot-water system (Survey response)	**Systems count**
Electric Cylinder (inc. night rate)	303
Electric + Solar Cylinder	1
Electric + Solid Fuel (Wetback) Cylinder	28
Electric + Solar + Wetback	2
Solid Fuel Cylinder	2
Gas Cylinder	30
Instant Gas	18

Table 30: HEEP hot-water systems

Table 30 shows that the majority of the HEEP hot-water systems (79% for the analysed sample) have only an electric storage water cylinder – an electric element is located inside an insulated tank of water, with the temperature controlled by a thermostat. Eight percent of the systems are have an electric cylinder with some form of supplementary heating, either solar, wet back or a combination. Eight per cent of the water heating systems are gas storage systems, 5% are instantaneous gas and less than 1% are solid-fuel-only.

Electric D-grade | Electric B-grade | Electric A-grade | Gas Instants | Gas Storage

Figure 52: Examples of hot water cylinders

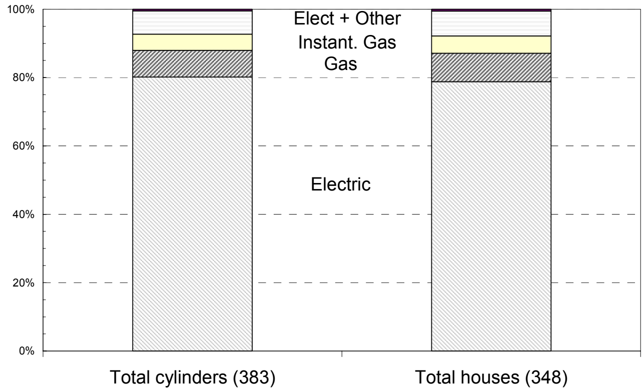


Figure 53: Hot water systems – by type and houses

Figure 52 provides illustrations of the different types of hot-water cylinders found in the HEEP sample. The 'worst' hot-water cylinder lacked any insulation (i.e. was a bare copper).

Figure 53 gives the proportions of the different types of hot-water systems for both the total number and the systems found in each house. The proportions are similar – the main difference relates to the houses with both electric and gas storage systems.

8.3.2 Hot-water service

House occupants don't like to run out of hot water. As part of the HEEP survey, house occupants are asked: 'Do you sometimes run out of hot water?'

Table 31 summarises the responses received from the randomly selected HEEP houses, categorised by the 'main' means of hot-water heating. Note that that where a house has had to be replaced in the sample (most often due to the occupants moving and the new occupants not wishing to continue as part of HEEP), the replacement is also included in this table. It should also be noted that each house may have more than one method of heating hot water, using one or more different fuel types.

Do you run out of hot water?	**Electric**	**Gas**	**Inst. gas**	**Total**
Yes	17%	21%	0%	16%
No	72%	62%	81%	72%
Don't know	11%	17%	19%	12%

Table 31: Hot water adequacy by fuel type for randomly selected houses

Table 31 shows that 16% of households report that they 'sometimes' run out of hot water – with a slightly higher proportion of householders with natural gas storage than electric storage.

Do you run out of hot water?	Mains	Low	Total
Electric	13%	20%	19%
Natural gas	27%	17%	25%
Average	16%	20%	20%

Table 32: Hot water adequacy by system pressure

Table 32 provides a breakdown by water pressure and fuel type for those households that answered (i.e. excluding 'Don't Know') this question. If anything, households with the 'main' system based on a natural gas storage cylinder would appear to have greater problems with supply than houses with electric systems. This could be due to a number of reasons, including:

- lack of awareness of how to control gas storage system water supply temperature
- too much awareness of how to adjust the electric storage system water temperature
- poor match between cylinder size and household requirements
- different expectations for the different fuel and water pressures

Further investigations into this issue will be undertaken in the coming year.

8.3.3 Cylinder sizes

Table 33 tabulates the number of hot-water systems and the cylinder volume. As instantaneous gas water heaters do not store water, the cylinder size is reported as 'missing'. The majority of hot-water systems are electric, so sizing distribution is dominated by electric systems.

Table 33 shows that most cylinders are either 135 litres (30 gallons) (50% of the electric cylinders) or 180 litres (40 gallons) (40%), with the remainder being split almost equally between the small cylinders located close to their end use (e.g. under sink kitchen hot water) and larger cylinders. These cylinder size proportions do not change greatly when electric cylinders with supplementary fuels are included in the analysis.

This cylinder size distribution pattern is also seen with gas storage cylinders, with 50% at 135 litres and close to 40% of the sample at 180 litres.

		Cylinder nominal volume							
System	**Missing**	**25**	**50**	**75**	**135**	**185**	**250**	**350**	**Total**
Electric storage cylinder	9	3	6	4	153	122	5	5	307
+ Solar + solid fuel wetback						1		1	2
+ Solar water heater								1	1
+ Solid fuel wetback	1				10	5	7		23
Gas storage cylinder (only)	2			1	15	11		1	30
Instant gas heater (only)	18								18
Solid fuel storage cylinder (only)						1	1		2
TOTAL	**30**	**3**	**6**	**5**	**178**	**140**	**13**	**8**	**383**

Table 33: Hot water systems by fuel source and cylinder volume

Cylinder size (volume) distribution varies by location. Figure 54 shows that in the North Island sample (Auckland, Hamilton, Wellington and Wanganui) 52% of the sample cylinders are 135 litres and 37% are 180 litres or greater. In the South Island (Christchurch) the reverse is the case, with 24% of the cylinders at 135 litres and 66% at 180 litres or greater.

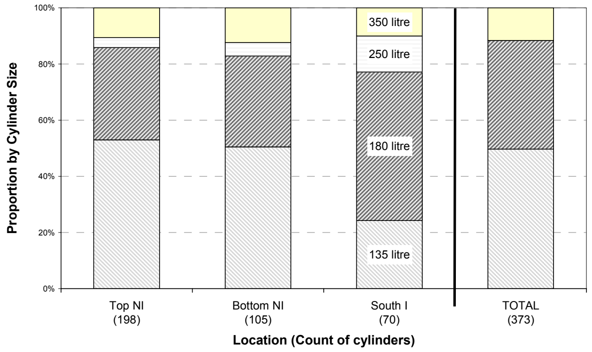


Figure 54: Cylinder size by region

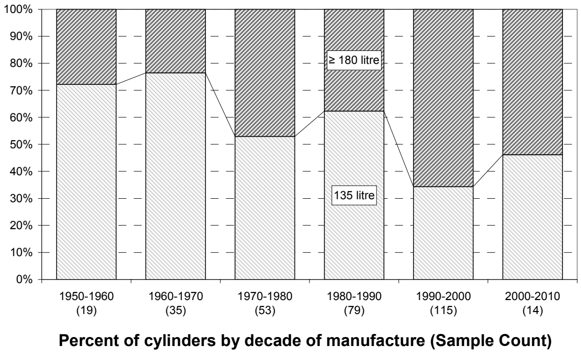


Figure 55: Cylinder size by age

It is likely that this difference in cylinder size distribution relates to policies implemented by local electricity suppliers over many years, rather than explicit consumer choice. As well as cylinder volume, the size of the elements related to local power company policy. In some areas (notably North Island) larger (2 to 3 kW) elements were required supporting the use of smaller cylinders, while in other areas (notably South Island) lower power (possibly less than 1 kW) elements were used with larger cylinders. The variation in element size related to the load control requirements, balancing the hot water demand and line capacity.

These policies continue to have on-going consequences, due first to the long lifetime of most hot-water cylinders and second to the difficulties of replacement. Anecdotal evidence suggests that cylinders are almost invariably replaced ‘like-with-like’ to ensure the replacement is able to fit in the space occupied by the failed cylinder or not exceed the permitted load on the existing wiring.

Jaye et al. (2001) reporting on a telephone survey of 111 craftsmen plumbers from throughout New Zealand found that respondents believed that ‘older homes were likely to have smaller hot-water cylinders set at higher temperature to compensate for small capacity’. Figure 55 examines the age distribution proportion for the 135 litre and large (greater than or equal to 180 litre) cylinders in the sample. The time period starts with the decade of the 1950s, as the sample size in the earlier decades is too small to permit a reasonable comparison. It can be seen that a higher proportion of the more recent cylinders are 180 litres or greater, suggesting there may be a shift to increased storage volume.

8.3.4 Water pressure

The ‘traditional’ New Zealand electric hot-water system is ‘low pressure’, based around header tank (or more recently a pressure reducing valve) feeding an open vent cylinder (less than 3.7 m or 37 kPa head). Over time the trend has been to ‘medium pressure’ using a pressure-reducing-valve (generally 7.6 m or 75 kPa head), and more recently to ‘mains pressure’ hot-water systems.

The HEEP house audit collects data on the existence of pressure relief valves but for this analysis, systems with either pressure relief valves or header tanks are counted as low pressure. Data on the cylinder or system pressure was not recorded in the early years of HEEP. In these cases, system pressures have been allocated based on available data:

- **cylinder insulation grade** – D and C grade electric cylinders are 'low' pressure
- **cylinder age** – electric cylinders older than 30 years are 'low' pressure
- **system type** – instantaneous gas are 'mains' pressure
- **cylinder photo** – cylinders marked 'low pressure' or '7.6 m head' are 'low', while cylinders marked 'mains pressure' are 'mains'
- **house exterior photograph (s)** – a roof vent pipe indicates the system is 'low', although the reliability of this methods is not considered to be high.

After these manual allocation methods were applied, the system pressure could not be categorised for only 53 systems (14% of the sample).

Of the houses for which pressure data is available, more than three-quarters (79%) are low pressure and less than one-quarter (21%) are 'mains' pressure.

Pressure	Low	Mains	Unknown	TOTAL
Electric storage	252	38	43	333
Gas storage	5	15	10	30
Gas instantaneous	-	18	-	18
Other	2	-	-	2
	259	**71**	**53**	**383**

Table 34: System pressure by fuel type

Table 34 provides the counts for the different system types by pressure. The majority of electric storage systems are low pressure, while the opposite is true for gas storage systems.

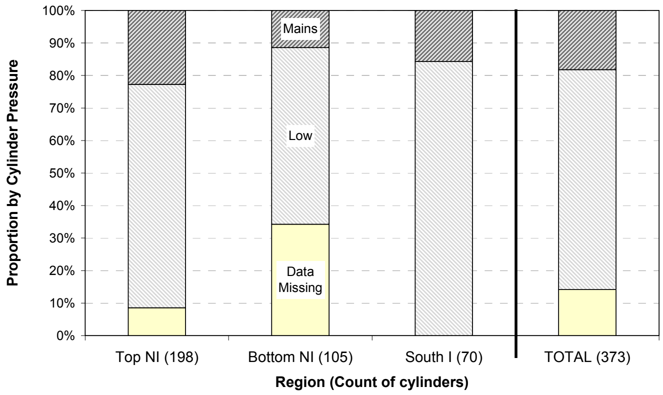
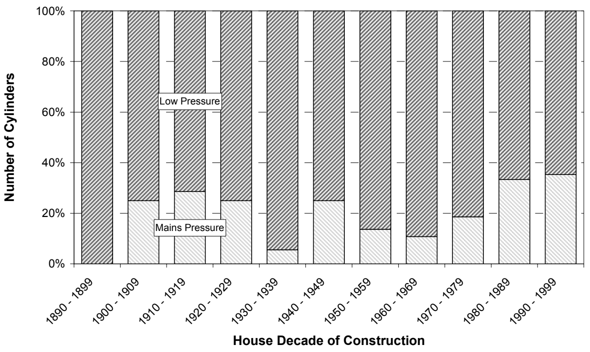


Figure 56: System pressure by region

Figure 56 analyses the hot-water system pressure by region and provides an overall distribution for the available data from the current HEEP sample. The number of cylinders in each region is given in brackets.

Figure 56 suggests there is no strong regional pattern for the use of mains pressure systems. For each of the three regions, 75% to 85% of the cylinders (for which information is available) are 'low' pressure.

The relationship between house age and cylinder age was also investigated. Both the year of the house construction and the year of cylinder manufacture are available for 86% of the cylinder sample (320 cylinders).



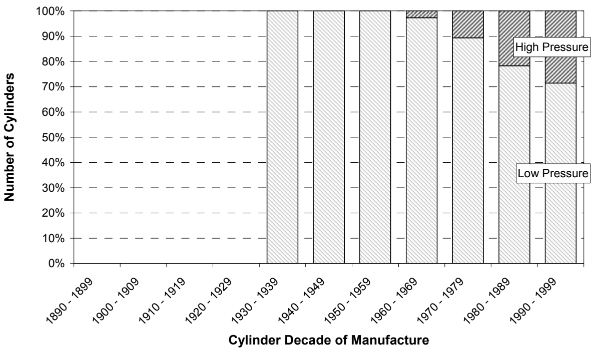


Figure 57: Pressure by house decades **Figure 58: Pressure by cylinder decades**

Figure 57 shows the distribution of hot-water pressure by house decade of construction, and Figure 58 by cylinder decade of manufacture. There are no cylinders manufactured before 1930 in the sample, so Figure 58 starts from the 1931-40 decade. It is not until the 1971-80 decade that there is a fall off in the use of low-pressure systems, and a sizable number of mains-pressure systems appear in the sample.

8.3.5 Hot water cylinder age

Houses have a longer life than hot water cylinders, and it is expected that as hot water cylinders fail they will be replaced, often with the same size although not necessarily with the same pressure. Figure 57 illustrates that even very old houses (which originally would have had low-pressure systems) are being retrofitted with mains pressure hot-water systems. About one-third (32%) of the houses but two-thirds (65%) of the hot-water cylinders date since 1980. The oldest cylinder in the sample dates from the 1930s. The data does not shown any obvious link between cylinder size and its lifetime.

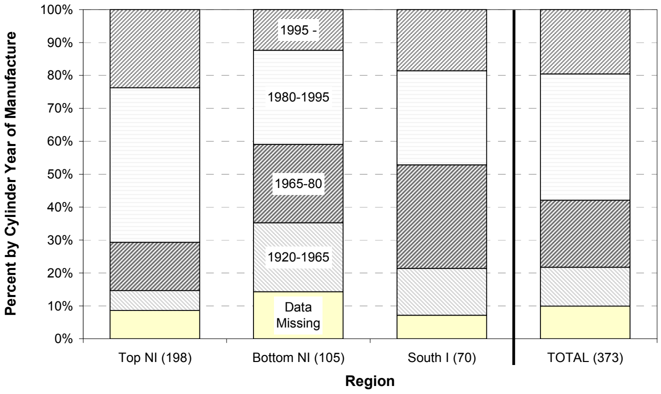


Figure 59: System age by location

Figure 59 shows the distribution of cylinders by year of construction and regional location. The grouping of construction years is based on the approximate years when a significant change in cylinder grades occurred. Most pre-1980 cylinders are ‘C’ or ‘D’ grade, and many 1980s and later cylinders are ‘B’ grade. ‘A’ grade cylinders have only been required since 2003.

Thirteen percent of the cylinders for which both cylinder and house age are available were manufactured before 1965; 23% were manufactured in the period from 1965 to 1980; 43% from 1980 to 1995, and the remaining 22% after 1995. Figure 59 shows a regional trend, with a higher proportion of younger cylinders in the top of the North Island compared to those in the South Island.

House year	Years ago	% of total	Cylinder same decade as house	Cylinder replaced
1890-1909	113-94	3%	0%	100%
1910-1929	93-74	9%	0%	100%
1930-1949	73-54	11%	9%	91%
1950-1969	53-34	32%	45%	55%
1970-1989	33-14	28%	77%	23%
1990-2003	13-0	18%	100%	0%

Table 35: House and cylinder age comparison

On average, 55% of hot water cylinders are within 10 years of the house age, but Table 35 shows this proportion varies with house age.

It was not possible to determine whether or not, these cylinders were originally installed at construction, as it is feasible (albeit unlikely) that the cylinder could be replaced within the first decade of the house life or a secondhand cylinder has been used.

Cylinder	Type	Usual working head	Life expectancy
Copper	Low pressure	2 – 7.6 m	20 – 50 years
Copper	Low pressure	12.2 m	20 – 40 years
Glass lined steel	Mains pressure	35 – 50 m	12 – 20 years
Stainless steel	Mains pressure	35 – 50 m	20 – 40 years (estimate)

Table 36: Life expectancies of cylinder types

Table 36 sets out life expectancies for different cylinder types from Williamson and Clark (2001)[xi]. The potentially long lifetime of older copper cylinder, low-pressure systems is supported by the results shown in the previous figures. Note that the cylinder life expectancy is affected by a range of issues specific to the house and area, notably the water quality.

8.3.6 Cylinders and house size

The physical attributes of a house (e.g. floor area, number and size of hot water cylinders) are far less flexible than the number of people that can be living in the house.

Figure 60 compares the floor area of the monitored houses with the total volume of hot water cylinders – in houses with more than one cylinder, this is the calculated total volume of all cylinders. Figure 60 includes only storage cylinders i.e. instantaneous gas systems are excluded from this analysis. Figure 60 suggests that designers and builders do place some value on providing larger hot water volumes for larger houses, although the scatter shows there is considerable room for improvement.

Figure 61 compares the total volume of hot-water storage to the number of occupants, and again there is no clear link. This would suggest that the provision of hot water designed into the house, is not matching the likely number of occupants over the lifetime of the house.

[xi] Note: this table uses data originally provided by BRANZ, but is here quoted from Williamson & Clark 2001

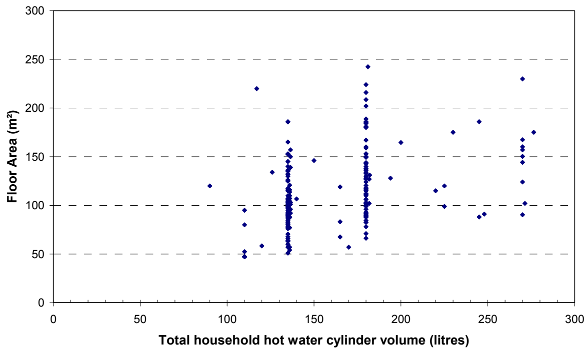


Figure 60: Total hot water volume vs. floor area

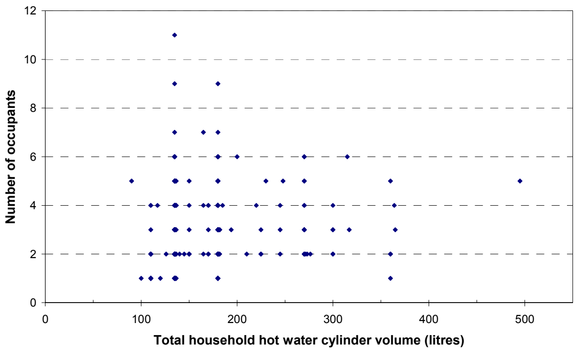


Figure 61: Total hot water volume vs. number of occupants

Clark et al. (2000) compare the actual volume of electric hot-water storage to the expected volume based on use of 45 litres of hot water per day per person. It was suggested that 27% of the houses surveyed needed a 270 litre cylinder, but only 9% had that capacity. At the other extreme, only 11% of their surveyed households could be expected to have sufficient hot-water delivery from 135 litre storage, but 34% had cylinders of that size.

8.3.7 Water temperatures by cylinder size

As part of the HEEP monitoring equipment installation, the hot-water tap temperature is measured at the tap closest to the hot-water cylinder. The hot water is allowed to run until the temperature is considered to be stable, and then it is then read using a digital thermometer. Either a Dick Smith Electronics 'Digital Pocket Thermometer' or 'Digital Stem Thermometer' is used. These have resolutions of 0.1°C and a claimed accuracy of ± 1°C. Limited calibration testing has confirmed the claimed accuracy.

Figure 62 shows the temperature distribution for electric 135 and 180 litre cylinders, both as 'bell' (dotted lines) and 'S' (solid lines) curves. The number of cylinders are in brackets.

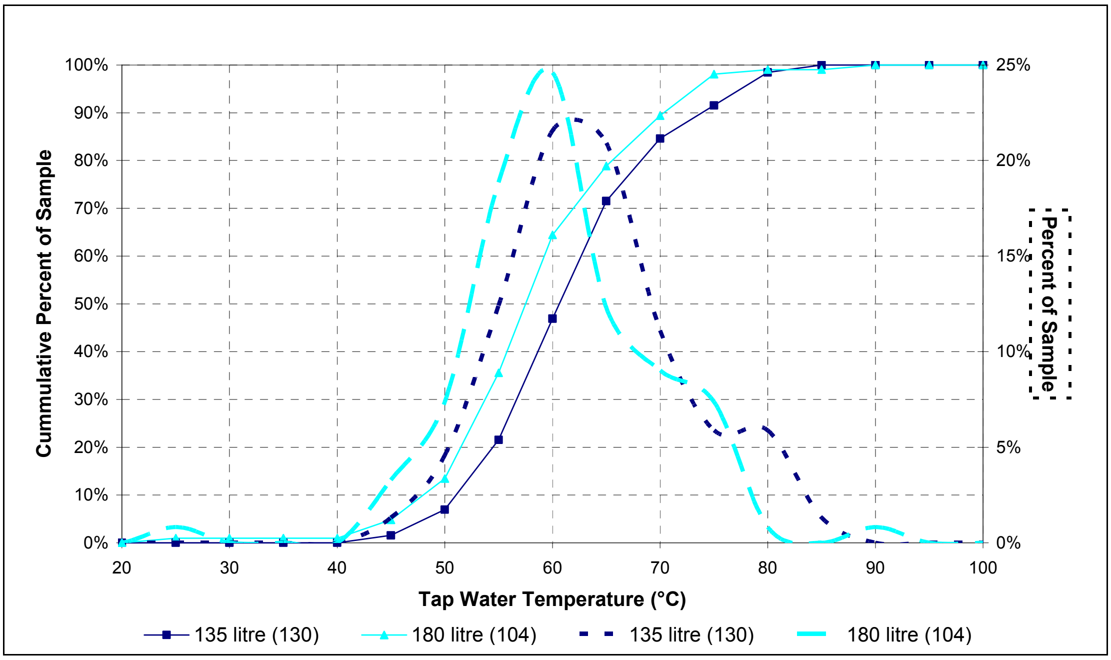


Figure 62: Distribution of hot water tap temperature by cylinder size (electric)

The two cylinder sizes have statistically different temperature distributions (z-score 3.6), with the mean temperature at 61°C for the 135 litre cylinder and 58°C for the 180 litre.

It should be noted that this does not mean larger cylinders always have safe hot-water temperatures. Tap temperatures above 65°C are found in 28% of the 135 litre cylinders and 21% of the 180 litre cylinders. Thus about one in five of the 180 litre cylinders have even more dangerously high water temperatures, compared with more than one in four of the 135 litre cylinders.

The HEEP temperature measurement is taken at a tap as close as possible to the hot-water cylinder. In many cases this will be in either the laundry or kitchen. Since 1993 it has been a requirement under the NZ Building Code Clause G12 for a mechanism to limit tap temperature to be installed (e.g. a 'tempering valve') on the supply to any 'sanitary fixture used for personal hygiene' (see Table 29). It is possible that some tempering valve installations permit water to be delivered at cylinder temperature to the laundry or the kitchen sink, as these are not considered to be 'sanitary fixtures'.

The HEEP installation also measures the hot water temperature at the shower. A comparison of the 'tap' and 'shower' hot water temperatures for the 25 houses which had a tempering valves, and in which both shower and tap temperatures were available, found five situations (20% of the sample) where this could be the case. However, only in one case was the temperature delivered at the tap nearest to the cylinder greater than 60°C.

8.3.8 Electric thermostats

A thermostat is a device that senses temperature and reacts at preset temperatures to turn a power supply on or off (Williamson & Clark 2001). Water heating thermostats are designed to regulate the supply of energy to the element and thereby maintain the water temperature within predetermined limits. The two main types of thermostat used with hot-water cylinders in New Zealand are the:

- **rod type**: usually concealed within the element box, it is not easily accessible to the householder. It is usually set during installation by the electrician, and requires the removal of the cover plate and the use of screwdriver to change the setting. "Rod type thermostats appear in many older cylinders and are not noted for their accuracy" (Williamson and Clark 2001). It is possible to replace rod type thermostats with capillary type thermostats.

- **capillary:** consumer-adjustable thermostats are generally based on a capillary type thermostat that 'are generally regarded as more accurate and more reliable than rod type thermostats' (Williamson and Clark 2001). The control knob is usually on the outside of the element box, and hence readily accessible to the user. This style of thermostat is covered by New Zealand Standard **NZS 6214:1988 :** 'Thermostats and thermal cut outs for domestic thermal storage electric water heaters (alternating current only)'.

The inaccuracy of rod type thermostats has long been known, but no information has been available on the performance in-use in actual New Zealand homes. The HEEP data is now able to be used to remedy this deficiency.

Glass-lined, mains pressure cylinders are designed only to operate to a maximum temperature of 70°C to 82°C depending on the vitreous-enamel lining (Southcorp 1995). All valve vented cylinders are required to be fitted with an over-temperature cut-out as a safety device should the primary thermostat fail.

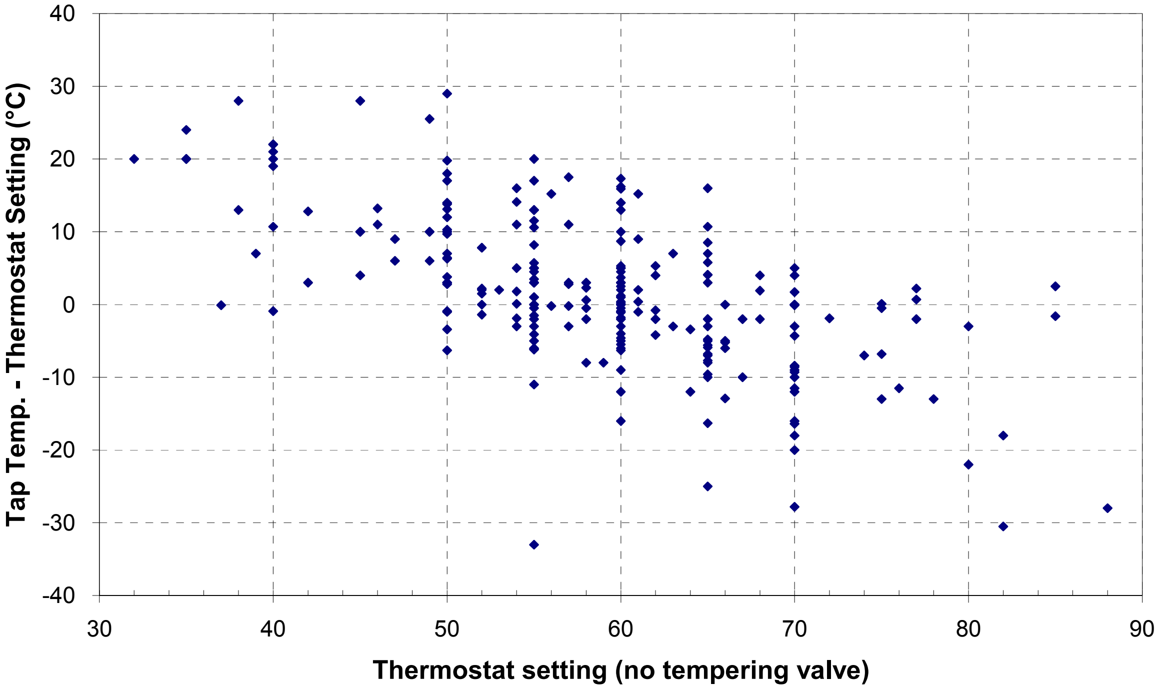


Figure 63: Variation between thermostat setting and delivered water temperature

Figure 63 plots the thermostat set temperature and the difference between the set temperature and the actual delivered temperature at the tap nearest to the hot-water cylinder with no tempering valve present, for the 243 cylinders for which both are available. If thermostat settings were perfectly represented by the tap temperatures, the points would all fall on the zero axis (x-axis), but this is clearly not the case with over one-quarter (28%) being more than 10°C above or below the thermostat setting (including 16% which are more than 15°C above or below the thermostat setting. A linear regression shows a strong relationship (r^2 = 39%), centred around 61°C, but it is clear that even when set at 61°C many cylinders do not maintain this temperature.

The distribution of the temperature differences in Figure 63 is close to a normal distribution (skewness = -0.17), and with a sample standard deviation is 10.3°C. This is somewhat higher than would be desirable.

As the common rod type, immersion thermostats are not marked with the date of manufacture, it is not possible to examine their reliability over time. One possible indication of the longevity of the thermostat is whether the temperature is marked in degrees Fahrenheit (°F) or Celsius (°C). This information is recorded during the HEEP audit, but remains in the documentation on each house. The use of this data source will be considered in the coming year.

8.3.9 How hot?

The hot-water system largely establishes the hot water supplies that will be available to the household. The cylinder volume (if a storage cylinder), the distribution piping or the electric element size can only be altered by specialists. A larger cylinder, improved distribution pipes, a larger electric element or a completely new system and fuel (e.g. change from a small electric storage cylinder to a instantaneous gas system) requires sizeable capital expenditure and the expert skills of an electrician and/or plumber

The only part of the hot-water system that most householders can readily alter is the thermostat (even if not a consumer-adjustable design).

Figure 64 illustrates the energy capacity of a range of different hot-water cylinders for different storage temperatures. The 'specific heat of water' (the energy required to raise one litre of water by 1°C) is 4.1786 $MJ.l^{-1}.°C^{-1}$ (at 40°C). Thus the energy stored in 135 litres of water maintained at 75°C (42 GJ) is almost exactly the same as the energy stored in 180 litres of water at 55°C (41 GJ)– except the water from the 135 litre cylinder is dangerously hot.

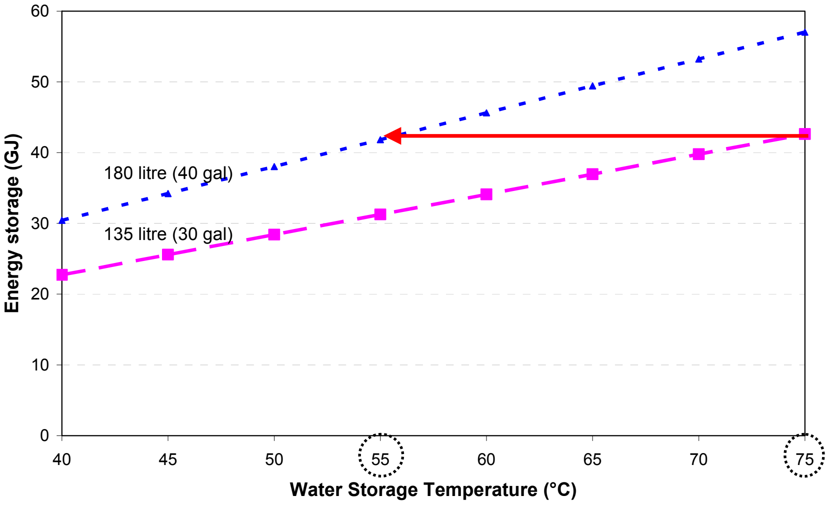


Figure 64: Hot water energy storage by volume and temperature

One consequence is that the higher water temperatures may be unsafe, with increased chance of burns[xii]. The drive for adequate warm water for showers has been shown in some circumstances to overcome safety considerations:

- Tustin (1991) reports on a project in Whakatane concerned with safe water temperatures, where 12 households were provided with consumer adjustable thermostats on their hot water systems. At the time of installation these were set to 55°C and the residents were told about safe water temperatures. On returning to the houses after one year it was found that 25% of households had adjusted the thermostat upwards (i.e. greater than 60°C) to avoid running out of hot water.
- A retrofit programme in the Bay of Plenty found that after a range of energy-efficiency options had been installed (including low flow shower heads which would reduce the demand for hot water) and thermostats were turned down, only a few houses increased the thermostat settings (Jo Hunt – Energy Options Ltd, pers. com. 2003)

[xii] Further research on hot water is available from the Injury Prevention Unit at the University of Otago (www.otago.ac.nz/ipru). Information on safety with hot water is available from Safekids (www.safekids.org.nz)

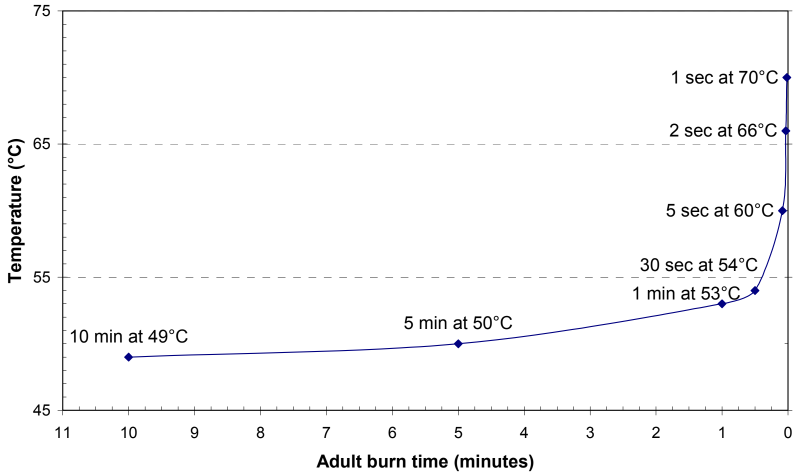


Figure 65: Time for full-thickness epidermal burns in adult skin

Figure 65 gives the time of exposure to hot water needed to cause full-thickness epidermal burns of adult skin at various water temperatures (Katcher 1981, adapted by Waller, Clarke & Langley 1993). Hot water is more dangerous to the very young and the elderly, whose skin is less able to withstand higher temperatures. For a child placing their skin into water at 54°C only 10 seconds is required for a full-depth burn, compared with 30 seconds for an adult (Jaye et. al. 1999).

These results suggest that campaigns asking house occupants to check 'is your hot water the right temperature?', and then provide guidance on how to adjust the hot water thermostat, do not actually deal with the critical issues.

Turning down the thermostat may result in short-term benefits (both safety and energy efficiency), but unless the system provides adequate hot water to meet the needs of the house occupants, the thermostat can readily be 'turned up'. Such campaigns also do not consider the poor performance of most electric hot-water cylinder thermostats, and this may be even more critical to reducing the opportunity for hot-water burns. It also needs to be recognised that only the use of tempering valves can ensure that unsafe temperatures are not possible (see Section 8.1).

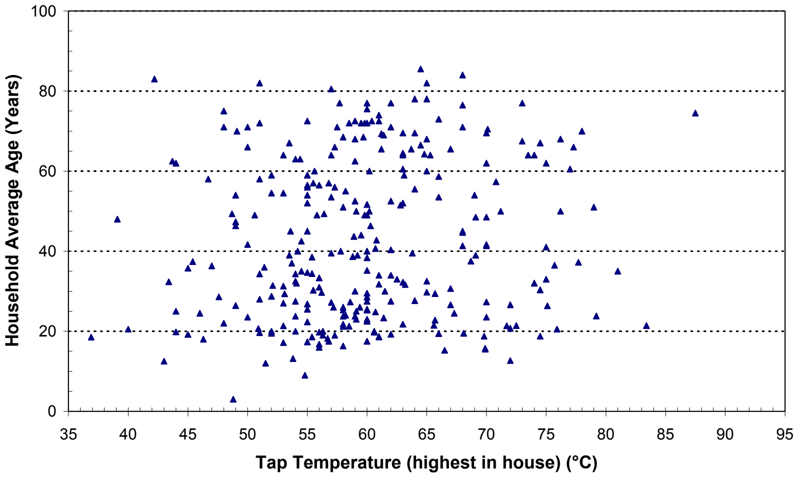


Figure 66: Hot water tap temperature vs. occupant average age

Figure 66 compares the measured tap hot-water temperature with the average age of the house occupants. There is no significant relationship. No pattern was found by comparing the age of the youngest person, or the age of the oldest person, with the tap water temperatures. This would suggest that age is no barrier to the provision of dangerously hot water.

Figure 67 gives the thermostat setting distribution, and Figure 68 the tap temperature distribution. The median for both the thermostat setting and the measured tap temperature is 60°C. However, the thermostat distribution has a skew of -6% (i.e. is asymmetric towards lower thermostat settings) and the tap temperature distribution skew is +8%. (i.e. asymmetric towards higher delivered water temperatures)

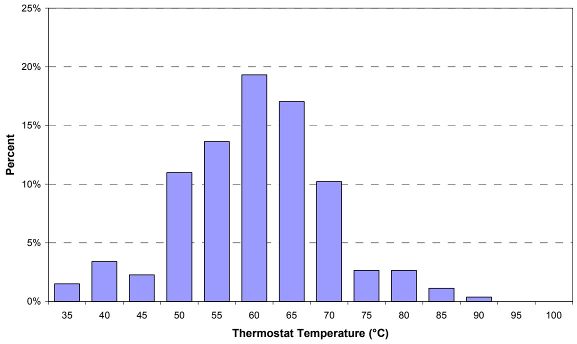


Figure 67: Thermostat setting distribution

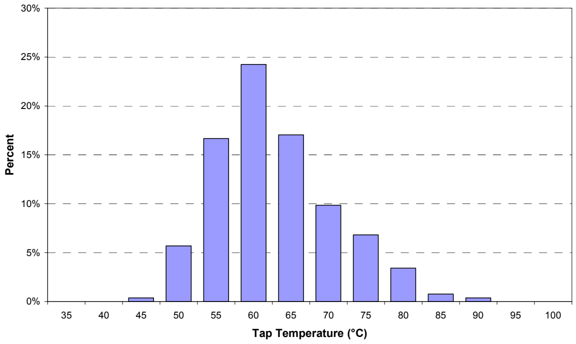


Figure 68: Tap temperature distribution

Figure 69 shows the thermostat settings and resulting nearest tap water temperatures for 273 HEEP hot water cylinders, and this is also summarised in Table 37. The temperature and thermostat data is recorded at the time of installation of the HEEP monitoring equipment. The installation involves a detailed inspection of the hot-water cylinder and its surroundings, and the measurement of water temperatures at the tap nearest to the cylinder after the water had run long enough to ensure maximum temperature had been reached. In a small number of houses, the cylinder had recently had such a large draw-off that the water temperature was obviously incorrectly low. Each point in Figure 69 represents one cylinder, with solid markers showing a tempering valve is present.

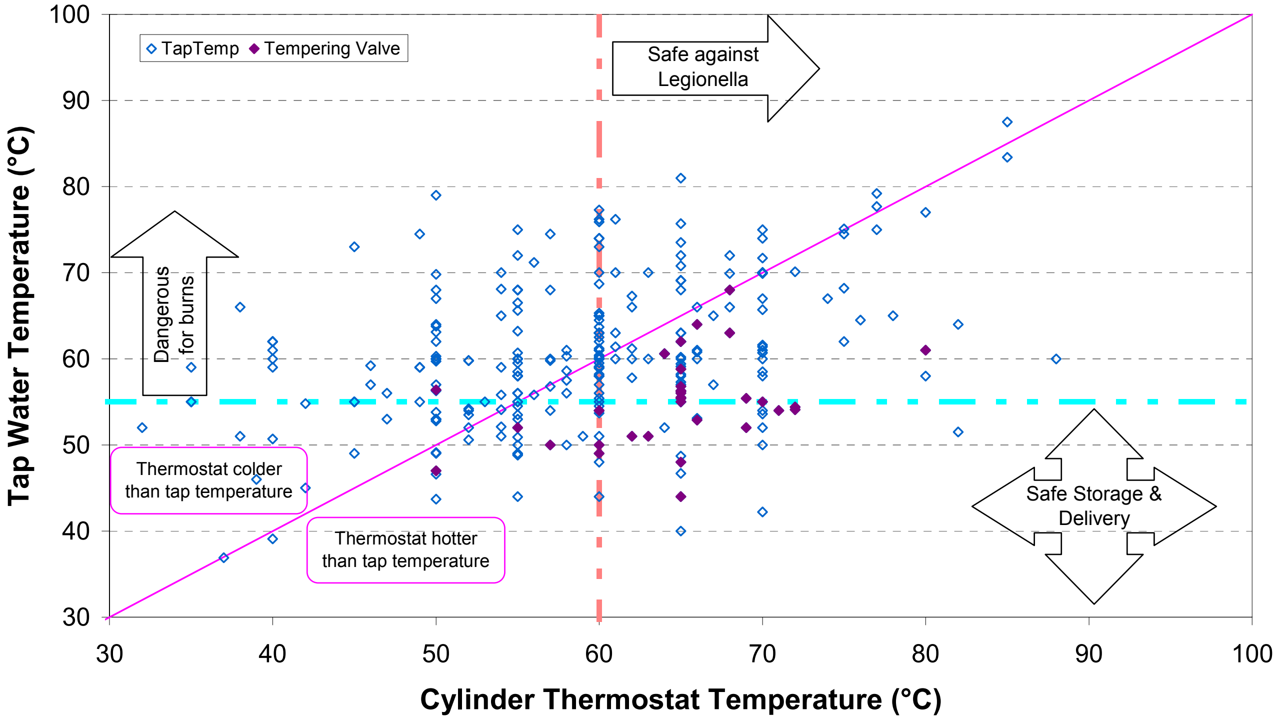


Figure 69: Thermostat setting versus tap hot water temperature

Tap >60°C & Thermostat <=60°C 20% (55)	Tap >60°C & Thermostat >60°C 23% (62)
Tap <=60°C & Thermostat <=60°C 39% (107)	**Tap <=60°C & Thermostat >60°C** 18% (49)

Table 37: Count of thermostat setting versus tap hot-water temperature

Table 37 reports that 43% of the hot-water cylinders deliver water at temperatures over 60°C (i.e. dangerously hot). As illustrated in Figure 63, the thermostat setting can bear little resemblance to the measured actual water temperature, so the recorded settings given in Figure 69 and Table 37 only provide an indication of the house occupants' expectations.

Table 29 (Section 8.1) set out the requirements of the NZ Building Code Clause G12 'Water Supplies', which in brief require the use of a tempering valve to permit hot water storage to be above 60°C and water delivery to be below 55°C.

The vertical (thermostat > 60°C) and horizontal (delivered water <55°C) dotted lines on Figure 69 illustrate these two constraints for housing. The sloped line in Figure 69 illustrates the case if a tempering valve was not present – the temperature of the delivered water would be the same as the thermostat setting (assuming perfect operation of the thermostat).

Figure 69 raises a number of health issues about the provision of hot water in homes:

- **Over 40% of the cylinders had UNSAFE delivered water temperatures:** 43% of the measured water temperatures were above 60°C, including 13% with delivered water temperatures over 70°C
- **One-third of the cylinders had INACCURATE thermostat control:** 67% of the delivered water temperatures are within ±10% of the thermostat setting. However, 25% of the delivered water temperatures are more than 20% higher than the thermostat setting – in other words even if people set the thermostat to what they believe to be a 'safe temperature', the tap temperature may be unsafe.
- **Even when users set the thermostat at a safe temperature, one-third of these cylinders had UNSAFE hot water delivered :** 35% of the cylinders had the thermostat set at 60°C or under, but about one-third of these houses had water over 60°C being delivered at the tap (i.e. 11% of all the cylinders in the sample). Thus even if the householder was attempting to ensure safe temperature water was delivered through correct setting of the thermostat, the thermostat was not providing it.
- **One out of seven houses with a tempering valve delivered hot water over 60°C**: Only 12% of the cylinders (for which thermostat and water temperature data was available) had tempering values to ensure water would be delivered at a 'safe' temperature. Of these systems, 45% were delivering water at less than 55°C, 40% between 55°C and 60°C, and 15% at a temperature above 60°C – although the maximum measured hot water delivery temperature for a cylinder with a tempering valve was only 64°C, compared to the maximum of 87°C for one electric storage system without a tempering valve.

These results help to identify potentially important hot water health and safety issues in New Zealand homes. The HEEP study will continue to monitor delivered and thermostat hot water temperatures. HEEP will also work toward developing an appropriate method of assisting in the identification of hot-water systems that are likely to have excessively high temperature water and tools to ameliorate the possible dangers.

9. SHOWER WATER FLOW

Although the time taken for a shower is under the control of the user, the water flow rate is established by the system in conjunction with the shower head.

The majority of New Zealand hot-water systems are low pressure, and the flow rate (as will be discussed later in this section) may not be high. Far higher flow rates can be obtained from mains pressure systems, in which the use of 'low flow' shower heads may a significant opportunity to improve the system energy efficiency – reducing the hot water use with the assumption that users will not increase the length of time they spend in the shower.

This was confirmed by a North American study of more than 1,100 houses in 14 cities (Mayer et al. 1999). It is expected that the large majority of these systems would be mains pressure. It was found that the average shower time increased by 25% for the low flow compared to the non-low flow showerhead, but as the flow was reduced by 53%, the total water use reduced by 66%. (See Appendix for further details).

9.1 Water efficiency

The water efficiency rating of a shower head relates to the water flow (litres per minute) required to give a comfortable shower. Table 38[xiii] gives the flow rates corresponding to the different ratings under AS/NZS 6400:2003 'Water efficient products – Rating and labelling':

Rating	Water efficiency	Flow rate
A	Good	> 12 to 15 litres per minute
AA	High	> 9 to 12 litres per minute
AAA	Very high	> 7.5 to 9 litres per minute

Table 38: Shower flow ratings

Although the HEEP survey attempts to find information on the presence or absence of low-flow shower heads, the occupants very seldom have such detailed knowledge. This problem was also found in a water use study in Perth, Western Australia (Loh & Coghlan 2003).

9.2 International comparison

The Appendix provides information and data from studies undertaken in North America, Australia and the UK on household shower water use and flow rates. No published survey has been found on water use by individual appliances (including showers) in New Zealand homes.

Internationally reported average shower flow rates are:

- 4 litres/min (low-flow, North America)
- 7 litres/minute (non-low flow, North America)
- 9 litres/min (Perth)
- 10 to 17 litres/min (Sydney),

[xiii] See also the web sites of the Water Services Association of Australia www.wsaa.asn.au & the Water Corporation of Western Australia www.watercorporation.com.au

9.3 Measured shower flows

The HEEP audit includes measurement of the shower flow rates for each shower. Table 39 provides summary statistics on shower water flows by water temperature and pressure. The 'cold' and 'hot' water temperatures were established either by turning on only the appropriate tap, or with continuous flow mixers turning to the highest flow position close to the appropriate end of the dial. 'Warm' was a mixture of hot and cold water at a suitable temperature. The 'average' results in Table 39 include systems for which the water pressure was not recorded (see Section 8.3.4 for further information).

Temperature	Pressure	Number in sample	Average flow rate (litres/min)	Flow standard deviation
Cold	Low	229	6.6	0.3
	Mains	83	8.9	0.6
	Average	351	7.4	0.2
Warm	Low	227	7.2	0.2
	Mains	80	10.6	0.6
	Average	351	8.2	0.2
Hot	Low	229	4.8	0.2
	Mains	78	8.4	0.5
	Average	351	5.9	0.2

Table 39: Average HEEP shower flow by water pressure and temperature

The maximum recorded flow rates were 20 litres/min for low pressure and 30 litres/min for mains pressure. On average, 25% of low pressure systems had 'warm' shower flows over 9 litres/min, while 60% of mains pressure systems were above this threshold.

9.4 Impact of reducing shower flows

There is increasing use of mains pressure systems (see Section 8.3.4), and thus planning must be undertaken on the basis of not the average shower flow rates, but the higher (often mains pressure) shower flow rates.

What would be the consequences of changing the shower heads measured with a flow over 9 litre/min to a 6 litres/min 'low flow' shower head?

Table 40 shows that this would result in a reduction in the average flow rate for low pressure systems (including those that have not been retrofitted) of 1.2 litres/minute and by 4.5 litres/minute for the mains pressure systems.

Pressure	Average flows		Average after retrofit	
	Flow (litres/min)	Standard deviation	Flow (litres/min)	Standard deviation
Low	7.2	0.2	5.9	0.1
Mains	10.6	0.6	6.1	0.1

Table 40: Effect on average flows from retrofitting 'low flow' shower heads

However, Table 40 disguises the impact the reduction in flow rates would have on individual houses. For houses with a shower flow above 9 litres/minute, the average flow reduction would be 6.8±0.4 litres/min for a low pressure system and 7.4±0.4 litres/min for a mains pressure system. This would have a significant impact not only the use of water and the energy required to heat the water, but also on the need to maintain excessively high water storage temperatures in inadequately sized hot water cylinders.

Charges per cubic meter Auckland region	**Base $/m³**	**% of freshwater subject to charge**	**Effective $/m³**
Watercare freshwater	0.515	100%	0.515
Metrowater Network fresh water	0.66	100%	0.66
Watercare waste water	1.88	75%	1.41
Metrowater Network waste water	0.93	75%	0.70
Total water charges			3.29

Table 41: Auckland water costs

Table 41 lists the current water charges for the Auckland region per cubic metre (1,000 litres)[xiv]. Waste water charges are based on 75% of the freshwater volume – thus for each litre of water consumed the cost is 0.329 cents ($0.00329 $/litre). All costs include GST.

Thus a house in Auckland that currently has a shower flow above 9 litres per minute which switched from a high flow to a low flow shower head (saving 7 litres per minute of water) and maintained a 5 minute shower, the **water savings would be around 11.5 cents per shower** (5 min x 7 litres/min x 0.329 c/litre) for the freshwater and waste water.

The energy savings from the reduced flow, based on heating the water from 14°C to 39°C and an electricity tariff of 13 cents per kWh, the **energy savings would be 13.2 cents per shower**.

The total savings would be approximately **25 cents per shower**, or over a full year $90 assuming one shower per day. Thus for a shower with a water flow of 13 litres per minute, the retrofitting of a low-flow shower head (product cost approximately $40), would have a payback of less than six months with one shower a day..

[xiv] Price source: http://www.metrowater.co.nz/frame_ourch_resid.html. Accessed November 2003.

10. HOT WATER STANDING LOSS METHOD UPDATE

HEEP has regularly reported on the standing losses of hot-water systems. With the addition of the Christchurch houses and the second year of Auckland houses, the number of hot water systems available for analysis has almost doubled. Unfortunately, with the increase in numbers there has been a large increase in the number of exceptional and unusual cases, which have caused problems for the standing loss analysis methods. The data currently coming in from the HEEP clusters (which are predominantly small towns and semi-rural areas) are even more unusual, as hot water electric network load would appear to be controlled more tightly in many of these areas. As a consequence, the methods previously used to estimate standing losses have been replaced by a new method.

10.1 Review of previous standing loss estimation methods

The standing loss of a hot-water cylinder is the energy used to maintain the water at the thermostat temperature when no draw-off occurs. During a long period where no hot water is drawn off, the element needs to switch on periodically to keep the water hot. Conceptually, the simplest method of estimating the hot water standing loss is to take data from overnight, when little or no water will be drawn off in most households, as the occupants are asleep. By looking at the average by time of day, the period of lowest consumption gives (in principle) a good estimate of the standing losses – see Figure 70, which was first used in the HEEP Year 2 report. This has been the main method for estimating standing losses in the past.

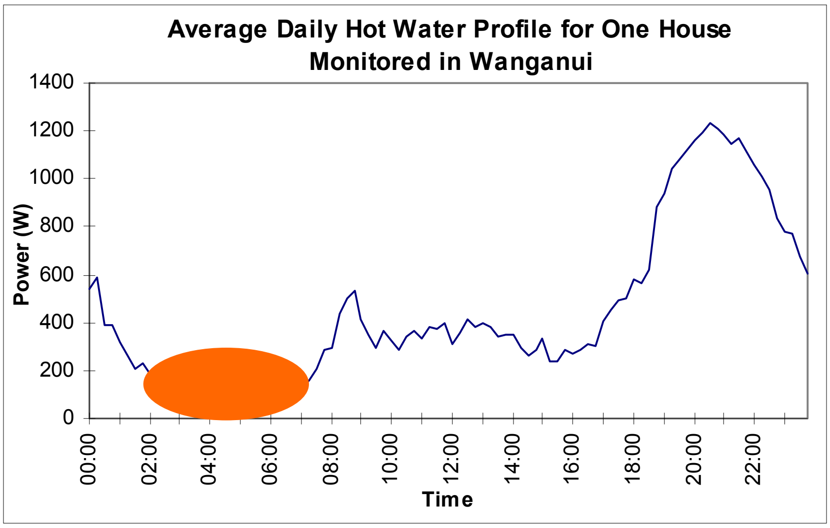


Figure 70: Average daily hot water energy use

Another method developed was to examine each individual recharge event. If standing loss recharge events are common, then the most commonly occurring recharge event in terms of the rate of energy loss will be associated with standing loss recharge. This was used when the first method failed for some reason.

Both of these methods are conceptually simple. However we have encountered many situations where they do not give realistic estimates. Some of the problems are due to:

- ripple control
- households with unusual occupants schedules
- leaking systems
- solid fuel fired wetback booster systems or solar systems
- large thermostat dead-bands or cylinders that rarely recharge
- small elements that rarely switch off
- night rate tariffs

The result of most of these is a big drop in the number of recharge events. Each of these problems will be discussed in detail, and the new analysis method introduced.

10.1.1 Ripple control

Ripple control is used to manage the network peak load during times of high demand and/or high electricity spot prices, by remotely turning off large numbers of hot-water cylinders Typically, ripple control might be used during the morning or evening for a period of one or two hours, depending on the network demand. In some of the small towns and rural areas monitored so far in HEEP, ripple control has been used much more intensively than in the cities, possibly in response to specific network constraints.

If ripple control is only used occasionally, and not always at the same time of day, then when the HEEP hot water data are averaged to a profile, the net effect is small and can be ignored. However, in many cases, ripple control was used extensively (e.g. Hamilton, Christchurch, and many of the clusters) and this can put a dip in the profile, which in turn can lead to an underestimation of the standing losses. Using a floating window of two or three hours can help, but in some cases this causes the standing losses to be taken during the ripple control period.

A fairly sophisticated method to remove long periods of ripple control was tested. This examined the time that a cylinder was off, and vetoed days when this occurred from being included in the analysis. This method did fix many of the problems, but unfortunately there were a large number of electric hot-water cylinders that have very long intervals between recharges, in many cases with intervals of between five and seven hours (see Figure 72). This routine could not distinguish these events, so to be used effectively it required that times of ripple control be determined from examination of all the hot-water systems monitored in that location.

Restricting the time of day during which the standing loss can be calculated is effective, providing the times to avoid are known. Unfortunately, ripple control regimes vary widely from location to location. An attempt was made to identify periods of ripple control by averaging the time series data for each region, and looking for extended periods when most or all of the electric hot-water systems were turned off. This worked well for some, but not all, areas. In particular, areas where HEEP is monitoring a small number of houses (e.g. less than 10) gave ambiguous results.

10.1.2 Houses with unusual schedules

A number of households have unusual schedules, for example:

- bedtimes after midnight, with perhaps a shower taken before retiring
- rising early or shift workers; families with babies.

To get around this, a floating window approach was adopted, with the standing losses calculated from the lowest energy using three consecutive hours in the day for each household, whenever this might be. This approach avoided most difficulties. However it did sometimes cause problems when ripple control was used during peak times in some regions.

10.1.3 Leaking systems

Some hot-water systems leak, and this can cause either very frequent energy recharges, or periods of the element being on continuously. Such cylinders can often be identified by visual examination of the data. Normally the household will eventually identify the problem, either through noticing water in the house, total failure of the hot-water system, or unusually high power bills, so only rarely will a cylinder leak for the entire monitoring period. Vetoing days where the cylinder does not ever turn off deals with this problem, if there is a short period of leaking.

Two out of 171 houses showed clear evidence of continued leakage over a long period. Figure 71 shows 10 days of data for a cylinder that stayed on almost all the time for about three months, after which its behaviour went back to normal. The times when it turned off in this example were periods of ripple control. This cylinder would have cost the occupants about an extra $150 per month until it was repaired.

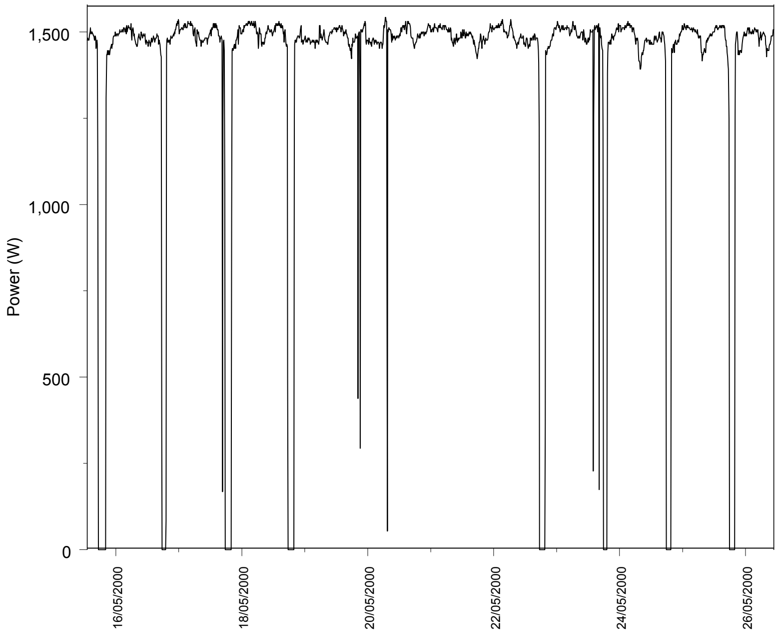


Figure 71: Leaking cylinder - only turns off during ripple control

10.1.4 Solid fuel wetback booster or solar

Wetback and solar water systems only have their gas or electricity consumption monitored directly. Most of the wetback and solar systems have had additional temperature monitoring equipment installed. The inlet, outlet and internal temperatures are measured using thermocouples. When this data is analysed we should be able to estimate the standing losses, and the energy contribution of solid fuel and solar energy for these systems. If that estimate cannot be performed properly, then the standing losses may not be able to be estimated

Wetback systems are typically not operated during summer, so taking data from summer periods only will normally allow standing losses to be calculated.

For solar systems, since the sun does not shine at night, standing losses can be calculated normally providing the daytime heating has not resulted in storage temperatures too far above the thermostat temperature.

Combined wetback and solar systems can be a problem, as many are deliberately operated to minimise electricity consumption, with some households permanently switching off the electricity supply. The only way then to calculate standing losses is to perform an energy balance based on the monitored temperatures. During periods of no wetback or solar input, and no water draw-off, the temperature will slowly drop in the cylinder, and standing losses can be calculated provided that the cylinder storage volume is known.

Two wetback systems in Hamilton used almost no electricity during the winter, as the wetback provided nearly all the required hot water. Standing loss calculations during these periods are impossible. To estimate the standing loss, any day that had zero energy consumption or on which the solid fuel burner was used for long periods were excluded.

10.1.5 Large thermostat hysteresis and/or infrequent recharge

On average, hot-water systems recharge about 10 times a day, or about every two to three hours. Many systems recharge much less often, with 25% recharging six or less times a day, and 7% less than three times a day. Figure 72 shows an example of a system that recharges only three times a day. The standing loss as calculated by the profile method was 0.7 kWh per day, but the usage during a holiday period was 1.7 kWh per day.

This behaviour may be caused by the thermostat having a large dead-band, so that the element only turns on once the cylinder has cooled by several degrees. Typically, recharge is triggered by an energy requirement of a few hundred Watt-hours, equal to a 1°C temperature drop for a 180 litre cylinder.

However, for many cylinders, the lowest recharge energy is larger, at 500 to 1000 Wh, corresponding to a thermostat dead-band of 3 to 5°C. Standing loss recharge is then only needed every four to eight hours, depending on the cylinder insulation. Often water draw-off occurs more frequently than every eight hours, so the recharge is trigged by draw-off rather than by the standing loss. If the hot water is used late at night, there will be no night recharge, until the occupants draw-off water in the morning. This gives an apparently very low standing loss.

For these cylinders, there is no time of day that is predominantly standing loss recharge, nor are individual recharge events associated mainly with standing loss recharge. The only way to estimate the standing losses of these cylinders is to find a number of days when there is no draw-off, for example during a holiday period.

This problem is not confined to A and B grade cylinders, which might be expected given their low standing losses, as a lot of D grade cylinders exhibit the same behaviour.

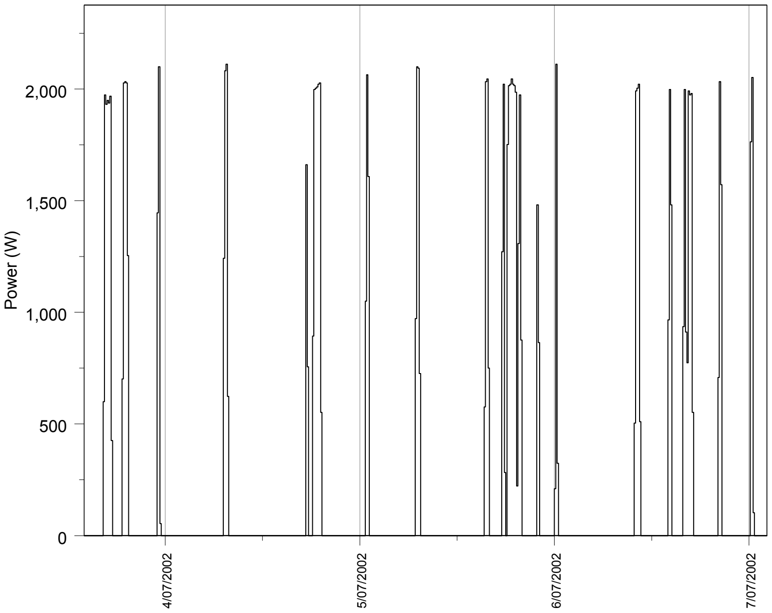


Figure 72: Cylinder that recharges occasionally

10.1.6 Small elements that rarely switch off

Hot-water systems that have elements of around 1 kW or less often spend large amounts of time on, simply because it takes about six hours for a 1 kW element to reheat a cold 135 litre cylinder. This slow recharge reduces the number of stand-alone standing loss recharge events that occur, and if hot water is used late at night, the cylinder can still be recharging well into the early hours of the morning, which leaves a small or non-existent window that can be ascribed to standing loss recharge. An example is given in Figure 73.

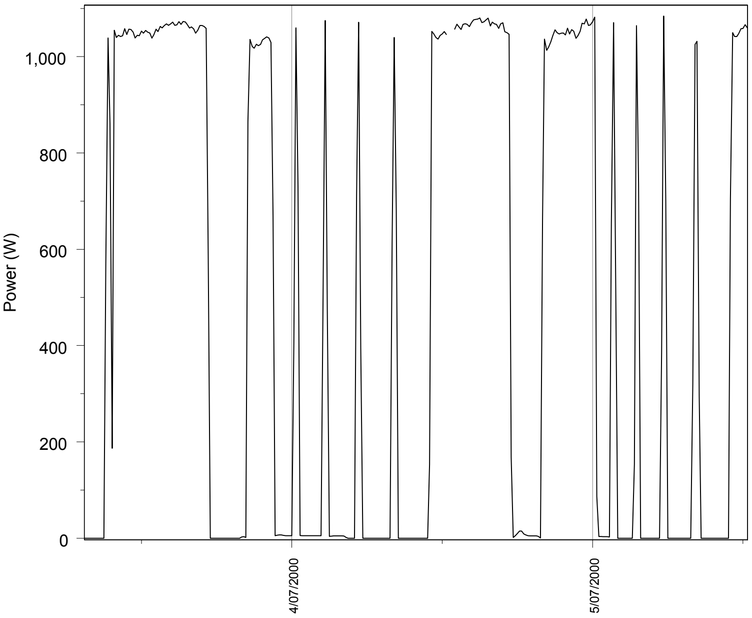


Figure 73: Cylinder that rarely turns off

10.1.7 Night-rate tariffs

Some systems are on a night-rate tariff, which supplies electricity between the hours of (typically) 11pm – 7am. A typical example of the energy use of these systems is given in Figure 74. Typically they have a very large recharge event at 11pm, lasting several hours, and then may have one or more recharge events before 7am. If people use hot water before 7am, there may be a draw-off recharge event.

The profile method does not work for these systems, as there are not enough hours overnight to avoid both the initial recharge, and any use at around 7am. Taking the minimum usage over this period is likely to give a value that is too low, as the recharging is not randomly distributed in time. Taking the first peak after the recharge works for some systems, but many have low standing losses, and do not recharge for standing losses at all overnight. The large amount of energy used to recharge the cylinder is also a problem, as it can lead to significant temperature stratification in the cylinder. Subsequent recharge may be caused by mixing of the water, rather than a drop in temperature from standing losses.

In one cylinder that had a number of recharge events after the initial recharge, there was a systematic decrease in the energy of each recharge, indicating that the average temperature in the cylinder was increasing.

In general, estimating the standing losses of night-rate systems is difficult, and we do not have much confidence in the estimates. Two ways that might give reasonable results are:

1) take a number of days when there is no draw-off, for example during a holiday period, and assume the energy use equals the standing loss, or
2) examining the recharge peaks and assume that the smallest recharge peaks are standing loss recharge.

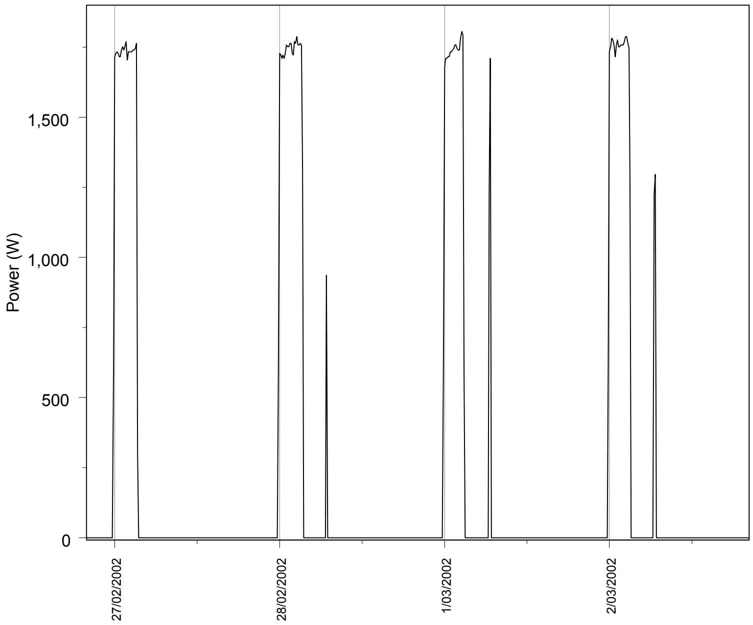


Figure 74: Night-rate hot water cylinder

10.1.8 Instantaneous hot water heaters

Gas or electric instantaneous hot water heaters in Auckland are assumed to have no standing loss. They may have a standby electric power consumption if they are electrically controlled, or the gas equivalent if operated by a pilot light.

10.1.9 Standing losses during periods of house vacancy

The new method for estimating standing losses is to visually inspect the data to find periods where the house is vacant. During these periods, the energy consumption of the hot-water system will be only to recharge standing losses. Typical examples of vacancy periods are given in Figure 75 and Figure 76, which use the total and hot water energy use as a selection mechanism. The only energy consumption seen in the total is from the hot-water cylinder, and other equipment that is switched on permanently, such as refrigerators. The vacancy period is, on average, five days, though for about one-quarter of the systems a vacancy period of only two days or less was used. For some systems, it is not possible to find a period of vacancy.

As unoccupied periods are generally very short, the temperatures in the house during that time will not be typical of the whole year. For example, a Christmas holiday period would be likely to have average temperatures around 19 to 20°C, about 5 to 8°C above the yearly average temperature. The standing losses for this period will be lower than normal, and this will need compensation. This compensation has not been undertaken for the estimates in this report – it is thought the difference will be between 5% and 10%.

The manually estimated standing losses now form a reliable data set, to which the results of automated procedures can be compared. Attempts will be made to automate the process.

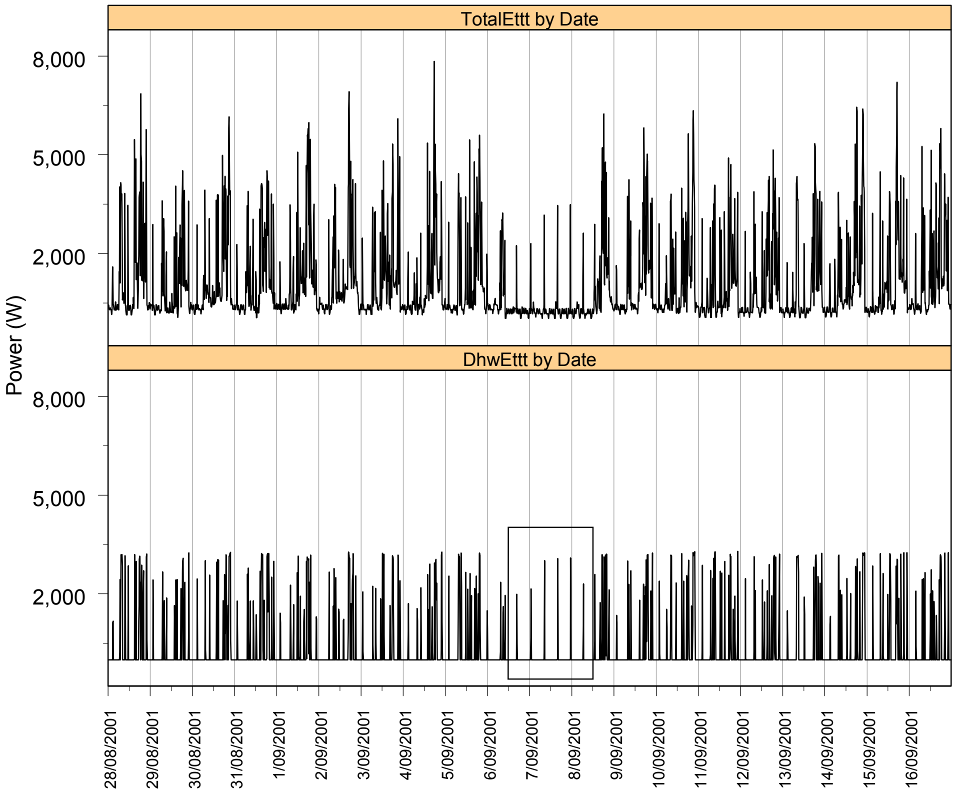


Figure 75: Example of a vacancy period

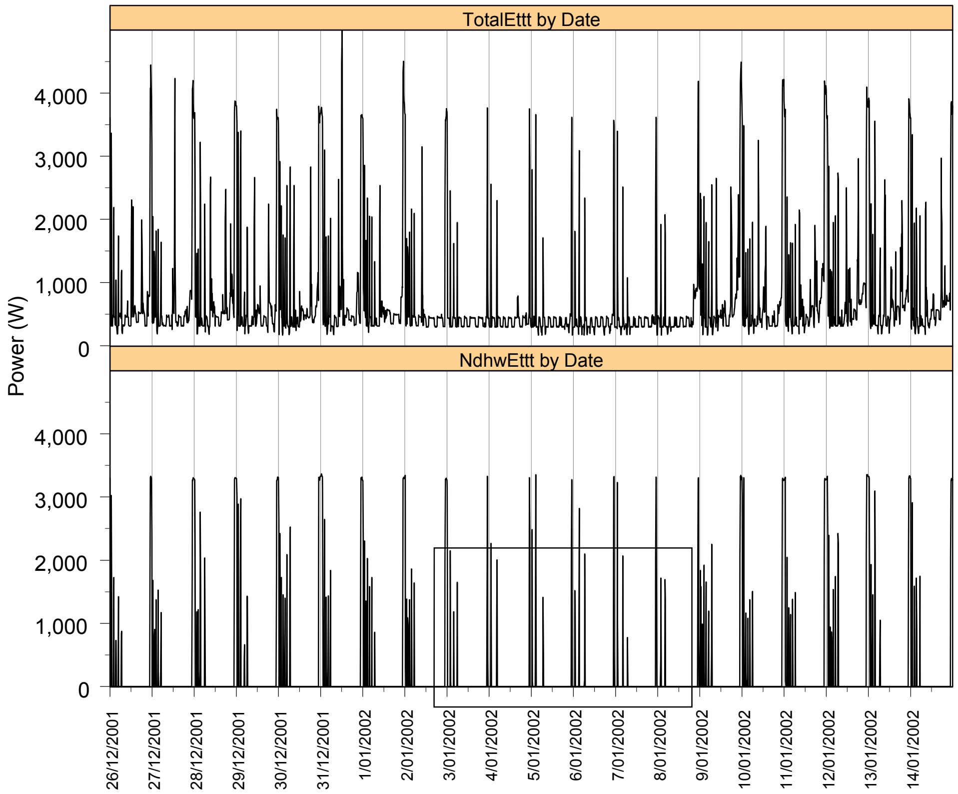


Figure 76: Example of a vacancy period for a 'Night rate' hot water system

10.2 Standing losses

For those systems where a period of house vacancy could be identified, the standing losses during those periods were used. Where a vacancy period could not be found the standing losses based on the profile were used, provided that more than 10 recharge events per day on average occurred, which was a criteria established by comparison with the vacancy period estimates.

A small number of hot-water systems are connected to wetbacks. These systems have been separated out from the electric only systems, and will be analysed separately later.

	Cylinder size (litres)	*Grade*	*Standing losses (kWh/day)*	*SD*	*N*
Electric	135	A or B	2.1	0.1	32
		C or D	2.9	0.2	25
		Wrapped	1.7	0.1	5
Electric	180	A or B	2.2	0.1	33
		C or D	2.8	0.4	5
		Wrapped	2.6		1
Electric	350	A or B	3.2	0.2	3
Gas	135		4.4	0.4	10
	180		3.7	0.4	9

Table 42: Estimated cylinder standing losses by type

As there are only small numbers of A and C grade cylinders, and their theoretical standing losses are very close to those of B (for A) and D (for C) grade cylinders, Table 42 groups the grades into 'A or B', and 'C or D' grades, with a 'Wrapped' group for those with cylinder wraps. No grading data is available for the gas cylinders.

Table 42 shows that the ‘A or B’ cylinders have lower standing losses than the ‘C or D’ group. This is highly statistically significant for the 135 litre cylinders, and significant at the 90% confidence level for the 180 litre cylinders.

Note that Table 42 excludes instanteous gas systems, and includes storage cylinders for which all the appropriate data was available – volume, grade (electric only), and standing losses.

There are only a small number of ‘wrapped’ cylinders. However, the five 135 litre wrapped cylinders have an average standing loss of 1.7 kWh per day, lower even than the ‘A or B’ grade cylinders.

Table 43 and Figure 77 give the revised energy use and standing losses by system type. Standing losses for electric systems are about 33% of the total energy use, on average. Total energy use for gas systems is more than double that of electric systems.

Appliance	*Total energy kWh/day*	*SD*	*Count*	*Standing loss kWh/day*	*SD*	*Standing loss % of Total Energy*
Electric storage	7.6	0.3	156	2.4	0.1	32%
Electric night-rate storage	7.5	0.8	9	2.7	0.3	36%
Natural gas storage	17.0	1.2	20	4.0	0.3	24%
Natural gas instant	15.7	3.8	15			0%

Table 43: Total energy consumption and standing losses by system type

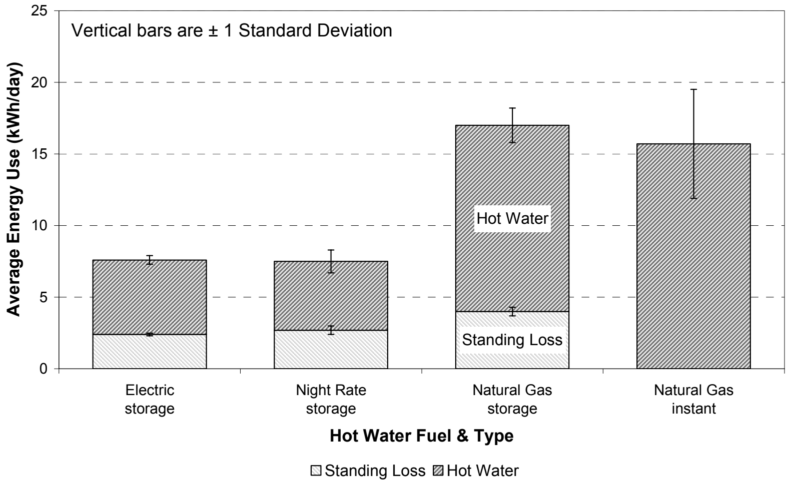


Figure 77: Energy consumption and standing losses by system type

It should be noted that unlike the standing loss analysis presented in the HEEP Year 6 report (Isaacs et al. 2002 – Section 5.3.2), no adjustment has been in this analysis made to match the standing losses derived from the measured performance to the same conditions as set out in NZS 4602:1988 (Standards New Zealand 1988).

10.3 Opportunities to improve cylinder energy efficiency

About 40% of the electric hot-water cylinders in the HEEP sample are C or D grade. To implement widespread cylinder wrap installation or cylinder replacement campaigns, information is needed on what type of houses these poorly performing cylinders are likely to be in. This would allow areas to be targeted that may have a high prevalence of C or D grade cylinders, The type of information might be available from the quinquennial Census and other public sources:

1) age of house
2) size of house
3) size, age and income of household.

Once households have been targeted, they need to be vetted at both the inquiry and visit stage to avoid retrofitting the lower loss, better insulated A or B grade cylinders. At that point information that is specific to the individual house and hot-water system can be used, such as:

1) age and size of hot-water cylinder
2) pressure (mains, low, header tank)
3) cylinder information such as brand, model, insulation type, etc.

Hot-water cylinders are normally installed when a house is built and replaced either if they fail, or as part of renovation. The age and grade data from HEEP, summarised in Table 44, bears this out.

All houses from the 1990s have A or B grade systems. Most houses from the 1980s have A or B grade systems. This is expected, as B grade or better cylinders were required after 1993, and A grade have been required since 2003. Houses from the 1950s to the 1970s have a mix of all cylinder grades, but older houses are likely to have mainly A or B grade systems as the original cylinder will have had to have been replaced at some time.

The richest mine of C or D grade cylinders is in the group of 1950s to 1970s houses. Most of the C or D grade cylinders in the 1960s and 1970s houses are the original cylinder, but only about half of those in the 1950s houses, and the oldest of these cylinders are likely to be near the end of their life. The cylinders in the 1970s houses are probably the best targets for cylinder wraps, as many of them are C or D grade, and they are likely to have a number of years of operation left. The cylinders in the 1960s houses are on average about 10 years older, and so are more likely to need replacement soon than those in the 1970s houses. Most of the cylinders in the 1950s houses are not the original cylinder, and any that are original are probably on their last legs. For older houses, (1940s and earlier) almost none of the original cylinders are still in place (many of these houses pre-date the widespread use of electric water heaters), and most of the C or D grade cylinders are likely to have been first or even second replacements.

Grade	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
A or B	3	2	6	8	9	14	23	16	23	34	1
C or D	1	1	13	4	4	22	22	21	7	0	0
% C or D	25%	33%	68%	33%	31%	61%	49%	57%	23%	0%	0%

Table 44: Count of cylinder grade by house decade of construction

There are major variations in cylinder grades with the region, as given in Table 45. The 'clusters' in Table 45 include Kaikohe, Whangarei, Minden, Arapuni, Foxton Beach, Waikanae, and Oamaru. In Auckland and Tauranga most of the cylinders are already A or B grade. In Wellington most are C or D grade. In the other regions there are about equal numbers. The reasons for this variation are not known – it could be caused by water conditions degrading cylinders faster in some regions, or economic and demographic factors. In Auckland, 75% of the C or D grade systems are in houses with incomes under $55,000 pa. In other regions, households with lower incomes are generally more likely to have C or D grade systems.

Region	*A or B*		*C or D*
Auckland	64	(80%)	16
'Clusters'	34	(52%)	32
Tauranga	7	(64%)	4
Hamilton	7	(44%)	9
Wellington	8	(32%)	17
Christchurch	17	(53%)	15
Dunedin	7	(54%)	6
Invercargill	3	(60%)	2

Table 45: Count of cylinder grade by region

Once regions or areas are targeted, the installer must decide whether the cylinder needs a cylinder wrap. HEEP information can give guidance here. The age of the cylinder (if known) is the best guide, as D grade cylinders are likely to be pre-1980, and most 1980s and later cylinders are B grade. Many modern cylinders have a label with the date of manufacture, and the make and model number, which can sometimes be used to determine the grade of the cylinder. Many cylinders, unfortunately, have no age mark or useful label and other information must be used. The insulation type is a good indicator, as A or B grade cylinders are usually insulated with polyurethane or polystyrene foam, and C or D grade cylinders generally have cloth or fibre insulation. Very old cylinders look obviously old, though this is only a help for the oldest ones – for example with cylinders of intermediate age it can be impossible to tell a 1970s C or D grade from a 1980s A or B grade cylinder. Any system with a thermostat that reads degrees Fahrenheit is almost certainly D grade. Very few cylinders larger than 180 litres are C or D grade.

HEEP has a large body of practical information for identifying the grade of cylinders from visual inspection. HEEP information can be used to help optimise the upgrading strategy, and increase both the uptake and eligibility rate of marketing and promotion, and the energy savings per wrap installed.

11. CONCLUSION

This is the seventh annual report on the Household Energy End-use Project (HEEP). Although data collection will not be completed until early 2005, the annual reports provide preliminary results from our research. Each report includes the increased house sample that has become available as the previous year's monitoring is completed. This year's report includes energy data from about 200 randomly selected houses, as well as a number of non-randomly selected houses. Regional coverage includes the full Auckland house sample, Hamilton, Wellington and Christchurch.

The funding highlight of the past year has been the allocation by the Foundation for Research Science and Technology under the 'Public Good Science & Technology' (PGST) 'Output Class 7: Research for Industry' for science funding to support the completion of the HEEP model by 30 June 2007.

The HEEP team has actively worked to ensure the results of the work are available to the widest possible range of stakeholders – including the public, special interest groups, government agencies and other researchers. The HEEP results have featured in advertising to assist New Zealanders in dealing with the electricity 'crisis' of mid-2003, as well as in more light-hearted promotions. The HEEP team will continue to undertake technology transfer, ensuring the results are not only widely available but recognised as the premier source of data on energy use in New Zealand housing.

11.1 Need for HEEP

Over the past 30 years since the last household electricity survey, there have been major changes in the way NZ houses are built and used:

- construction materials (e.g. particleboard was introduced in the mid-1960s and since the 1970s has been the predominant flooring material)
- building code (e.g. thermal insulation required since 1978)
- appliances (e.g. microwave ovens widely available from the late 1970s)
- consumer expectations
- work practices
- the characteristics, size, age, configuration and cultural diversity of New Zealand households.

All these factors affect the complex relationship between energy demand, indoor temperature, perceived comfort, household energy costs, and the local climate.

Overseas data shows that even small changes in behaviour or thermal resistance in a dwelling may have very significant impacts. Effective strategies to generate energy efficiency through changing household practices and behaviour or dwelling performance, cannot be developed without an understanding of New Zealand's unique patterns of energy use arising from its particular permutation of factors relating to climate, dwelling and household practice. This programme is designed to allow us to understand this unique New Zealand dynamic. By understanding these, and some of the multitude of other, interactions the programme will assist New Zealanders to improve the benefit they obtain from their expenditure on energy and energy using buildings and appliances.

Households spent about $1,745 million on (non-transport) energy in 2001 (Statistics NZ 2001). HEEP will provide guidance as to opportunities for both conservation and efficiency – improving the energy efficiency by only 1% would result in a $17 million benefit, as well as 0.1% reduction in national CO_2 emissions (MED 2002b). As a potential example, previous HEEP reports have shown that around 44% of residential energy is used in hot-water cylinders and that the number of cylinders with poor levels of insulation is high. The HEEP model should allow a realistic assessment of the likely consequences of a national policy to raise insulation levels in cylinders and support full cost-benefit analysis.

11.2 Household energy use by end-use

Section 4.1 provides a revised analysis of the energy used both at the total household and individual appliance levels. No statistically significant difference has been found in total energy use between the four regions – with the strata-weighted average over the four HEEP locations for electricity and natural gas reported at 1154 ± 52 W. Note that this value currently excludes portable LPG heaters and solid fuel burners. Work is continuing on incorporating energy resulting from the use of these remaining fuels into the analysis.

Updated pie charts illustrating the average energy end-use breakdown by region and as a strata-weighted average are given in Section 4.2. On average, hot water is the biggest use of household electricity and gas at close to 30%, with space conditioning following at 22%. Lighting at 11% is one-half of the energy used for space heating, while refrigeration follows in fourth place with 10%. The importance of lighting and refrigeration has not been well recognised, perhaps due to the comparatively small power load.

11.3 Indoor temperatures

Comparing the temperatures by region from the 1971/72 Household Electricity Survey (Statistics 1976) with the HEEP results does not appear to suggest that there has been any increase in average temperatures. However, the data reported in Section 5.1 shows wide distribution, and this will be subject to further investigation.

Section 5.2 shows that there is a significant difference in the start and finish of the heating season. Households in cooler climates, on average, start heating earlier in the year and finish heating later in the year than those in warmer climates. A similar pattern was found for the time-of-day heating pattern. The start of heating is progressively earlier going from warmer to cooler regions, being about 30 minutes earlier at each location going from Auckland at 5:50pm through to Christchurch at 4:20pm. The time of the maximum rate of increase of temperature is approximately the same in all regions, ranging from 6:20 to 6:50pm, with no apparent pattern. The end of heating appears to be weakly related to the household bedtimes.

The temperature distribution continues the pattern report last year, with nearly 30% of households having average winter evening (June through August, 5 pm to 11 pm) temperatures below the World Health Organisation recommended minimum of 16°C. Section 5.3 also reports that there are significant correlations between mean winter evening temperatures and the house age, presence of insulation, and house floor area.

There is a very strong relationship between the age of the house and the winter temperatures. Currently, we can conclude that post-1978 houses are 1.0°C warmer on average and that their winter evening energy use is not significantly different from the pre-1978 houses. This difference is slightly less than that given in the Year 6 report, and the reduction has been caused in part by pre- and post-1978 houses in Christchurch having no significant difference in winter evening temperatures.

11.4 Winter energy use

Section 6.1 reports that 93 out of the 280 houses (33%) reported that the main heating is by solid fuel – second only to the use of electric heating (42%); 14% of the households report their main heating fuel is LPG, and 11% by natural gas.

The HEEP method for analysing the solid fuel energy use is continuing to be developed, and thus the heating energy analysis includes only electricity, natural gas and LPG. Section 6.2 reports that the mean space heating energy use is 3650 kWh per year, with a minimum of 253 kWh/yr and a maximum of 14,120 kWh/yr. Normalised to floor area, heating energy use ranges from a minimum of 0.8 kWh/m²/yr to a maximum of 42.9 kWh/m²/yr with an average of 13.5 kWh/m²/yr.

There is a wide scatter of energy use by floor area (Section 6.3) and house age (Section 6.4), neither of which should a strong relationship. Section 6.5 explores the inter-relationship of the heating schedule, achieved average winter evening temperatures and the heating fuel. Houses heated by solid fuel heaters tend to have warmer temperatures than houses heated by electricity, natural gas or LPG.

A preliminary ‘heating index’ has been developed to explore the impacts of different heating schedules. As would be expected, houses that heat long hours have a higher mean winter evening living room temperature, although there is a very wide spread of temperatures for both the heating index and the energy use.

11.5 LPG heaters

Section 7 provides an overview of the use of LPG heaters. Thirty percent of the HEEP sample have LPG heaters, averaging just over one per house. The operation of portable (unflued) LPG heaters also releases quantities of water vapour into the heated space. Just over one-third (35%) of the houses with LPG heaters have a dehumidifier, whereas the houses that do not have an LPG heater have about a 21% chance of having a dehumidifier – this is statistically significant at the 1% level.

The patterns of LPG heater use do not reflect their ability to provide larger amounts of heat – with the majority used at levels that are comparable with the heat that can be provided by portable, plug-in electric heaters. Seventy two percent of the heaters are predominantly operated on low setting, 11% are operated on medium and 17% are predominantly operated on high setting. These settings are often not varied, with close to three-quarters of the heater spending more than 80% of their use at the one setting. Most LPG heaters are not heavily used – over 50% of the LPG heating energy is used by only 20% of the heaters.

11.6 Seasonal mortality

Buildings protect the occupants from the excesses of the external climate. Although it is possible in many parts of New Zealand to achieve this through ‘passive’ solar design which maximises the use of free solar energy, the majority of houses use purchased energy to ensure the indoor climate is acceptable to the occupants. HEEP measures and reports on the energy use and temperatures. There is no simple measure of whether the conditions within the building support the well-being and health of the occupants. One approach is to examine some health consequence, which should show minimum seasonality (variation across seasons) if the people are well protected from the variation in the external climate.

Section 3 examines the whole population seasonal mortality for Japan, the UK, Australia, New Zealand, the USA and Sweden. The analysis found that over the 30-year period from 1970 to 2000 there has been a steady increase in the seasonality of mortality in the USA and Sweden. Japan and the UK have remained reasonably constant, and in both New Zealand and Australia it has been decreasing.

Age-specific monthly mortality data was obtained for New Zealand and Australia. It was found that over the period 1980 to 1999, in New Zealand only the 0 to four-year age group is demonstrating a strong downward trend, although a small downward trend is apparent in the five to 64-years and 65-years plus age groups. However, for all three Australian age groups, seasonality is decreasing. the reduction is greatest for the 0 to four-year age group, but the other two groups are showing a greater decline than is the case for New Zealand.

A review of international and New Zealand literature shows there is increasing evidence of a link between energy efficiency and occupant health. Health, and other non-energy benefits of improved house energy efficiency can be of sizeable value – with one USA study suggesting they were close to being equal.

11.7 Hot-water systems

Section 8 provides analysis of the hot-water systems and temperatures found in the HEEP sample. Of the houses in the current HEEP database (including both random and non-random houses), 91% have one hot-water system, 8% have two systems and 1% have three systems. None have more than three hot-water systems.

The majority of the HEEP hot-water systems (79%) only have an electric storage water cylinder – an electric element is located inside an insulated tank of water, with the temperature controlled by a thermostat. Eight percent of the systems have an electric cylinder with some form of supplementary heating, either solar, wet back or a combination. Eight per cent of the water heating systems are gas storage system, 5% are instantaneous gas and less than 1% are solid-fuel-only.

Most cylinders are either 135 litres (30 gallons) (50% of cylinders) or 180 litres (40 gallons) (40%), with the remainder being split almost equally between the small cylinders located close to their end use (e.g. under sink kitchen hot water) and larger cylinders. Cylinder size (volume) distribution varies by location. In the North Island sample (Auckland, Hamilton, Wellington & Wanganui) 52% of the sample cylinders are 135 litres and 37% are 180 litres or greater. In the South Island (Christchurch) the reverse is the case, with 24% of the cylinders at 135 litres and 66% at 180 litres or greater. These size distributions are likely to reflect historic energy supplier policy, as there appears to be a shift to larger cylinders in newer homes.

The system water pressure has also changed in more recent years. Over three quarters (79%) of the HEEP sample are low pressure and with the rest (21%) are 'mains' pressure. Three percent of the cylinders from the decade of the 1960s are mains pressure, 9% in the 1970s, 17% in the 1980s and 26% in the 1990s.

Houses have a longer life than hot-water cylinders, and it is expected that as hot-water cylinders fail they will be replaced, often with the same size but not necessarily with the same pressure. Even very old houses (which originally would have had low pressure systems) are being retrofitted with mains pressure hot-water systems. About one-third (32%) of the houses, but two-thirds (65%) of the hot-water cylinders date since 1980. The oldest cylinder in the sample dates from the 1930s.

The analysis of the hot water temperatures and systems raises a number of energy, safety and health issues about the provision of hot water in homes:

- **Over 40% of the cylinders had UNSAFE delivered water temperatures:** 43% of the measured water temperatures were above 60°C, including 13% with delivered water temperatures over 70°C.
- **One-third of the cylinders had INACCURATE thermostat control:** 67% of the delivered water temperatures are within ±10% of the thermostat setting. However, 25% of the delivered water temperatures are more than 20% higher than the thermostat setting . In other words, even if people set the thermostat to what they believe to be a 'safe temperature', the tap temperature may be unsafe.
- **Even when users set the thermostat at a safe temperature, one-third of these cylinders had UNSAFE hot water delivered :** 35% of the cylinders had the thermostat set at 60°C or under, but about one-third of these houses had water over 60°C being delivered at the tap (i.e. 11% of all the cylinders in the sample). Thus, even if the householder was attempting to ensure safe temperature water was delivered through correct setting of the thermostat, the thermostat was not providing it.
- **One out of seven houses with a tempering valve delivered hot water over 60°C**: Only 12% of the cylinders (for which thermostat and water temperature data was available) had tempering values to ensure water would be delivered at a 'safe' temperature. Of these systems, 45% were delivering water at less than 55°C, 40% between 55°C and 60°C, and 15% at a temperature above 60°C – although the maximum measured hot water delivery temperature for a cylinder with a tempering valve was only 64°C, compared to the maximum of 87°C for one electric storage system without a tempering valve.

These results help to identify potentially important hot-water health and safety issues in New Zealand homes. The HEEP study will continue to monitor delivered and thermostat hot water temperatures. HEEP will also work towards developing an appropriate method to assist in the identification of hot-water systems that are likely to have excessively high temperature water and tools to ameliorate the possible dangers.

11.8 Shower flows

The shift to mains pressure systems has a particular impact on water flow, as discussed in Section 9. The average shower flow of 8.2 litres per minute (l/m) measured in the HEEP shower sample – which is equivalent to an AAA equivalent shower head – disguises the effects of system water pressure.

The average shower flow for a low pressure hot water system is 7.2 l/m and for a mains pressure system is 10.6 l/m. The maximum recorded flow rates were 20 l/m for low pressure and 30 l/m for mains pressure. On average, 25% of low pressure systems had ‘warm’ shower flows over 9 l/m, while 60% of mains pressure system were above this threshold.

Thus, a house in Auckland that currently had a shower flow above 9 litres per minute which switched from a high flow to a low flow shower head (saving 7 litres per minute of water) and maintained a five-minute shower, the savings would be about **11.5 cents per shower** for the freshwater and waste water.

The energy savings from the reduced flow, based on heating the water from 14°C to 39°C and an electricity tariff of 13 cents per kWh would be **13.2 cents per shower**.

The total savings would be about 25 cents per shower (46% due to reduced water and 53% due to reduced energy), or over a full year $90 assuming one shower per day. In this case the retrofitting of a low-flow shower head (product cost about $40), would have a payback of less than six months assuming only one shower a day – obviously the payback would be far faster for two or more showers a day.

11.9 Hot water standing loss analysis

HEEP has regularly reported on the standing losses of hot-water systems. With the addition of the Christchurch houses and the second year of Auckland houses, the number of hot-water systems available for analysis has almost doubled. Unfortunately, with the increase in numbers there has been a large increase in the number of exceptional and unusual cases, which have caused problems for the standing loss analysis methods. The data currently coming in from the HEEP clusters (which are predominantly small towns and semi-rural areas) are even more unusual, as hot water electric network load would appear to be controlled more tightly in many of these areas. As a consequence, the methods previously used to estimate standing losses have been replaced by a new method. Section 10 also discusses methods to maximise the opportunities to improve hot-water cylinder energy efficiency.

Section 10 provides estimates of the average total energy use and the standing losses for the four cylinder types: electric storage, electric night rate storage, natural gas storage and natural gas instant. Total energy use ranges from 7.5 kWh/day for electric night rate storage to 17 kWh/day for natural gas storage. Average standing losses as a percent of the total energy use range from 24% for the natural gas storage to 36% of electric night rate storage.

12. REFERENCES

12.1 HEEP Reports

Electronic (PDF) copies of all HEEP executive summaries are available from the BRANZ web site www.branz.co.nz. Printed copies are available from BRANZ, at the addresses given in Section 1.2 (page 2) at the current advertised price. The full reference for each report is given below:

Year 1: Stoecklein A., Pollard A.& Isaacs N. (editor), Ryan G., Fitzgerald G., James B. & Pool F., 1997 **Energy Use in New Zealand Households: Report on the Household Energy End-use Project (HEEP) - Year 1** Energy Efficiency & Conservation Authority (EECA), Wellington.

Year 2: Bishop S., Camilleri M., Dickinson S., Isaacs N. (ed.), Pollard A., Stoecklein A. (ed.), Jowett J., Ryan G., Sanders I., Fitzgerald G., James B., and Pool F. 1998. **Energy Use in New Zealand Households - Report on the Household Energy End-use Project (HEEP) - Year 2.** Energy Efficiency and Conservation Authority (EECA), Wellington.

Year 3: Stoecklein A., Pollard A., Isaacs N., Camilleri M., Jowett J., Fitzgerald G., Jamieson T., and Pool F. 1999. **Energy Use in New Zealand Households - Report on the Household Energy End-use Project (HEEP) - Year 3.** Energy Efficiency and Conservation Authority (EECA), Wellington.

Year 4: Camilleri M., Isaacs N., Pollard A., Stoecklein A., Tries J., Jamieson T., Pool F., and Rossouw P. 2000. **Energy Use in New Zealand Households. Report on Aspects of Year 4 of the Household Energy End-use Project (HEEP)** BRANZ SR 98, Judgeford.

Year 5: Stoecklein A., Pollard A., Camilleri M., Amitrano L., Isaacs N., Pool F. and Clark S. (ed.), 2001 **Energy Use in New Zealand Households, Report on the Year 5 Analysis for the Household Energy End-use Project (HEEP)**, BRANZ : Judgeford (SR 111)

Year 6: Isaacs N., Amitrano L., Camilleri M., Pollard A. & Stoecklein A 2002 **Energy Use in New Zealand Households, Report on the Year 6 Analysis for the Household Energy End-use Project (HEEP)**, BRANZ Ltd: Judgeford, November 2002. (SR 115)

12.2 HEEP *BUILD* articles

The BRANZ magazine *BUILD* has published results from HEEP on a regular basis. Recent articles are listed here:

Isaacs N.P. 2002 **Year 6 results of the Household Energy End-use Project (HEEP)** *BUILD* 73 Dec 02/Jan 03 pp68-79

Isaacs N.P. 2003 **Are NZ houses comfortable?** BUILD April/May 2003 pp36-37

12.3 HEEP Conference Papers

A number of the papers presented over the years by the HEEP team are available on BRANZ website. They can be downloaded free in PDF format. Hard copies can also be purchased online from BRANZ Bookshop or through BRANZ Customer Services Manager.

Stoecklein A., Pollard A., Camilleri M., Amitrano L., Clark S. & Isaacs N. 2002 **Findings from the Household Energy End-use Project (HEEP)** in *Proc. International Symposium on Highly Efficient Use of Energy and Reduction of its Environmental Impact.* Osaka, 22-24 January 2002 (BRANZ Conference Paper No. 102)

Stoecklein A., Pollard A., Camilleri M., Tries J. and Isaacs N. 2001 **The Household Energy End-use Project: Measurement Approach and Sample Application of the New Zealand Household Energy Model** in *Proc. CIB World Building Congress,* Wellington, New Zealand, April 2001 (BRANZ Conference Paper No. 87)

Camilleri M.T., Pollard A.R., Stoecklein A.A., Amitrano L.J. & Isaacs N.P. 2001 **The Baseload and Standby Power Consumption of New Zealand Houses** in *Proc IRHACE Technical Conference*, March 2001 (BRANZ Conference Paper 100)

Pollard A.R., Stoecklein A.A., Camilleri M.T., Amitrano L.J. & Isaacs N.P. 2001 **An Initial Investigation in New Zealand's Residential Hot Water Energy Usage** in *Proc IRHACE Technical Conference*, March 2001 (BRANZ Conference Paper 99)

Tries J., Stoecklein A., Pollard A., Camilleri M & Isaacs N. 2000 **Understanding energy use in New Zealand homes**. *Electricity Engineers' Association Annual Conference*, Auckland, June 16-17, 2000 (BRANZ Conference Paper 79)

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13. APPENDIX – INTERNATIONAL REVIEW OF SHOWER WATER FLOW RATES

A literature review of shower water flow rates found very few references to actual measurements at the appliance level. The majority of work, internationally and in New Zealand, has examined total household water use, not end-uses. This appendix provides references to American, Australian and English research results.

13.1 New Zealand

The only survey found, Hendtlass (1983), investigated the differences in total water use between houses with and without solar water heating, based on a time-of-day and length-of-use reported in a user-completed survey. It did not report on actual water use.

13.2 America

During 1996-1999 the American Water Works Association Research Foundation (AWWARF) supported a major research study to understand how households use water. Dataloggers were attached to water meters in 1,188 homes in 14 cities across the USA and Canada (Mayer et al. 1999[xv]).

It was found that about 42% of the water was used indoors, and the remaining 58% used outdoors. The mean per person indoor daily water use was 260 litres (including leakage), including water use estimates by appliance:

- toilet water use was estimated at 70 litres per person per day
- clothes washer use was 57 litres/person/day
- shower use was 44 litres/person/day
- direct tap use was 41 litres/person/day
- leaks accounted for 36 litres/person/day
- baths were 5 litres/person/day
- dishwasher use was 4 litres/person/day
- other domestic use was 6 litres/person/day.

The research investigated the use of low-flow shower heads – these are shower heads designed to restrict flow to a rate of 9.5 litres per minute (2.5 US gallons per minute) or less. Table 46 summarises the reported results for showers, with the average shower flow calculated from the average water use and shower time.

Table 46 shows that average shower time increased by 25% for the houses with low-flow shower heads, compared with the houses with non-low flow showerheads, the total water use reduced by 34%.

Shower head type:	Average shower time	Average shower water use	Derived average shower flow
Low flow	8 min 30 sec	33 litres/person/day	3.9 litres/min
Non low-flow	6 min 48 sec	50 litres/person/day	7.4 litres/min

Table 46: North America – shower water use

[xv] Project Summary available at www.awwarf.com/research/topicsandprojects/execSum/241.aspx

13.3 Australia

Harrington & Foster (1999) note that there is little data on regional variation in usage patterns for hot water. They suggest showers will typically comprise between 40% to 60% of hot water usage for personal washing. Table 47 provides a summary of the data they collected.

Source	Average duration per person	Frequency per household	Flow rate
Perth (MWA 1985)	8.1 minutes	2.3 /day	
NSW (ABS 1987)		16 /week	
Sydney (Yann 1990)	7.3 minutes		10 to 17 litres/min
QLD – winter (SRC 1993)	8.6 minutes	3.2 /weekday	
QLD – summer (SRC 1993)	8.1 minutes	3.7 /weekday	

Table 47: Australia – shower water usage

The values from Yann (1990) given in Table 47, would suggest water use for an average shower in Sydney would be between 73 and 124 litres

The Water Corporation of Western Australia undertook a 'Domestic Water Use Study' in Perth during 1998 to 2001 (Loh & Coghlan 2003). They found difficulties in obtaining accurate information from householders on the efficiency rating of their showers (i.e. A, AA etc), resulting in the only meaningful distinction possible between shower types was whether one or more water-efficient showers (of any type) was owned or not., Table 48 taken from that study, gives water consumption for each type of shower i.e. conventional normal flow and water-efficient shower roses.

In the case of the normal flow showers, there is no significant difference between water usage (litres per shower) by the residents in either single or multi-residential households. There is also no significant difference between shower durations for a normal flow or water-efficient shower rose. The average shower lasts about seven minutes (ranging from 6.7 to 7.3 minutes).

Type of residence	Shower type	L/day	L/shower	Min/shower	L/min
Single residential	Normal flow	152	60	7	9
	Water- efficient	135	48	7	7
Multi-residential	Normal flow	113	64	7	9
	Water-efficient	110	58	7	8

Table 48: Perth – shower water use

Loh & Coghlan (2003) suggest, as observed from Table 48, that water savings of one to two litres a minute could be achieved by changing to a water-efficient shower rose. Thus for a seven-minute shower, a water savings of seven to 14 litres can be achieved, amounting to a water savings of between 2.6 and 5.1 kilolitres/person/year.

A comparison with the similar study carried out in 1981/82 (Metropolitan Water Authority 1985) shows that average shower water use has increased from 47 litres/person/day to 50 litres/person/day, although there has been a major reduction bath water use down from seven litres/person/day to only one litre/person/day.

13.4 United Kingdom

'Water UK' (the U.K. water industry trade association) reports that a typical shower uses 35 litres of water[xvi].

The UK "Office of Water Services" (OFWAT) reports that this would cost on average £0.05 (about $NZ 0.15), compared to £0.09 ($NZ 0.27) for heating the water (OFWAT 2002)

In August 2000 the Environment Agency commissioned a report of shower use in the UK[xvii]. The manufacturers reported:

- Electric showers (7.5kW to 10.8kW) – flow rate of 3 to 7 litres/min (62% of sales)
- Mixer showers – flow rate of 5 to 15 litres/min (30% of sales)
- Power showers – flow rate of 12 to 20 litres/min (8% of sales)

The responses to a questionnaire sent to staff in water industry related organisations were that:

- 80% of respondents owned showers of which 73% were fixed (not detachable hoses)
- 72% of people spend less than 10 minutes in a shower.

The mean shower flows were:

- Mains water pressure - 7.6 l/min
- Mixer (attached to bath taps) - 6.1 l/min
- Electric - 5.5 l/min
- Pumped - 9.6 l/min
- Non-specific (other) - 5.3 l/min.

[xvi] Accessed through http://www.water.org.uk/index.php?raw=262 September 2003

[xvii] Pers. com. from Rob Westcott, Principal Water Analyst, Water Demand Management, UK Environment Agency. 17 October 2003