STUDY REPORT

No. 115 (2002)

Energy Use in New Zealand Households

Report on the Year 6 Analysis for the Household Energy End-use Project (HEEP)

Supported by:

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Energy Use in New Zealand Households – HEEP Year 6 Report
November 2002
Executive Summary

This report covers the activities of the sixth full year of the Household Energy End-use Project (HEEP). HEEP represents a major commitment by funding and research organisations to make available improved knowledge about the actual energy use of real New Zealand houses occupied by real families. This report is based on data from 100 homes, with a further 100 houses being monitored each year. Monitoring will be completed in early 2005.

If you are interested in participating in HEEP or would like further information about obtaining outputs customised to your specific needs, please contact the HEEP team. We acknowledge the support of the funders listed on the front cover.

Background

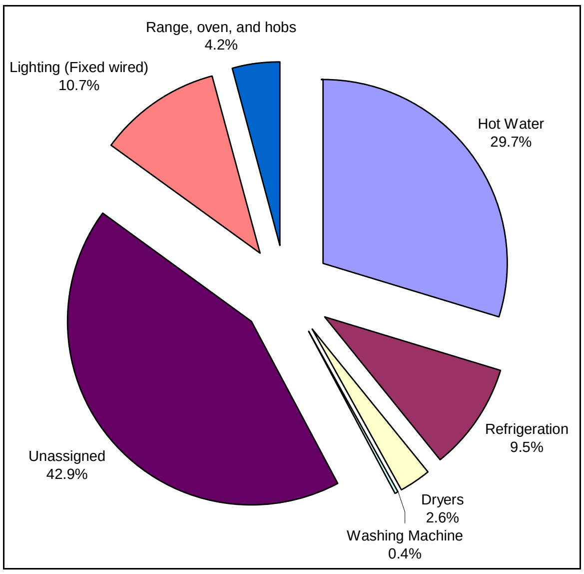
All our homes use energy in various forms and for a wide range of end-uses, yet our understanding of household energy consumption is limited. Until HEEP was established in 1995, the most recently available data came from the 1971/72 household electricity survey.

Over the past 30 years many questions have been raised about household energy use – how warm are New Zealand houses, and has this changed over 30 years? How often are 'new' appliances used, and what is their impact on peak power or energy use? Do insulated houses use more or less space-heating energy? HEEP is starting to provide answers to these questions, and will answer many others.

HEEP covers four key topics leading to improved knowledge of the residential energy use:

- **Fuel use patterns** (all fuels – electricity, natural gas, LPG, solid fuels, solar, etc.)
- **Energy end-use** data (includes 'real time' analysis of how energy is used in the household-appliances, space conditioning, water heating, lights, etc.)
- **Occupant profiling** (number, income, socio-demographic details, etc.)
- **Household profiling** (construction, appliances, total income, etc.).

Household Energy Use



Work has been underway understanding New Zealand's energy supplies for well over 100 years. Exploration for coal, natural gas and oil deposits is expensive but is actively pursued. On the other hand, HEEP is the only activity investigating household energy demand.

The average energy use per household has grown by about 2% since 1990 but as the number of households has increased, the total household energy use has increased by 16%. If the National Energy Efficiency and Conservation Strategy (NEECS) goal of reducing this total energy use is to be achieved, it will be necessary to understand the reasons for the energy demand.

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HEEP now estimates the average Auckland, Wellington and Hamilton household energy use is 10,500 kWh/year, including electricity, natural gas and LPG. Work is continuing on the analysis of solid fuel use, but preliminary results suggest that it will not result in a sizable increase. One reason is that heating fuels are only used for a few hours per day during the four to five month heating season, so although the impact on monthly energy use may be significant, it is not for annual average energy use.

There is no statistically significant difference in average household energy use between HEEP houses in Auckland, Hamilton and Wellington. Improved estimates of household appliance energy use have been prepared. Over the three locations, hot water accounts for about 30% of electricity and gas use, lighting about 10%, refrigeration about 10%, cooking about 4% and clothes washing and drying about 3%.

HEEP Model

One output of the HEEP research will be a model of the residential energy sector. Linking together energy demand, household socio-demographics, occupant behaviour and the building's physical attributes, the HEEP model will provide a range of outputs to meet the needs of policy and implementation programmes.

The UK residential sector energy model BREDEM provides an example of the type of outputs. BREDEM shows that over the period 1970 to 1996 the average energy use per household has not increased, while the average indoor temperature has increased from 13°C to 17°C. The space heating energy consumption per house has remained stable over 36 years, despite use of central heating increasing from 34% to 87% of UK houses.

BREDEM was used to analyse the impacts of government mandated energy efficiency measures applied to UK housing. It showed that they have resulted in energy savings of roughly 37% – of which 20% is due to improved insulation, and the remaining 17% to improved heating efficiency.

In the absence of the HEEP model, only a limited evaluation can be made of the New Zealand situation. For comparison, annual energy use per New Zealand household increased from 40 GJ in 1980 to 43 GJ in 2000, and the proportion of houses with central heating has remained static at 5%. There is no evidence that internal temperatures in New Zealand homes have increased. However, their low thermal performance suggests that should the internal temperatures increase, there would be a sizable increase in energy use and in climate change gas production.

International Comparisons

Country	Household energy use (kWh/year)
New Zealand	10,500
Australia	16,400
UK	22,200
US (average)	26,700
Canada	39,700

New Zealand households use less energy than those in many other developed countries. The table shows that the average New Zealand household uses 30% less energy than Australia, close to 50% less than the UK, and 70% less than Canada. Given the climates found in these countries, some difference is not unexpected but it is likely the low New Zealand value relates to low levels of space heating energy use.

Year 6 Executive Summary

The table below compares household expenditure on ‘energy’ for the five countries. For all five countries, the proportion of expenditure on stationary energy (i.e. excluding transport energy) is within the range 2.6% to 3.5%, even for countries expected to require greater indoor temperature control – either due to hot or cold external temperatures. The reasons for this apparently similar proportion of expenditure have not been investigated, but could be due to a range of factors, including energy pricing policies, house thermal performance, occupant expectations or even the expenditure survey methodology.

Country	Description	Deciles										All
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Households
New Zealand	Domestic fuel & power	6.0%	5.5%	4.8%	4.0%	3.4%	2.8%	2.3%	2.0%	1.8%	1.5%	3.4%
UK	Fuel and power	6.5%	6.7%	5.5%	4.2%	3.6%	3.2%	2.9%	2.6%	2.4%	2.0%	3.1%
		Quintiles										
			1st		2nd		3rd		4th		5th	
Australia	Domestic fuel & power		3.7%		3.3%		2.7%		2.3%		2.0%	2.6%
USA	Nat. gas, elect, fuel oil etc		4.9%		4.4%		3.6%		3.0%		2.4%	3.5%
Canada	Water, fuel, electricity											3.3%

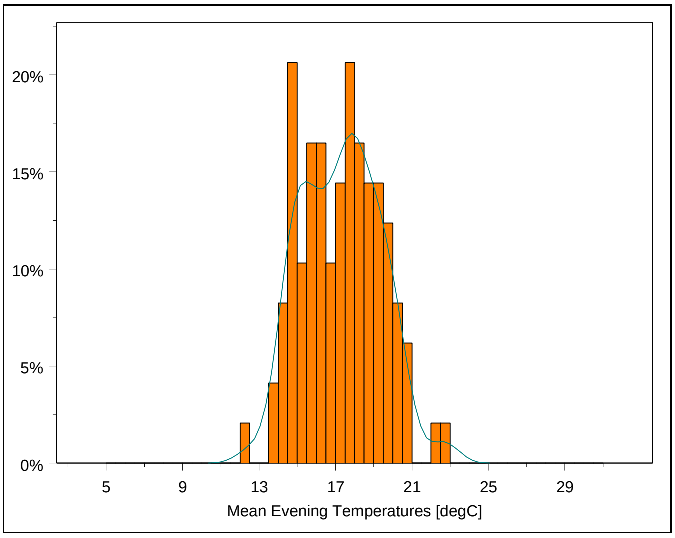
In all four countries for which expenditure against income data is available, the proportion spent on energy decreases with increasing income, with New Zealand and UK showing the largest difference (4.5%) between the lowest and highest income groups. Examination of the Statistics NZ ‘Household Economic Survey’ (HES) shows that over the period 1987 to 2001, the proportion of expenditure spent by low income households has increased while for higher income households it has remained static.

Indoor Temperatures

Patterns are emerging as to how houses are heated. There is some variation in the heating season length – ranging from four months in Auckland to closer to five months in Hamilton and Wellington. For most of the HEEP houses, heating starts around May and finishes in September. Hamilton houses are the warmest, followed by Auckland and then Wellington.

City	Start heating	Peak temperature	Heating period
Auckland	5:45 pm	8:30 pm	4½ hours
Hamilton	4:30 pm	7:00 pm	4¾ hours
Wellington	5:00 pm	9:30 pm	7 hours

The time of heating for the three regions are shown in the table. No obvious explanation for the differences has been found, and this will be further investigated in other locations.



The graph provides an overview of the winter evening temperatures in all the monitored houses (including non-randomly selected houses). This follows the normal (bell shaped) distribution, with an average temperature of 17.3°C and a standard deviation of 2.1°C.

Household heating is strongly zoned, e.g. while the living areas are heated, less than 50% of households heat bedrooms, and most do not heat utility rooms (bathrooms, laundry, etc).

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The winter evening temperatures measured in living rooms were compared to the range of socio-economic responses provided from the household occupant survey. No correlation was found between household income or house floor area and winter evening temperatures. This confirmed the egalitarian nature of New Zealand society – high-income households are no warmer than low-income households.

Insulation group	Average winter evening temperature	Winter evening energy use
Pre-1978	17.0 ± 0.2°C	1070 ± 280 W
Post-1978	18.4 ± 0.4°C	1130 ± 150 W

There is a significant correlation between winter evening temperatures and the age of the house. Currently, we can conclude that post-1978 houses are 1.4°C warmer on average and that their winter evening energy use is not significantly different from the pre-1978 houses. This would suggest that where it is possible to achieve warmer temperatures, New Zealanders will do so.

LPG Heaters

The number of households with portable gas heaters has increased from 2% of households in 1984 (the least popular of the eight heating types surveyed at that time) to 33% (452,800) of households in 2001 (second only to portable electric heaters). The increase in the usage of portable gas heaters is closely matched to the reduction in usage of the other two types of portable heaters surveyed: portable electric heaters (reducing from 89% of houses in 1984 to 71% of houses in 2001); and portable kerosene heaters (reducing from 11% to 1%).

HEEP has developed a special technique to permit the monitoring of time-of-use and power output of portable gas heaters. Coupled with graphical data exploration tools, this provides for the first time, detailed information on the use of LPG heaters. For this report, use data from ten heaters in nine houses was available. It was found that they are:

- mostly used on **'Low' setting**: The majority of the heaters (7 out of 10) were used the majority of the time (73% to 100%) on a 'low' setting (1.3 kW to 1.7 kW), while of the remaining three heaters, only one was used for the majority of the time at a 'high' (3.6 kW to 4.3 kW) setting.
- generally used for **short periods of time**: Only three of the heaters are used (on average) for more that one hour per day, and of the other seven heaters, six are used for on average half an hour or less per day over winter.

This does not seem to match an expectation that as LPG heaters are capable of higher power outputs than standard '3-pin plug' electric heaters (which are limited to 2.4 kW), they would be used for longer periods of time at higher settings. It was also observed that for houses with a high evening LPG heater use, electricity peaks occur before or after the heater use.

Hot Water

Hot water is a major energy use in the average New Zealand home. Previous HEEP reports found hot water energy use was on average 4000 kWh/year/house or about 44% of total energy. The average hot water standing loss is 1000 to 1100 kWh/system/year, representing about 11–12% of total energy use or 25–30% of the hot water heating energy.

The table below provides selected new information for the three types of hot water systems – electric storage, natural gas storage and natural gas instantaneous – monitored by HEEP. About 75% of the houses have electricity as the main fuel for hot water supply, 15% use natural gas and 10% use instant natural gas. Both the amount of energy and delivered hot water used for houses with natural gas systems is higher than for electric systems.

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Based on Auckland, Hamilton, Wellington HEEP monitoring	Strata weighted average	Electric storage	Natural gas - Storage	Natural gas - Instant
Age (years)	15±1	18±2	12±2	3.4±0.8
Cylinder volume (l)	158±4	152±4	150±10	-
Standing loss (kWh/day)	2.5±0.2	2.6±0.1	4±0.4	-
Used hot water energy (kWh/day)	7.3±0.6	5.3±0.4	12±2	14±1

Large reductions in energy use and Greenhouse Gas emissions can be achieved by upgrading the energy efficiency of hot water systems, and by reducing hot water consumption. EECA's "Residential Grants Programme" has implemented a range of improvements to hot water systems, which include cylinder wraps, pipe insulation and low-flow shower heads. The projects have been run by various interested groups including community groups, local energy trusts and power/lines companies, and commercial companies.

The HEEP data supports the calculation of the change in GHG emissions resulting from upgrading the insulation on the hot water cylinder, based on: the energy use/GHG emissions before upgrade; the energy use/GHG emissions after upgrade; the lifetime of upgrade and the lifetime of system if the upgrade was not put in place.

In the houses monitored to date, poorly insulated cylinders have been found far more often than expected. About 30% of cylinders are more than 25 years old, with the oldest at more than 45 years. Clearly, old cylinders are widespread in New Zealand, with around 40% C (pre 1986) or D (pre-1976) grades. With an average age of 33 years for D grade electric cylinders (and the youngest 15 years), this would suggest that old cylinders are not replaced until they are over 40 years old. This would also suggest that the benefits from retrofitting cylinder wraps may be greater than previously expected.

Of the hot water systems surveyed, very few of any age or grade had cylinder wraps or pipe lagging. Pipe lagging is likely to be equally cost effective on sizes and types of hot water systems, including gas systems. Savings for pipe lagging are approximately 120 kWh per year, giving a saving of about $16 per year, and payback from 6-18 months, depending on the cost of lagging.

Replacing a 180 litre D grade cylinder with a new A grade cylinder gives greater energy savings and GHG reductions than wrapping the cylinder. Similarly, installing a heat pump, solar water heater, or changing to gas fuel will result in energy and GHG savings. However, unless the cylinder needs to be replaced (e.g. due to age, house modifications, etc) then cylinder wrapping is by far the most cost-effective measure, as shown in the table below.

Measure	Cost	Energy savings	Simple Energy Payback	GHG savings
Cylinder wrap	$100	$88/yr	1.1 yr	$6.40/yr
New A grade	~$1200	$100/yr	12 yr	$7.30/yr
Hot Shot heat pump	~$1800	$274/yr	6.4 yr	$20/yr
Solar	$3500+	$356/yr	10 yr	$26/yr
New gas cylinder	~$2000	~$300/yr	6.7 yr	~$25/yr

HEEP results could be used to develop a decision support tool for selecting houses (or locations) most likely to benefit from improved hot water system efficiency activities.

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No simple relationship has been found between the size of the hot water cylinder and the size (floor area) of the house, but older houses often have smaller cylinders. When this is coupled with a larger number of occupants, it is not uncommon for the water temperature to be increased to unsafe levels. Tap temperatures are on average higher for electric storage cylinders than for natural-gas storage cylinders, although the storage volumes are similar. A 135-litre cylinder storing water at 75°C holds the same hot water energy as a 180-litre cylinder with water stored at 55°C, but the higher temperature is clearly unsafe for all users. Where smaller cylinders have to be replaced, consideration should be given to increased cylinder size.

Uses of HEEP

The HEEP results have already played a crucial role for energy companies to evaluate opportunities to manage their loads and deal with proposed legislative changes, for appliance supplies to understand how consumers use their products, and improving the debate over how energy is actually used in New Zealand households.

Internationally the use of theoretical or modelled data as the basis for energy-efficiency requirements is recognised as inadequate. For example, in June 2002 the US Department of Energy withdrew a proposal for changes to Energy Star windows, doors, and skylights, citing a “lack of empirical data on the role of solar heat gain in certain regions of the country”.

HEEP results are supporting the revision of the New Zealand Building Code Clause H1 : Energy Efficiency, the National Energy Efficiency and Conservation Strategy (NEECS), identifying opportunities for greenhouse gas reduction to meet the requirements of the Kyoto Climate Change Strategy, and the ‘Minimum Energy Performance Standards’ (MEPS) and labelling programmes. HEEP research will also feed into environmental performance indicators being developed by the Ministry for the Environment and Statistics NZ.

HEEP is not a longitudinal study investigating changes in patterns of energy use over time; nor does it investigate the impacts of energy-efficiency changes to houses. The HEEP results will provide critical baselines for such studies, including current health and housing research.

Monitoring and Methodology

The use of BRANZ designed and built dataloggers, coupled with trained field staff, has resulted in high-quality data for analysis. The data can be processed promptly and analysed soon after collection.

The current monitoring of 100 houses in Auckland, Waikanae and Christchurch will finished in February 2003, so the database will hold 200 houses for the HEEP Year 7 report. The 100 houses to be monitored in Year 8 are spread around New Zealand – Invercargill, Dunedin, Oamaru, Waikanae, Waikato, Tauranga and Northland. Installations for year 8 are taking place from November 2002 to February 2003, and removal 11 months later.

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Location	*Year(s) monitored*	*Number of houses*
Wellington	1999	43
Hamilton	2000	17
Auckland	2001/02	98
Waikanae	2002	10
Christchurch	2002	37
Foxton Beach	2003	10
Oamaru, Dunedin, Invercargill	2003	30
Northland, Tauranga, Waikato	2003	59
Tasman, Marlborough	2004	20
Wairoa, Gisborne, Napier	2004	30
Franklin, Rodney, Thames	2004	30
Rotorua, Taupo	2004	30
TOTAL RANDOM HOUSEHOLDS		**414**

Random selection of households started in 1999. The table shows the progress to date and future plans for the target sample of 400 randomly selected, monitored houses. Data is also held on 66 non-randomly selected houses.

Further details of the planned locations, the monitoring methodology, monitoring documentation and analysis procedures are provided in the full report.

Other issues discussed in the full report include:

- Use of the Energy intellect Limited (formerly Total Metering Limited) TMA3100 remote monitored, integrated three-phase energy meter and data logger. This is providing new data on time-of-day Power Factors.
- Further analysis of the distribution of baseload and standby power.
- The use of 'Artificial Neural Networks' understand solid fuel heater patterns of use.

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 the BRANZ web site.

Copies of the full Year 6 report are available from BRANZ, using the order form below:

Postal address: BRANZ, Private Bag 50908, Porirua City, NZ.
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ENERGY USE IN NEW ZEALAND HOUSEHOLDS

Report on Year Six for the Household Energy End-use Project (HEEP) – November 2002, BRANZ Study Report SR 115

Authors:

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REFERENCE

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.

ABSTRACT

This report covers the activities of the sixth full year of the Household Energy End-use Project (HEEP) and is based on data from 100 houses in Auckland, Wellington and Hamilton. The year six monitoring is being carried out in Auckland (50 houses), Waikanae (10 houses) and Christchurch (37 houses).

New Zealand households use less energy than many other developed countries (around 10,500 kWh per household per year), possibly due to lower indoor winter temperatures. A correlation between house age (since 1978 thermal insulation has been required) and winter evening temperatures was found, but no correlation with house income. The report discusses use of LPG (liquefied petroleum gas) heaters, opportunities for improving the energy efficiency of hot water system, compares energy use for natural gas and electric hot water cylinder, and provides a breakdown of household energy end-uses. As with previous annual reports, further background to the study and the monitoring methodology are provided.

In-depth customised analysis of the information is available to financial supporters of the HEEP investigation.

Acknowledgements

Since the HEEP project began, funding support has been received from the following organisations, and we gratefully acknowledge their contributions:

- 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 co-operation this research would not have been possible.

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1. INTRODUCTION

This is the sixth 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.

Further information is available from the sources listed in Section 1.9 (see page 13).

1.1 Overview

New Zealand has 1.4 million homes and every year we build on average 22,000 more. All these homes use energy in various forms and for a wide range of end uses, yet our understanding of household energy consumption patterns is limited. Until HEEP, the most recent data available on household energy use was the 1971/72 household electricity survey.

This lack of current energy end-use data has also meant that many activities are based on theoretical modelling rather than on modern behavioural data from real households. There have been massive changes in New Zealand society, and in energy-use trends in this period. There have been changes in fuels (including the wide availability of natural gas), new types of appliances (such as Liquid Petroleum Gas (LPG) heaters), new appliance classes (for example, microwave ovens), new New Zealand Building Code requirements (NZBC Clause H1: Energy Efficiency) and new construction systems (for example, polystyrene cladding). There have been significant societal changes (ethnic diversity, regional drift, etc),changes in consumer spending (‘convenience foods’, and increases in new home size and changes in construction processes.

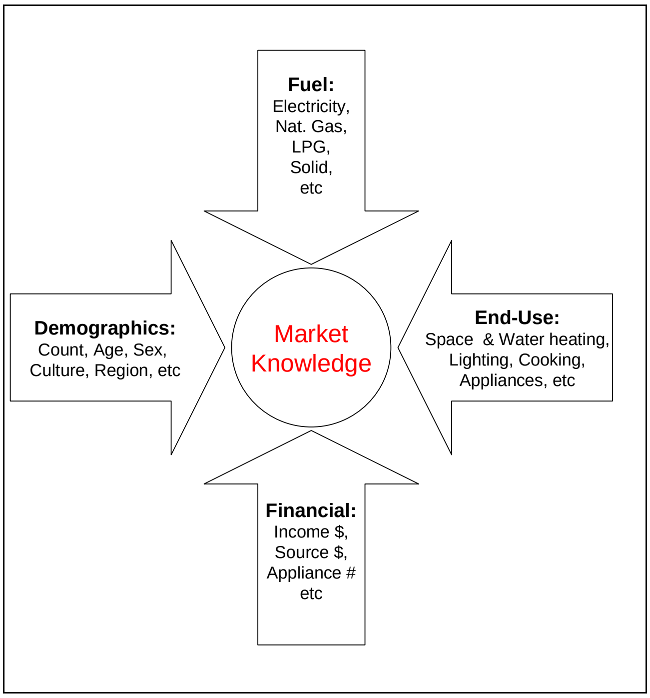
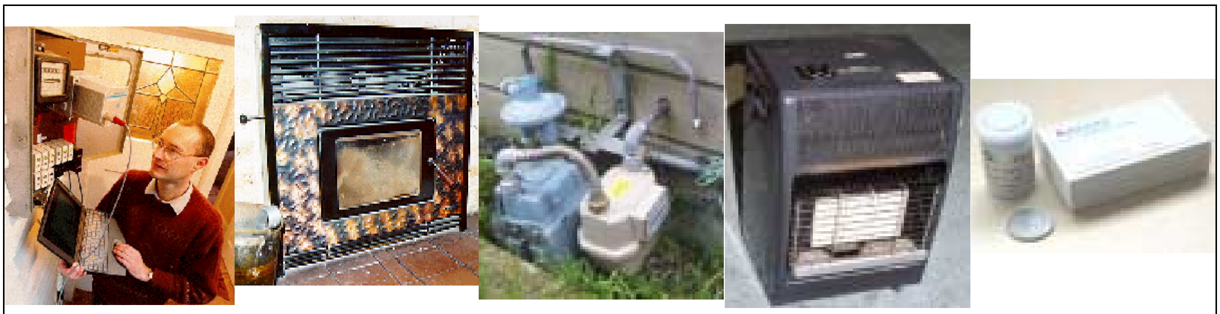


Figure 1: HEEP – information collected

Many unanswered questions have also been raised – how warm are New Zealand houses, and has this changed over 30 years? How often are these ‘new’ appliances used, and what is their impact on peak power or energy use? Do insulated houses use more or less space-heating energy? HEEP is starting to provide answers to these questions, and will answer many others.

The HEEP research covers four key fields, and will lead to improved knowledge of the residential energy use (Figure 1):

- **Fuel use patterns** (all fuels – electricity, natural gas, LPG, solid fuels, solar, etc)
- **Energy end-use data** (includes ‘real time’ analysis of how energy is used in the household-appliances, space conditioning, water heating, lights, etc)
- **Occupant profiling** (number, income, socio-demographic details, etc)
- **Household profiling** (construction, appliances, total income, etc).



Electricity Solid Fuel Natural Gas LPG Temperature

Figure 2: HEEP monitoring

Figure 2 illustrates the range of monitoring carried out by HEEP:

- Electricity
- Solid fuel
- Natural gas
- LPG
- Temperatures.

Previous reports provide additional details on the monitoring methodology (see Section 13.1, page 95 for a detailed listing).

1.2 Objective

The objective of the HEEP work is to build a model based on the main drivers that determine household energy-consumption patterns. This is done by establishing:

- **Energy consumption:** *how much energy is used by households*
- **Energy types:** *which types of energy are used by households*
- **Appliances:** *which household appliances use this energy*
- **Time periods:** *during which seasons and times of day energy is consumed*
- **Household types:** *how do different types of households use energy*
- **Occupant behaviour:** *what behaviours affect household energy use*
- **Energy service:** *what service is provided by the energy use.*

Data collected during the project will enable HEEP participants to extract specific information to suit their needs. The potential range of analysis is very wide, and may include:

- **Energy supply:**
    - *improved forecasting tools*
    - *ability to plan resources to meet demands*
    - *ability to estimate effects such as greenhouse gas emissions*
    - *analysis of changing use trends of different energy types*
- **Energy demand:**
    - *demand patterns and ability to shift loads*
    - *load analysis tools and data*
    - *measurement of energy efficiency 'take back' effects*
    - *extensive metered energy-use data*
    - *data for cost/benefit analysis on enhanced supply facilities*
- **Appliances:**
    - *better product and customer knowledge*
    - *potential for technical equipment improvements*
    - *potential for service improvement*
    - *information on speed of energy-efficient appliance uptake*

- **Socio-economics or demographics:**
    - *end-use group analysis*
    - *correlation of energy use, climate and socio-demographic groups*
    - *impact of fuel prices and income levels on energy use*
- **Health:**
    - *information on indoor temperature patterns and occupant health*
    - *information on water heating and danger from scalding*
- **Building characteristics:**
    - *potential for energy-efficiency upgrades*
    - *future building design information*
    - *information on building materials.*

The project has been designed to suit a wide range of participants, with particular analyses able to be tailored for specific needs. At the same time, all the data collected will contribute towards the overall understanding of the energy performance of households.

1.3 Related research

HEEP is not a longitudinal study investigating changes in patterns of energy use over time; nor does it investigate the impacts of energy-efficiency changes to houses. The HEEP results will provide critical baseline data for such studies. Some examples of current research are given below.

1.3.1 Health

The "He Kainga Oranga - Housing and Health Research Programme" being carried out at the Wellington School of Medicine and Health Sciences, is investigating the links between health and housing with different research projects (see: www.wnmeds.ac.nz/healthyhousing.html).

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 will measure the impact of the insulation project 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. The work is being supported by the Health Research Council with support from EECA, Housing New Zealand Corporation and a range of other local government and industry organisations.

The data collection is being carried out over the winters of 2001 and 2002. A nominal 1,400 households, in seven regions throughout the country, are participating in the study by making subjective temperature assessments daily and filling in questionnaires on their house and health. Objective measures are also being made dust collection, measurements of temperature and humidity, as well as data on the number of hospital/GP visits and data from power and gas companies.

The households were chosen on the basis of a member having pre-existing respiratory problems, the dwelling being single storey and uninsulated, the occupants planning to stay in the dwelling for the duration of the study and their agreeing to participate.

During and after the 2001 winter the baseline data was collected. Over the summer of 2001/2002 a randomly selected half of the households are being insulated to bring the houses in line with the current Building Code. Then, during and after the 2002 winter the comparison data will be collected, and finally the remainder of the houses will be insulated to the same standard.

1.3.2 Energy efficiency and indoor climate

A BRANZ research project which began in 1997, has been investigating the effect that retrofitting insulation has on indoor climate (Cunningham et al. 2001).

Insulation was retrofitted in two stages, to improve the thermal performance of the house (product R-values, not the construction R-values, are given in brackets) (Cunningham 2002):

- Stage 1 (June 1998) – roof (R-3.6) & floor (R-2.6)
- Stage 2 (June 1999) – walls (R-2.6).

Table 1 shows that after the first retrofit the average winter space heating power load reduced, the indoor temperature improved and the relative humidity (RH) reduced. The indoor/outdoor temperature difference provides a measure of the effectiveness of the additional insulation, as higher indoor temperatures could occur in a warmer winter.

After the second retrofit, the occupants decided to take some of the benefits as increased temperatures, and thus increased their heating power load. The increase in indoor/outdoor temperature difference shows this was a real benefit of the additional insulation. There was also a reduction in the relative humidity, although it was not enough to make conditions unsuitable for dust mites.

Description	**Daily heating**	**Indoor temperature**	**Indoor/outdoor temperature difference**	**Indoor relative humidity**
Before 1st retrofit	1200 W	10.4°C	2.0°C	68%
After 1st retrofit	540 W	12.8°C	2.4°C	64%
After 2nd retrofit	670 W	13.7°C	3.3°C	60%
Outcome:	**Cheaper to heat**	**Warmer**	**Warmer**	**Drier**

Table 1: Impact of retrofits on winter power consumption & indoor climate

1.4 Indicators

Although HEEP is concerned with the collection and analysis of monitored data collected at ‘appliance level’, Figure 12 illustrates that such data is essential to permit more aggregate types of analysis to be undertaken. The results of HEEP will be of value to the development of two types of performance indicators Environmental Performance Indicators and Socio-Economic Indicators for the Environment.

1.4.1 Environmental performance indicators

Since the mid-1990s, the Ministry for the Environment has been co-ordinating the Environmental Performance Indicator (EPI) Programme to develop a set of environmental indicators for environment reporting. The EPIs comprise fourteen strands[i], based on component parts of the environment and the main areas where impacts from human activities (pressures) originate.

The EPI ‘energy’ strand includes as an indicator ‘residential energy use per household (GJ/household)’. This is a broad indicator of the efficiency of energy use in the residential sector. It combines data on total energy used in the residential sector with data on the number of households, estimated from Census data. The indicator does have some limitations. Being

[i] Air; marine; climate change; ozone; land; waste; freshwater; transport; amenity; pest, weeds and diseases; energy; biodiversity; toxic contaminants and contaminated sites; and Māori. (See www.environment.govt.nz)

an indicator calculated as an average of two national numbers, it does not show changes over time, or differences between, the various types of households.

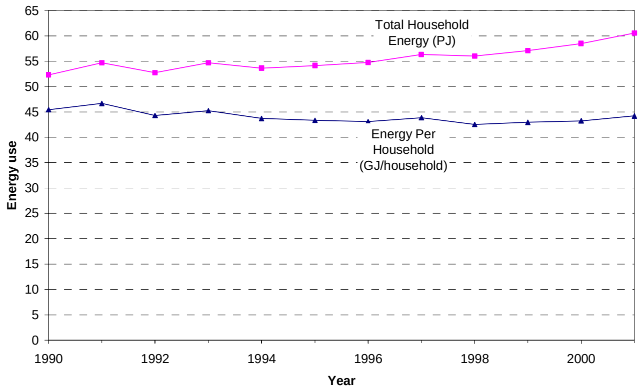


Figure 3: New Zealand household energy use

The data for this indicator come from the Ministry of Economic Development and Statistics NZ's Census data, and are available on their web site[i]. The Ministry for the Environment will report the indicator annually. Figure 3 gives this indicator for the period 1990-2001 using EECA data[ii]. The energy use per household has grown slightly over the decade, increasing by about 2% from 1990 to 2001, although the total household energy use increased by 16%.

HEEP data will provide an improved understanding of the drivers for changes in household energy use, and thus improve the validity and usefulness of the indicator.

1.4.2 Socio-economic indicators for the environment

Statistics NZ and the Ministry for the Environment are working together on a set of social and economic indicators that can be used for integrated environmental reporting. Although the social and economic indicators can be used independently, the intention is that they be used in combination with the Ministry for the Environment's EPIs. The final report on the social and economic indicators was released in July 2002 (Statistics 2002c).

It was originally proposed that "household expenditure on energy/heating, by type, as a percentage of the total expenditure on energy/heating" be used as a socio-economic indicator. It was decided not to use this indicator due to the difficulty in linking the data provided by the indicator to the effects on the environment. Ideally this indicator would measure physical units, such as electricity used. Expenditure changes may reflect price changes in electricity, rather than the volume of electricity consumed.

A future (Stage 2) indicator is proposed to be "change in home heating fuel type" This indicator will supplement the EPI energy indicators by providing information on the numbers of dwellings that use a particular type of heating. The EPI indicators will supply data on the amount of energy that households use. More detailed information regarding the specific types of gas heating is unfortunately not available.

The Household Economic Survey (HES) would provide more frequent data than the five-yearly Census of Population and Dwellings, but the HES does not provide data at detailed sub-national geographic areas, such as urban areas, where air quality problems can be most prevalent (see Section 10.3, page 77). HEEP will provide data to improve understanding of the drivers for change to this indicator, and ultimately improve the indicator's usefulness.

[ii] pers. com. Dr Harbans Aulakh, Senior Monitoring Advisor, EECA, 7 August 2002

1.5 HEEP database

The HEEP database holds the full collection of monitored data for each HEEP house. Separate database structures are also maintained for the householder survey and appliance measurements. These all relate to each other through the unique house identifier code.

It should be noted that all HEEP data is collected under a confidentiality agreement that explicitly forbids the release of any data which could identify an individual household.

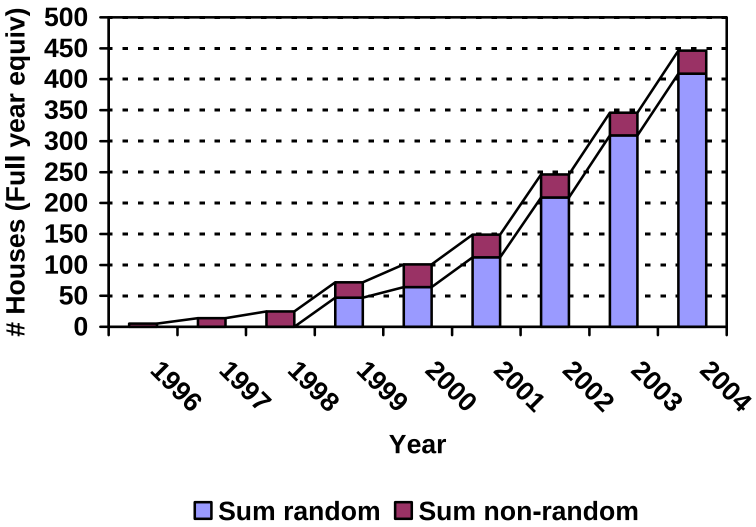


Figure 4: Number of HEEP houses

Figure 4 shows how the number of houses in the HEEP database has increased over the project's lifetime. Non-random houses are selected to provide data on a particular issue, most notably to meet a commercial need. The randomly selected HEEP houses are not available for further research studies, and thus the non-random houses permit a wider range of investigations to be undertaken.

1.6 HEEP end-use monitoring

Table 2 summarises the monitoring coverage for end-use and whole-house monitoring. The exact number of individually monitored appliances and individual temperatures monitored in any given house will depend on the availability of the monitoring equipment and the probability of selection established for that house. Under normal conditions three temperatures will be monitored in any house, but this can be increased depending on the house characteristics, or specific research needs.

The principal difference between the two monitoring approaches is the ability to use the results of the end-use monitoring for detailed analysis of individual appliance energy-use.

HEEP needs to monitor a minimum number of end-use houses in order to provide case study and generic information on specific appliances. If detailed analysis is required, then this can be provided with full-cost recovery. A minimum of 25% of the HEEP houses in any given location are end-use monitored, either with purpose-designed EUM equipment or with HEEP-developed Siemens Appliance Monitoring (SAM) units.

Monitoring	End use	Whole house
Total electricity	✓	✓
Total gas	✓	✓
Total LPG	✓	✓
DHW (electric or gas)	✓	✓
Individual gas appliances	✓	×
Individual electric appliances	✓	×
Indoor temperatures	✓	×
External temperatures	3 ±	3 ±
Occupant survey	✓	✓
Energy audit	✓	✓
Appliance standby power	✓	✓

Table 2: Monitoring coverage - end-use and whole-house

1.7 HEEP data analysis

The HEEP analysis effort to date has focused on collecting, cleaning and entering into the appropriate database the monitoring and survey data. The Year 6 report represents the first output of a mature HEEP data collection and analysis system. A set of standard analysis tools have been developed which can be selectively applied to the HEEP data – for example, to randomly selected houses, to the entire database, or to selected portions e.g. low-income households. This provides an increased ability to provide a range of valuable information to potential users. This information starts with the annual reports, which provide an indication of the type of information it is possible to extract from the database.

Figure 5 illustrates the wide range of potential users of the results of the HEEP research. In many cases the preliminary results are already being used. Users and potential users include:

- EECA and the Government in support and development of the 'National Energy Efficiency And Conservation Strategy' (NEECS)
- EECA's Residential Grants Programme allocation methodology
- Government as it implements Kyoto Climate Change Gas emission control strategies;
- Building Industry Authority's future development of New Zealand Building Code Clause H1: Energy Efficiency
- BRANZ and other industry organisations for the future development of ALF, Green Home Scheme and other energy or environmental design or assessment tools;
- managers, operators and participants in the electricity marketplace interested in the use of user time-of-day 'profiles'
- suppliers and users of distributed generation technologies
- 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
- suppliers of competing fuels
- researchers and policy developers working in health and housing
- individuals and organisations in need of baseline data on household energy, temperatures and other properties of houses
- local and Central Government interested in reducing localised pollution due to household energy use.

Figure 5: Potential users of HEEP results

Figure 6 illustrates the relationship between the monitored HEEP data and the analysis which will lead to the model of the New Zealand residential energy economy. It also shows that although some of the issues under consideration relate to the physical building construction and the climate, there are also a wide range of interactions with the occupants.

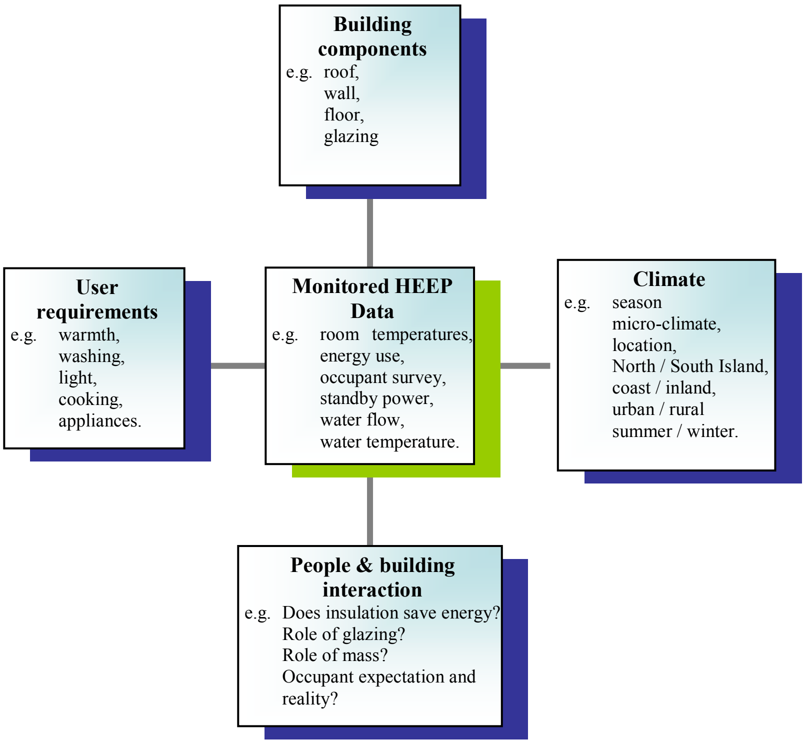


Figure 6: HEEP opportunities and interactions

Table 3 summarises the various analyses reported in the HEEP reports issued to date. It should be noted that each year data from an increasing number of houses becomes available for analysis, thus improving the reliability.

Analysis	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**
TOTAL ENERGY						
Household energy end-uses	✓				✓	✓
Weekly electrical energy consumption	✓					
Average daily electricity use by time of day	✓					
Average daily electrical heating energy by time of day	✓					
Heater energy-use profiles	✓		✓	✓		
Total energy-use by city	✓					✓
Time-of-use profiles		✓		✓	✓	
Weekdays vs. weekends		✓				
Seasonal energy use					✓	✓
Peak energy		✓				
House electrical baseload			✓			✓
ALF/heating model calibration				✓	✓	
APPLIANCES **(see note below)**						
Appliance energy-use analysis	✓			✓		✓
Appliance energy-use by city	✓					✓
Appliance stock / EERA comparison		✓				
Appliance energy use and labelling/ MEPS		✓			✓	
Appliance ownership & socio-economic measures			✓		✓	
Standby losses			✓		✓	✓
DHW						
Hot water energy use		✓			✓	✓
DHW standing losses		✓	✓		✓	✓
TEMPERATURE						
Temperature profiles	✓				✓	✓
Space Temperature vs. energy use	✓				✓	✓
Sampling Plan (inc. size, house & appliance selection)	✓	✓	✓		✓	✓

Note: Individual appliances used as examples:
Year 1 (1997): washing machine, freezer, fridge/freezer, night-storage heaters
Year 2 (1998): solid fuel burner, gas & electric water heating, lighting, hot water
Year 3 (1999): heated towel rails, spa pools, dehumidifiers
Year 4 (2000): LPG heaters
Year 5 (2001): Lighting, gas & electric water heating
Year 6 (2002): LPG heaters, gas & electric water heating

Table 3: Data analysis overview

1.8 HEEP future plans

The goal of HEEP includes the development of an energy model of New Zealand housing. The model must deal with more than the physical natural of the housing stock, it is also necessary to cover the occupants and their behaviours. HEEP is a multi-year project, with data collection taking place from 1995 to early 2005. The random selection of houses will ultimately cover all of New Zealand.

The first few years of the HEEP project focused on the development and implementation of large-scale monitoring and data analysis methodology for the types of energy used in households, and on other specific monitoring problems. This involved setting up a series of selected (non-random) households as pilot studies, as well as specific case studies that concentrated on particular areas or household types. The selected household numbers, locations and year of monitoring are shown in Table 4 below.

Location	*Year(s) monitored*	*Number completed*
Wanganui	1996/97	28
Christchurch (limited data quality)	1996/97	15
Wellington	1998	11
Hamilton (pensioner)	2000	12
TOTAL NON-RANDOM HOUSEHOLDS		**66**

Table 4: Non-randomly selected HEEP households completed to date

Random selection of households started in 1999. Table 5 shows the progress to date on the target sample of 400 randomly selected, monitored houses:

Location	*HEEP year completed*	*Year(s) monitored*	*Number completed*
Wellington	4	1999	43
Hamilton	5	2000	17
Auckland	7	2001/02	98
Waikanae	7	2002	10
Christchurch	7	2002	37
TOTAL RANDOM HOUSEHOLDS			**205**

Table 5: Randomly selected HEEP households monitored to date

Monitoring will be completed for Auckland, Waikanae and Christchurch at the end of the 2002 calendar year, and this data will provide the basis for the HEEP Year 7 report. The 200 houses in the HEEP sample at that stage will represent 620,000 households, or 49% of the country. For the remaining two years of monitoring, the progress is planned to be 100 houses per year – representing about 25% of the national household stock.

The HEEP Year 5 report (Stoecklein et al. 2001) provides full details on the sampling methodology. Figure 7 (extracted from the Year 5 report) illustrates locations of the clustered (rural) and the non-clustered (urban and suburban – shown with circles around names) monitoring areas. The identification numbers in brackets, e.g. (1), represent the order that location was drawn in the creation of the random sample.

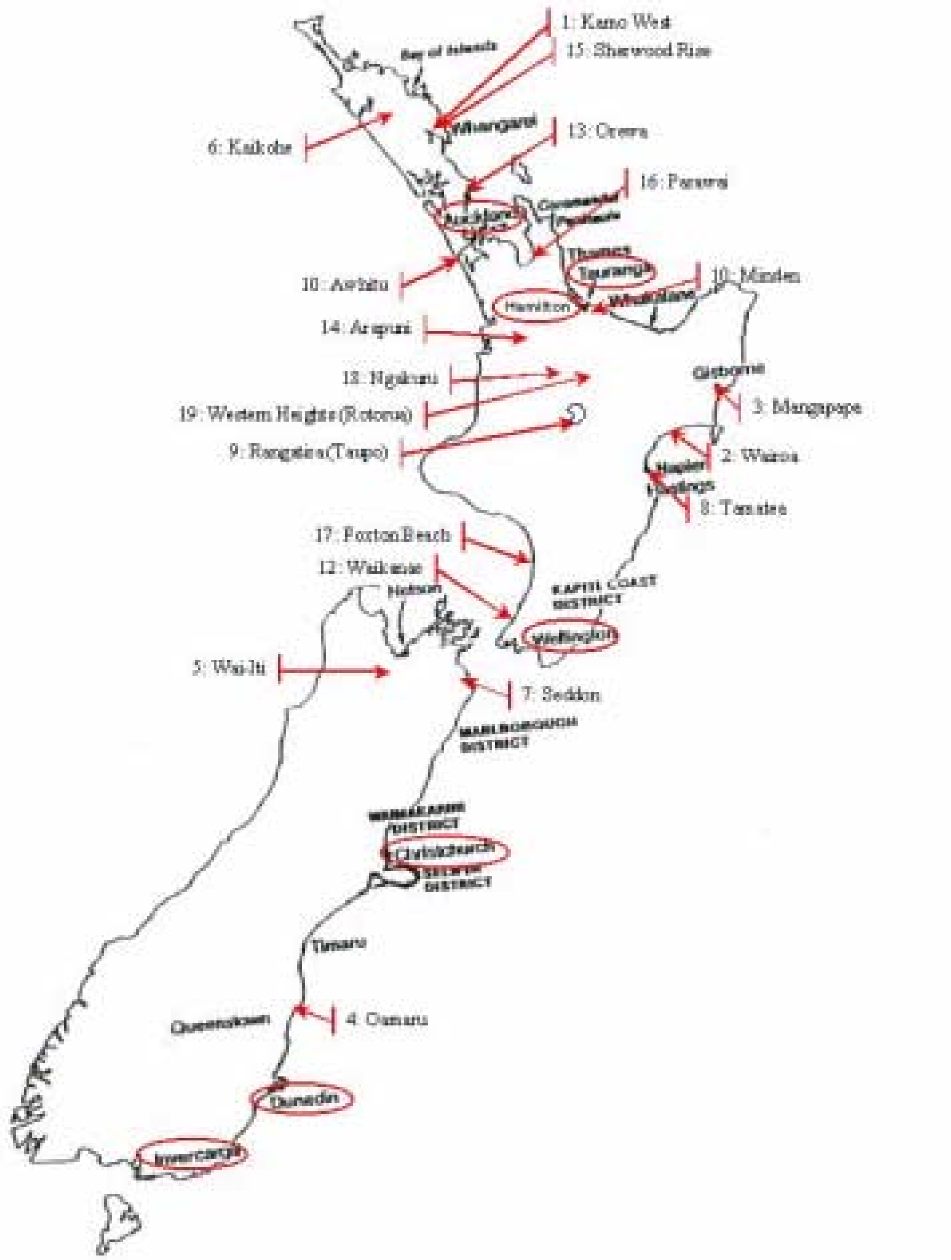


Figure 7: Location of monitoring areas

Table 6 lists the locations identified in Figure 7, and groups them into areas which can most readily be covered by the minimum number of field staff, whilst maintaining a reasonable geographical coverage. Equipment would be installed in the month given, and removed approximately 11 months later. The following month is then used to check and calibrate equipment. The 'strata' and 'cluster' classifications given in Table 6 refer only to the selection mechanism, not to any differentiation in monitoring.

Install	Statistics NZ Area unit (Region)	Island	#	Strata / cluster	Cluster #	Location
Nov-01	Waikanae (Kapiti Coast)	North	10	C	12	Waikanae
Nov-02	Foxton Beach (Horowhenua)	North	10	C	17	Foxton
Dec-02	Oamaru South (Waitaki)	South	10	C	4	Dunedin
Dec-02	Dunedin City	South	14	S		Dunedin
Dec-02	Invercargill City	South	6	S		Dunedin
Feb-03	Kamo West (Whangarei)	North	10	C	1	Northland
Feb-03	Kaikohe (Far North)	North	10	C	6	Northland
Feb-03	Sherwood Rise (Whangarei)	North	10	C	15	Northland
Feb-03	Minden (Western Bay of Plenty)	North	10	C	11	Tauranga
Feb-03	Tauranga City	North	9	S		Tauranga
Feb-03	Arapuni (South Waikato)	North	10	C	14	Waikato
Nov-03	Wai-Iti (Tasman)	South	10	C	5	Tasman
Nov-03	Seddon (Marlborough)	South	10	C	7	Marlborough
Dec-03	Wairoa (Wairoa)	North	10	C	2	East Cape
Dec-03	Mangapapa (Gisborne)	North	10	C	3	East Cape
Dec-03	Tamatea North (Napier City)	North	10	C	8	Napier
Feb-04	Awhitu (Franklin)	North	10	C	10	Franklin
Feb-04	Orewa (Rodney)	North	10	C	13	Rodney
Feb-04	Parawai (Thames-Coromandel)	North	10	C	16	Thames
Feb-04	Rangatira (Taupo)	North	10	C	9	Taupo
Feb-04	Ngakuru (Rotorua)	North	10	C	18	Rotorua
Feb-04	Western Heights (Rotorua)	North	10	C	19	Rotorua

Table 6: Proposed future monitoring schedule

Table 7 further summarises Table 6, showing the number of installations by month and location. It can be seen that by current planning all monitoring will be completed and loggers removed by February 2005.

Install	Month #	Year #	Location(s)
Nov-01	10	10	Waikanae
Nov-02	10		Foxton Beach
Dec-02	30		Invercargill, Dunedin, Oamaru
Feb-03	59	99	Northland, Tauranga, Waikato
Nov-03	20		Tasman, Marlborough
Dec-03	30		Wairoa, Gisborne, Napier
Feb-04	60	110	Franklin, Rodney, Thames, Rotorua, Taupo
TOTAL	219		

Table 7: Proposed future monitoring locations

Table 8 provides a count of monitoring equipment currently available. The HEEP Year 5 (Stoecklein et al. 2001) report provided a background to the proposed remote monitoring methodology, which is based exchanging data loggers by mail. This approach relies on the availability of adequate numbers of exchange data loggers and suitable householder participation.

Logger type	Count
BRANZ Temperature	391
BRANZ Pulse	257
BRANZ Microvolt	147
EUM	12
Electricity meter	295
Gas meter	63

Table 8: HEEP monitoring equipment

When the current HEEP monitoring is completed with the removal of equipment from houses in March 2005, the equipment listed in Table 8 will become available for other uses.

Based on HEEP monitoring to date, it is possible for one person to fully download data from approximately five houses per day, or by direct exchange of loggers, visit 10 houses in one day and use the following day to download elsewhere. Depending on the distances to be travelled, the downloading and management of 40 to 50 loggers is a full-time job. BRANZ therefore holds enough loggers to deal with a maximum of two remote logging locations (i.e. a maximum of 20 houses).

Based on this, and a review of international experience, it has been decided that HEEP field staff will be used wherever possible. As well as making the best use of the logging equipment this approach will also ensure data quality is guaranteed by the project, rather than relying on the goodwill of the householders.

1.9 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 11 (page 90) 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.

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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1.10 Acknowledgements

The number of participants involved in HEEP has steadily increased over the years since the project's inception. The following have been involved during the period covered by this report, and their support is gratefully acknowledged:

Building Research Association of New Zealand Inc (BRANZ)
Energy Efficiency and Conservation Authority (EECA)
Foundation for Research, Science and Technology, Public Good Science & Technology Fund (PGST)
Transpower New Zealand Ltd
The WEL Energy Trust

Key research providers for HEEP include:

John Jowett, Consultant Statistician
Victoria University Wellington, School of Architecture

The advice of Les Shorrock, BRE is also acknowledged.

2. RESIDENTIAL SECTOR ENERGY MODELS

The HEEP model will build on the results of the HEEP monitoring in conjunction with other modelling tools. This section reviews the approach being taken by the HEEP model, and provides information on the UK BREDEM model. A brief review of the physics of steady state heat flow is also given.

2.1 The HEEP model

In the past, energy use in houses has been mostly described and modelled purely as a function of the building's thermal performance, together with the efficiency of the space heating system, the water heating system and other appliances. It has become increasingly clear that this approach ignores the critical influence of human behaviour (Kempton & Neiman 1987). Research results indicate that the attitudes and behaviour of an energy consumer influence a large proportion of their energy use. The HEEP model aims to relate physical and technological determinants as well as socio-demographic determinants of energy use to New Zealand households. Figure 8 illustrates a conceptual structure for the HEEP model.

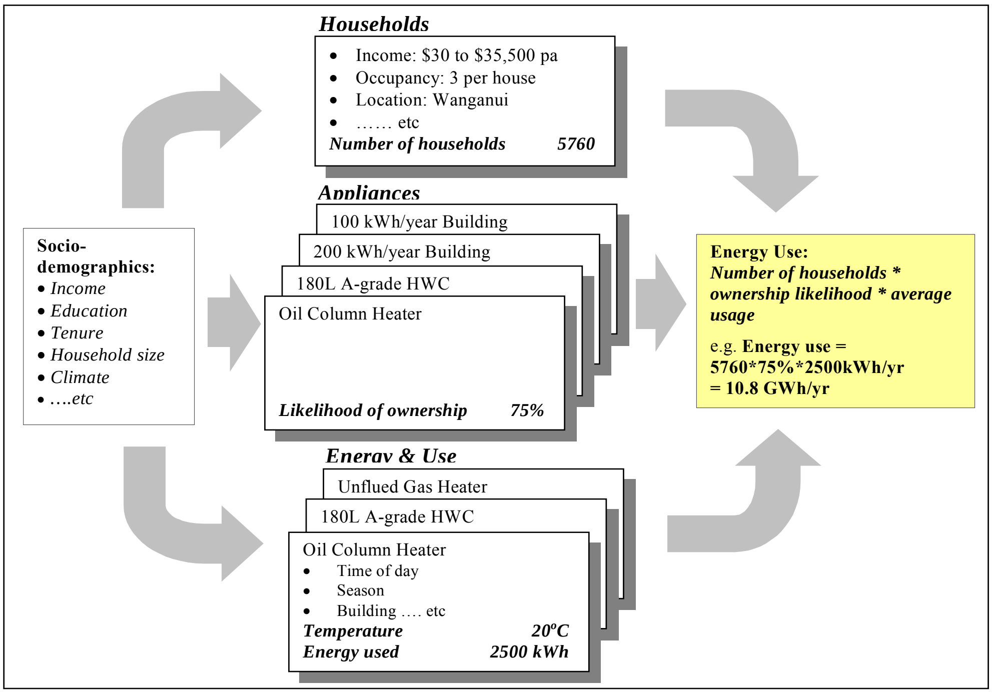

Figure 8: Conceptual HEEP model structure

Figure 8 uses the assumption that household energy-use is driven by three key determinants:

a) **Households:** *the number of households in a particular class that match certain physical and socio-demographic criteria.*

b) **Appliances:** *the likelihood that households in a particular class own certain appliances.*

c) **Energy & use:** *the average energy usage of a particular appliance for this user class to provide a given level of energy service.*

As shown in Figure 8, the example of energy use answers the question:

How much electric heating energy is used per year by three-person households with an annual income of between $30,000 and $35,000 in Wanganui who heat their houses to a comfortable 20°C temperatures using oil column heaters?

Figure 9 provides an overview of the HEEP project, with the current research position illustrated by the dotted line.

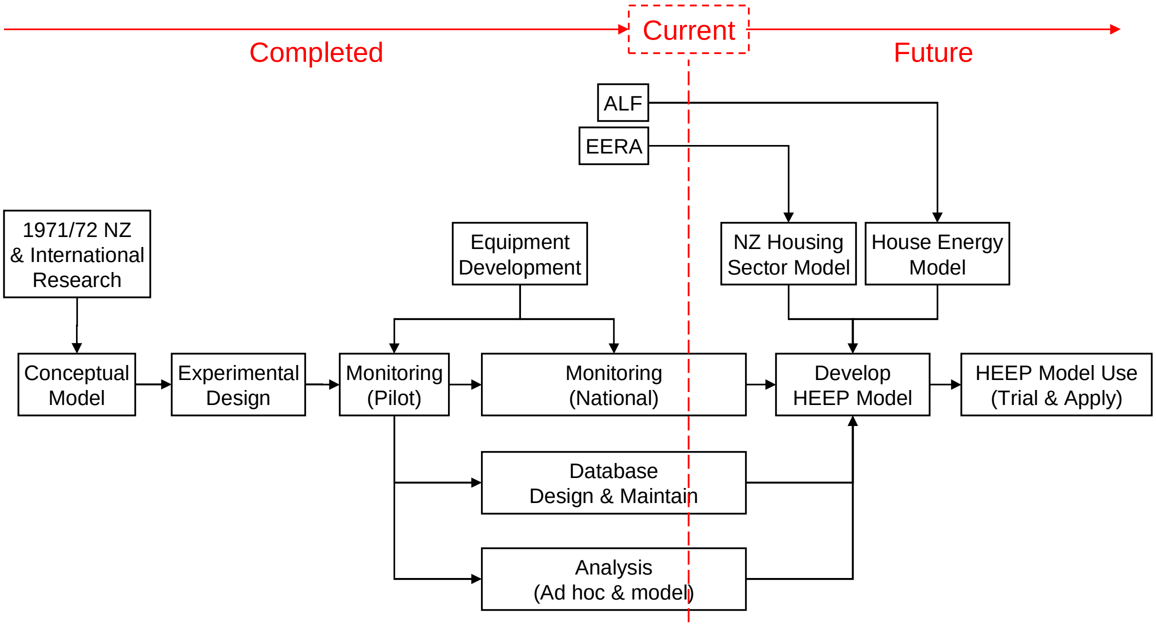

Figure 9: HEEP programme overview

Figure 10 illustrates the expected use and possible structure of the HEEP model. The user will enter key base data, including the numbers of different types of households, the demographics (e.g. young families), the income ranges (e.g. high or low), 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 includes both a house energy model and a housing sector model, which are used in successive repetition within the HEEP model to balance with the residential total energy use, provided from national energy data. The output interface provides the results in an appropriate format. These results could include an estimate of average temperatures for different housing classes, the energy-use distribution, and the hot water energy use etc.

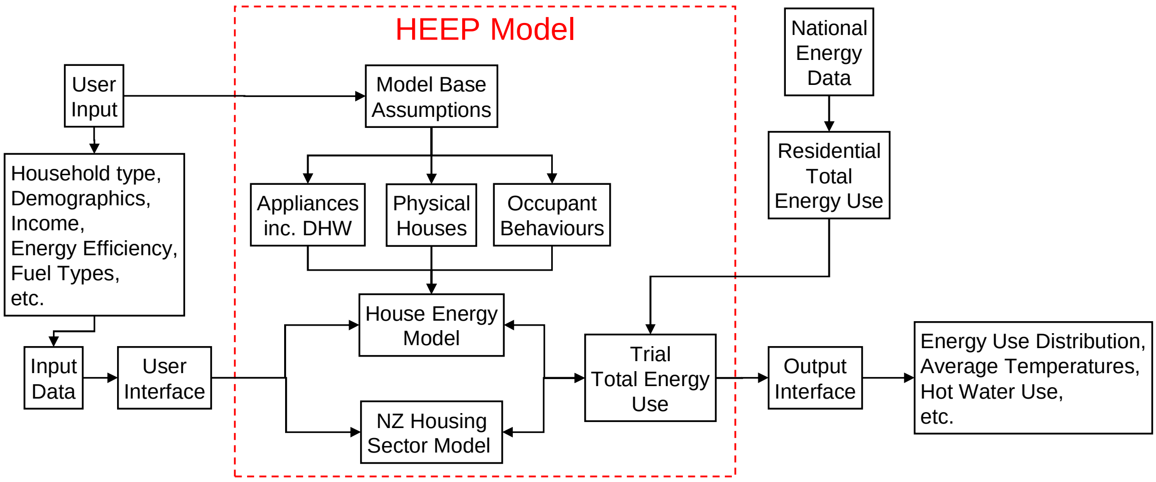

Figure 10: HEEP model overview

It should be noted that the exact structure of the HEEP model will depend on a wide range of factors, including the results of the house monitoring.

2.2 BREDEM – UK residential sector energy model

The UK BREHOMES model provides an example of the type of model expected to be generated by the HEEP research. BREHOMES enables broad estimates to be made of the magnitude of the changes (if any) in the indoor temperatures with changing thermal performance of the building envelope and energy performance of major appliances (Shorrock 1991). This is achieved by calculating heat balance equations for each year, and then deducing a 24-hour average internal temperature during the six 'winter' months.

These "macro-level" models deal with national and regional issues but are based on "micro-level" or individual house models. The BREHOMES model is based on the single house model "BREDEM". BREDEM traces its origins to the early 1980s (Shorrock & Anderson 1995), and is now available in annual (Anderson et al. 1996) and monthly (Anderson et al. 1997) versions. The monthly version is similar to the model described in ISO 9164 (ISO 1989). The BREDEM model considers the building's physical features (construction, heating systems, location) and makes assumptions on the household operations (temperatures, hours used, patterns of appliance use) in order to develop estimates of space heating, water heating, lighting, appliances, and cooking energy-use (Anderson et al. 1985).

The BREHOMES model disaggregates housing stock into seven age groups, 18 built forms, four tenures and the presence of central heating (Shorrock 1997 Pers. Com). For each of these 1,008 variations, BREHOMES uses a version of BREDEM to evaluate the energy use of 10 typical heating patterns. Over three (or more) "calculation loops" the calculated energy is reconciled to the known total energy used, using a variable related to the average demand indoor temperature (Shorrock et al. 1991). It is reported that this variable appears plausible, at around 20°C in centrally heated homes and 18°C in other houses. While models can be used for these purposes, they must be compared to reality, to ensure that all crucial components are included and that the model deals with changes in patterns of energy use over time. BREDEM builds on data collected in the five yearly (from 2001 it will be conducted annually) English House Condition Survey (DTLR 2002) and the UK energy statistics (e.g. DTI 2002, 2002b).

The absolute values of the temperatures cannot be quoted with as much confidence as estimates of the extent of the rise. However, the general level of temperatures in houses has been suggested by a number of surveys. One such survey, carried out in February and March of 1978 gave the average daytime temperature of occupied dwellings as approximately 17°C and 14°C for centrally heated and non-centrally heated houses respectively. The 24-hour averages would be slightly lower than these values[iii].

The following analysis of UK indoor temperatures and energy use is based on reports by Shorrock et. al. (1992, 1993, 1998), based on the BREHOMES model.

[iii] Note: As temperatures are the last values to be calculated in the processing, they can change depending on the new figures for numbers of households, insulation ownership, boiler efficiencies, lights and appliances use, etc. The values in Shorrock 1998 differ slightly from those in Shorrock 1993, although this does not alter the conclusions given here.

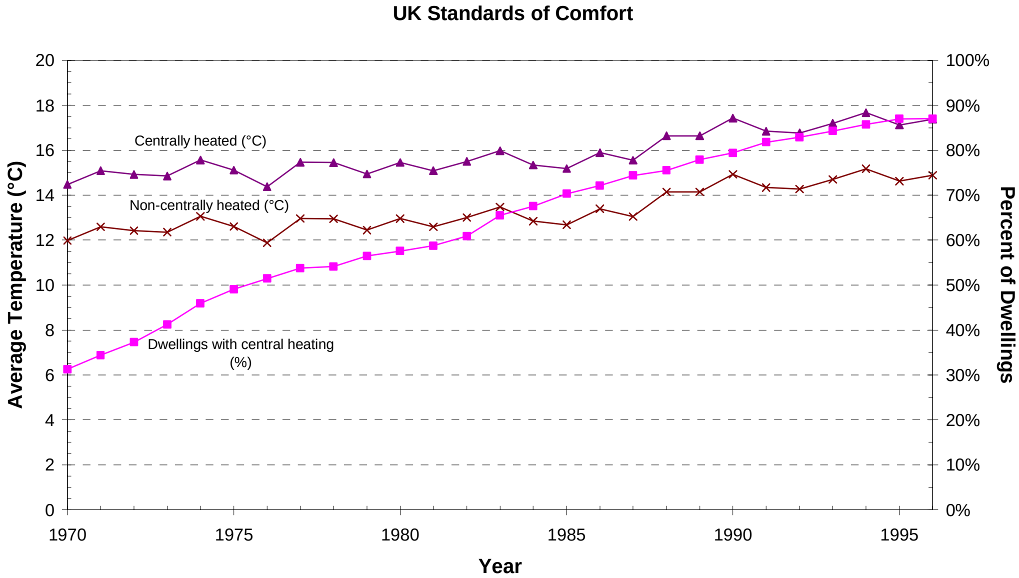

Figure 11: UK residential temperatures 1970 – 1996

Year	Dwellings with central heating	Calculated internal temperatures: Centrally heated	Calculated internal temperatures: Non-centrally heated	All house average	Average external temperature	Total houses (1000s)
1970	31%	14.5°C	12.0°C	12.8°C	5.8°C	17,987
1975	49%	15.1°C	12.6°C	13.8°C	6.4°C	18,988
1980	58%	15.5°C	13.0°C	14.4°C	5.8°C	20,010
1985	70%	15.2°C	12.7°C	14.4°C	4.8°C	21,017
1990	79%	17.4°C	14.9°C	16.9°C	7.6°C	22,140
1995	87%	17.1°C	14.6°C	16.8°C	6.9°C	23,300
1996	87%	17.4°C	14.9°C	17.1°C	5.7°C	23,482

Table 9: UK space heating & internal temperatues 1970-1996

Over the 20 years from 1970 to 1990, there were major changes in the way UK houses were heated, and major changes in the temperatures within these houses. Table 9 shows the proportion of houses with central heating more than doubled from 1970 to 1990, increasing from 34% to 79%, and further rising to 87% in 1995 (Shorrock 1998). It is likely that around 90% of all UK houses now have central heating, which, coupled with uncertainty as to where temperature saturation may lie, may have implications for emissions targets under the Kyoto Agreement (Shorrock – Pers. Com. 2002).

This increase in calculated internal temperatures could have resulted in the major increase in domestic energy use. Table 9 and Figure 11 show how the calculated indoor temperature increased by 2.9°C for both centrally heated houses (14.5°C in 1970 to 17.4°C in 1996), and non-centrally heated houses, albeit from a lower starting point (12.0°C in 1970 to 14.9°C in 1996). The major structural shift in heating systems towards central heating (31% of homes in 1970 to 87% in 1996) gave an increase in the average temperature across all houses of 4.3°C. This steady increase in indoor temperatures has been occurring regardless of the changing external temperatures – averages are also given in Table 9.

It would be expected that, eventually, the average temperature would stabilise as more and more households achieved their desired comfort levels. For most people, a living room of about 21°C temperature during occupied periods would be regarded as comfortable. A temperature perhaps 2°C below this would generally be considered adequate elsewhere in the dwelling, so that a whole house average comfort level might be around 19-20°C. Achieving this temperature throughout a dwelling for 24 hours per day, therefore, could be taken to be an ultimate comfort level beyond which most people would not wish to go. At current rates of increase this level could be reached in the U.K. in perhaps 2020.

The benefits for the UK changes in thermal performance requirements since 1970, coupled with improved heating appliance efficiency, has meant that the energy used per house has remained almost static, as shown in Table 10.

Year	Actual energy used	1970 insulation	1970 insulation & efficiency	Insulation savings	Efficiency savings	Total savings (PJ)	Average energy GJ/house
1970	1,502	1,502	1,502	-	-	-	84
1975	1,505	1,582	1,673	78	90	168	79
1980	1,621	1,854	2,025	233	171	404	81
1985	1,703	2,079	2,383	376	304	680	81
1990	1,652	2,092	2,442	441	349	790	75
1995	1,724	2,278	2,742	554	464	1,019	74
1996	1,953	2,605	3,165	653	560	1,213	83

Table 10: UK energy benefits of insulation & energy efficiency standards

Table 9 and Table 10 show that the average UK household used 84 GJ of energy in 1970 for an average 24-hour winter temperature of 12.8°C. In 1996 this household energy-use was largely unchanged (84 GJ vs. 83 GJ), the average external temperature almost the same (5.7°C vs. 5.8°C) but the average internal temperature had increased from 12.8°C to 17.1°C. For New Zealand annual energy use per household increased from 40 GJ in 1980 (Rossouw 2002 Pers. Com.) to 43 GJ in 2000 (see Figure 3, page 5), although there is no evidence internal temperatures have increased (see Table 30, page 64)

The corresponding space heating figures were 50 GJ in 1970 and 51 GJ in 1996. The space heating energy consumption per house appears to have remained very stable over 36 years, despite use of central heating increasing from 34% to 87% of houses. Table 12 (page 27) shows the comparable figure for New Zealand houses with central heating has remained static at 5% since 1984.

The BREHOMES model can then help answer the key question for UK housing:

> If insulation and efficiency levels had remained as they were in 1970, how much more energy would have been required to maintain the average 1996 internal temperatures?

Table 10 shows the energy consumption calculated from the temperatures given in Table 9, but assuming that the insulation and efficiency levels are those for 1970. The 1996 consumption is calculated to be 3,165 PJ, which is 1,213 PJ more than the actual consumption of 1,953 PJ. Of this difference, 653 PJ (54%) would be ascribed to improvements in house envelope thermal insulation and 560 PJ (46%) to improved heating efficiency.

To rephrase the values given in Table 10, it may be concluded that by 1996 the energy efficiency measures applied to housing have resulted in a saving of roughly 37% relative to what the consumption would have been without those measures – of which 20% is due to improved insulation, and the remaining 17% to improved heating efficiency.

2.3 Modelling heat flows

The main path for steady state heat flow is conduction, and it is described by Fourier's Law.

$$R = \frac{(T_{Inside} - T_{Outside})}{Q} \qquad \textbf{Equation 1}$$

where:

R =	Thermal resistance ($m^2 °C\ W^{-1}$)
T_{Inside} =	Temperature on inside of material
$T_{Outside}$ =	Temperature on outside of material
Q =	Heat Flux ($W.m^{-2}$)

Thus, steady state conduction heat flow depends on the:
- thermal resistance ("R-value") of the material (i.e. the higher the thermal resistance the lower the heat flow); and
- temperature difference inside to outside (i.e. the greater the temperature difference the higher the heat flow).

The thermal resistance of some materials is very low (e.g. metal, plaster board), while others have a very high thermal resistance (e.g. fibreglass, wool, macerated paper etc.).

Fourier's Law relates the flow of heat to the temperature difference between the inside and outside. If the average outside temperature is 13°C, and the inside is heated to 18°C, the heating energy needed to maintain this 5°C difference relates to the level of thermal resistance between the inside and outside. In this example if the outside temperatures drop, or the inside temperatures rise, by only 1°C – the result is a 20% increase in the heating energy use, assuming the thermal resistance is unchanged.

The winter (May to September) Auckland long-term average (1909–80) temperature is 12.2°C, and many of the current HEEP houses have average winter evening temperatures less than 18°C, so this example is not just hypothetical. Table 11 compares 20°C indoor with annual average winter temperatures in Auckland, Hamilton, Wellington, Christchurch and Invercargill (data from NZMS 1983). If all Auckland householders decided to be 1°C warmer in winter, the energy supply and climate change gas emission implications would be major.

City	Inside temperature	Average winter external temperature	Temperature difference inside to outside
Auckland	20°C	12.2°C	7.8°C (base case)
Hamilton	20°C	9.7°C	10.3°C (1.3 times Auckland)
Wellington	20°C	9.4°C	10.6°C (1.4 times Auckland)
Christchurch	20°C	7.5°C	12.5°C (1.6 times Auckland)
Invercargill	20°C	7.7°C	12.3°C (1.6 times Auckland)

Table 11: Average winter temperatures for selected cities

For the same inside temperature in Christchurch as in Auckland, on average, it takes either:
- about 1½ times as much energy <u>and</u> the SAME thermal insulation

or
- the SAME energy <u>and</u> about 1½ times as much thermal insulation.

The HEEP results to date from 100 houses (see Table 30, page 64) show that there is only a small temperature difference from inside to outside in New Zealand houses, and this may be important when developing the HEEP model. This may require a different approach than for other countries with large indoor-outdoor temperature differences.

It should be noted that research has found that the relative heating load for identical houses under identical operating regimes does not depend solely on the average external temperature. Even under ideal conditions, heating energy use is a complex combination of instantaneous temperatures, solar radiation, wind, cloud cover, house orientation, and house construction etc (Isaacs 1993b).

It is this dynamic combination of factors that leads to the requirement for more sophisticated modelling. This will ensure individual house construction characteristics are suitably represented, but in aggregate over the 'nation'. It should then be possible to deal with these issues in a more broad manner. The final HEEP model will need to be tested against the measured results from individual houses, and for groups of houses in aggregate. This will form a crucial base for the development of the HEEP model.

3. END-USE DATA

There is limited availability, and limited understanding of the benefits of high quality end-use energy data. This section reviews the current situation in New Zealand. It also provides brief summaries of data available from the quinquennial Census and the regular Household Economic Survey.

Using only thermal simulations as a basis for energy-efficiency requirements is now being recognised as inadequate. For example, the US Department of Energy announced in June 2002 the withdrawal of a proposal for changes to Energy Star windows, doors, and skylights, citing a "lack of empirical data on the role of solar heat gain in certain regions of the country" (Garman 2002).

The lack of recent New Zealand empirical data was illustrated by Orion New Zealand Ltd's submission to Environment Canterbury on the potential impact of the proposed air pollution controls on the electricity infrastructure in Christchurch. In order to determine typical household electrical space and water heating usage Orion made use of five sources of information (Orion 2001):

- **Orion's own historical experience** – 'historical knowledge' to 1998, when under the Government reforms Orion sold its retailing operations and hence no longer metered household electricity usage.
- **Electricity Ashburton** – unlike Christchurch, Ashburton houses have a separate hot water meter, and thus an estimate of the proportion of household electricity used for hot water was available for a region close to Christchurch
- **Energy Wise Monitoring Report June 2000** (EECA 2000a) – which builds on the HEEP Year 2 report and the EECA End-Use Database (see Section , page 24).
- **Rockgas Ltd**: As Christchurch does not have piped natural gas, LPG is used in some houses for space heating, water heating and cooking. This supplier provided data on average gas usage per house in the Christchurch market.
- **HEEP** – although the HEEP report is not fully referenced, graphs taken directly from the report suggest the use of HEEP Year 4 report (Camilleri et al. 2000).

As two of the five references used by Orion are based on HEEP work, and only one of the others has any detail beyond 'average' energy use, it is clear that the energy industry needs high quality empirical data.

This is also shown by the interest in the HEEP reports. Monitoring of the BRANZ web site shows that the HEEP Year 3 and 4 reports were downloaded on average over 80 times a month (1 April 2001 to 31 July 2002), while the Year 5 "Executive Summary" was downloaded 207 times in the first month it was available.

Examples of other users of HEEP data include:

- Tenants Protection Association (1999) – in an article looking at effects of a proposed coal ban on tenants in Christchurch, HEEP Year 1 report data on indoor temperatures was used to show how monitored homes were often colder than World Health Organisation (WHO) recommendations.
- Lebot (2000) and Vowles (2001) – include New Zealand in their reviews of domestic standby energy, based on the HEEP Year 3 report.
- Energy market analysis – we have been advised on a confidential basis of the use of HEEP results to support specific industry analysis.

At present there is only limited understanding of where, how and why energy is used in New Zealand. One of the goals of HEEP is to provide answers to these questions for the residential sector. This section provides a background to the issues, and links them with current activities.

3.1.1 The need for energy end-use data

The benefits of good quality end-use data collection, analysis and opportunity identification, were demonstrated by the New Zealand Energy Research and Development Committee (NZERDC) and the Liquid Fuels Trust Board (LFTB) in the 1970s and 1980s (see, for example, Isaacs 1993a). They too managed limited funding, but funded the full cost of understanding energy end-use – including data collection. Their reports form the base for almost all of our current understanding of New Zealand energy end-use. However, both the NZERDC and LFTB were disestablished in 1986and since then there has been no systematic approach to understanding energy use in the New Zealand economy.

Furthermore, the commercialisation of the energy sector has reduced the availability of previously public data. Energy retailer or network data is now treated as commercially confidential. In the past it was much more accessible and provided a useful alternative if no better end-use data was available. A range of reports have considered the need for such data, and all supported the need for up-to-date energy end-use data.

The recommendations of the 1996 'Review of Energy Statistics' (Statistics NZ 1996) expressed concern about the then availability of data on the end-use of energy, and stated in order to remedy this deficit:

> *"This involves significantly new expenditure on new and modified surveys. It is, however, a basic subject in which we are still relying on survey information carried out up to 20 years ago."*

The issue was again picked up in the Parliamentary Commissioner for the Environment's 2000 review of progress on energy efficiency and renewable energy initiatives (PCE 2000). It recognised the existence of HEEP but found that other areas of the economy urgently needed similar work, and thus recommended to the Minister for Energy:

> *"7. In the short to medium term, assess:*
> *d) the level of funding and agency support for research into national and sectoral energy efficiency trends in order to provide robust time-series data on New Zealand's energy use, particularly for the transport and industrial manufacturing sectors;"*

Even Government policy research has found the current energy end-use data to be inadequate, with an IEA study examining indicators of energy use and efficiency in New Zealand (Schipper et alia, 2000), commenting unfavourably on the *"limitations in New Zealand data"*.

Although obtaining energy end-use data should be a mix of Government operational activity (e.g. Statistics NZ, EECA, Ministry of Economic Development, Ministry for the Environment's 'Environmental Performance Indicators' etc) and research, at present it appears to be largely the responsibility of the research community. Data is collected to meet particular research needs, as there is no agency or organisation with responsibility for ensuring coverage, consistency and reporting. This issue is now part of the National Energy

Efficiency and Conservation Strategy (EECA 2001) for each of the four energy-using sectors[iv], and hence some action is to be expected in the coming year.

3.1.2 End-use data "pyramid"

In order to understand how energy is used in the economy, it is necessary to have quality statistics on where it is used. The end-use data "pyramid" (Figure 12) provides an illustration of the different statistics that are available[v]. The higher up the pyramid, the more aggregated the data becomes, the lower down the pyramid the more detailed the data. Isaacs et al. (1992) provide a more detailed framework for data requirement for energy monitoring.

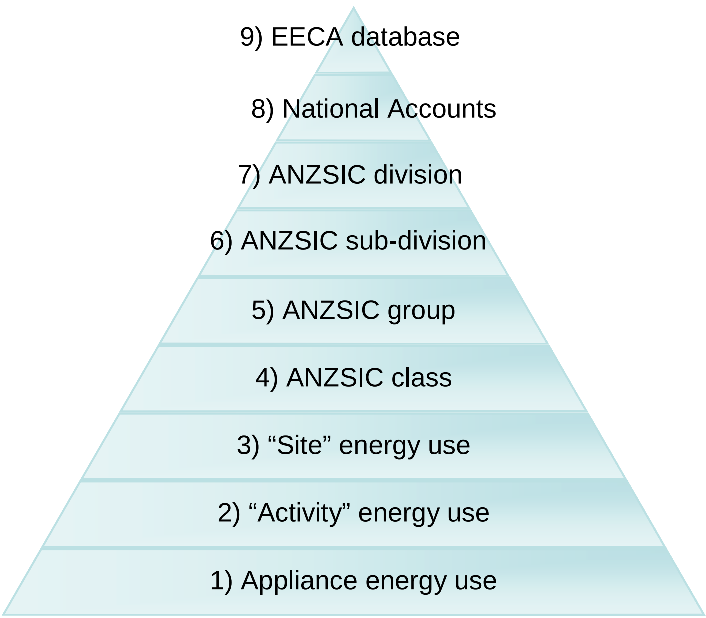

Figure 12: End-use data hierarchy

1. **Appliance**: the most detailed level, this represents a single appliance or energy end-use, e.g. lamp, dishwasher, truck.
2. **Activity** – a number of energy-using appliances providing a single product e.g. a well-lit room.
3. **Site** – the combination of a number of activities, most often relating to a physical location. It should be noted that the combination need not be the same for any two (or more) sites, e.g. a hotel may, or may not, include a swimming pool or a 24-hour kitchen.
4. **ANZSIC – Class**: 4 digit code. The current level at which Statistics NZ collects data. This is likely to include the energy used at an individual site or possibly at a number of sites. The ANZSIC classification is applied to the overall organisation, thus for example an office building will be included in the main activity of the organisation such as forestry. This limits the usefulness of the data if the interest is in an area which supports other activities, e.g. office building energy use[vi].
5. **ANZSIC group:** 3 digit code amalgamates the 4 digit code level data.
6. **ANZSIC sub-division**: 2 digit code amalgamates the 3 digit code level data.
7. **ANZSIC division**: one of 17 categories, each identified by an alphabetical character which amalgamates the 2 digit code level data.
8. **National Accounts**: The combination of all the various ANZSIC data (and other appropriate data) on the economy.
9. **EECA Energy End-Use Database**: builds on this collected and combined data (EECA 2000a).

[iv] Central and Local Government; Industry; Building and Appliances; and Transport

[v] Based on a presentation to the **Energy Statistics Stakeholders Forum**, Wellington, 14 June 2002.

[vi] see www.abs.gov.au "Statistical Concepts Library - 1292.0 Australian and New Zealand Standard Industrial Classification (ANZSIC)"

The EECA "Energy End-Use Database" is used to generate a variety of statistics on New Zealand's energy-use performance, including reviews of shifts in energy use in different sectors of the economy (EECA 2000b). HEEP provides critical data to ensure that the database is correct now and for future updating of the residential sector component.

Lermit & Jollands (2002) use a similar 'indicators' pyramid to illustrate the different levels at which consumer energy can be analysed and energy intensity indicators developed. Their pyramid has four levels:

(1) Basic use of analysis, e.g. refrigerators
(2) End-use, e.g. appliances
(3) Sector e.g. residential, and
(4) Total consumer energy (See also EECA 2002a).

Figure 12 (developed independently) is concerned more with links to the current energy data framework than the Lermit & Jollands pyramid.

3.1.3 Collecting end-use data

Understanding how the end-use data can be used, and its relationship to higher level agglomerations, does not define the most appropriate mechanisms for the collection of such data. These mechanisms could be through 100% sampling, random sampling, on-going or one-off ad hoc surveys. However, there is a need for a formal structure to ensure that different mechanisms of data collection can beneficially be used together to maximise the long-term value of the data.

It is this lack of data on household energy end-use that led to the creation of the Household Energy End-Use Project (HEEP). Previously the only data on household energy use came from the **1971/72 Household Electricity Study** (conducted by the then New Zealand Electricity Department and the Department of Statistics) (Statistics 1973). That data is becoming increasingly irrelevant as new technologies and changes in society alter the way energy is used. For many other energy-using sectors, data is limited to research carried out in the 1970s and 1980s.

HEEP data collection takes place at the 'appliance' (Figure 12, Level 1) and 'activity' (Figure 12, Level 2). The level of the monitoring is a trade-off between cost and the need for data. It is based on the need to understand both the provision of energy services – such as space temperatures, hot water, lighting, cooking, other appliances etc; and the use of different fuel types – including electricity, natural gas, LPG, solid fuel, solar, etc.

HEEP is building on its detailed end-use data collection to develop knowledge of the how, why, when and where energy is used in New Zealand houses. Confidentiality agreements cover the use of data for research, excluding its release either as raw data or in a form that could be used to identify any individual household. It should be noted that this approach does not stop the use of data from an individual house, as could be the case with some other survey-based studies.

HEEP has been designed to undertake as little expensive data collection as possible in order to develop a realistic model of the residential energy sector. Turning this data into knowledge will include:

- development of our understanding of the conditions inside New Zealand houses
- identification of business opportunities, e.g. improving appliance energy efficiency
- quantification of the role of building envelope

- improving comfort, design and construction of houses.

The HEEP residential energy-use model will provide a baseline against which future changes resulting from Government policy such as the National Energy Efficiency and Conservation Strategy can be measured. It will support other policy initiatives of EECA and the Ministry for Economic Development. It will support the development of the NZ Building Code Clause H1: Energy Efficiency. The data will form the foundation for the development of design tools to improve the thermal performance (e.g. ALF – Annual Loss Factor) and efficiency performance (e.g. HERS – Home Energy Rating Scheme) of New Zealand houses, as well as the component parts of buildings (e.g. WERS - Window Efficiency Rating Scheme).

3.2 2001 Census

The results from the 2001 Census (Statistics NZ 2002a) do not provide data on how energy is used – merely on what types of heating appliances are available, and in this provide a comparison for the monitored HEEP houses.[vii] The 2001 Census revealed the following information on space heating:

- Electricity is the main fuel used to heat private occupied dwellings.
- Electricity was used in 72.0% of all private occupied dwellings in 2001, compared with 77.2% in 1996.
- In 2001, 44.7% of private occupied dwellings used wood as a means of heating, compared with 33.9% in 1996 and 16.2% in 1991.
- Coal use has declined from 13% of private occupied dwellings in 1996 to 9.3% in 2001.
- The use of solar power has increased by 38% between 1996 and 2001, from 0.7% of private occupied dwellings to 0.9% in 2001.

In later HEEP reports the fuel types used in HEEP houses will be compared to the 2001 Census results.

3.3 Household amenities

Figure 13 and Table 12 give the proportion of households with different space heating amenities over the period 1984 to 2001 from the regular Household Economic Survey (Statistics NZ 2002d). Over that period there has been a steady decline in the proportion of houses with portable electric heaters, ‘other’ fixed electric heaters, and open fires. There has been a growth in the proportion of households with fixed gas heaters and slow combustion burners, but the largest growth has been in the availability of portable gas heaters. It should be noted that the availability of some appliances has increased over this time period, and they do not appear in the earlier surveys (indicated by a ‘#N/A’ in Table 12, or a missing column in Figure 13).

[vii] see: www.stats.govt.nz/domino/external/web/prod_serv.nsf/htmldocs/2001+Census+of+Population+and+Dwellings

Amenity	1984	1990	1995	2001
Electric range or wall oven	93%	94%	94%	94%
Gas, goal or oil-fired range	6%	10%	10%	13%
Microwave oven	#N/A	52%	72%	82%
Clothes-washing machine	#N/A	96%	97%	97%
Clothes dryers	49%	58%	62%	64%
Combination refrigerator/freezer	64%	75%	79%	82%
Separate refrigerator	39%	34%	29%	29%
Separate deep-freeze unit	60%	57%	55%	50%
Dish-washing machine	13%	21%	29%	39%
Colour television (owned)	70%	88%	95%	98%
Monochrome television (owned)	26%	13%	8%	#N/A
Colour television (hired or rented)	16%	9%	3%	0%
No owned television or hired or rented colour TV	5%	3%	3%	2%
Video recorder (owned)	#N/A	55%	75%	83%
Video recorder (hired or rented)	#N/A	2%	0%	0%
Subscriber TV decoder (owned)	#N/A	#N/A	9%	31%
Subscriber TV decoder (hired or rented)	#N/A	#N/A	10%	29%
Portable electric heater	89%	85%	79%	71%
Other fixed electric heater	34%	33%	30%	27%
Portable gas heater	2%	10%	20%	33%
Fixed gas heater	6%	9%	11%	12%
Portable kerosene heater	11%	5%	2%	1%
Wet-back fire heater	#N/A	21%	19%	15%
Open fire	49%	32%	25%	17%
Slow-combustion fire	27%	30%	34%	32%
Central heating	5%	5%	5%	5%
Electric night-store heater	#N/A	#N/A	10%	9%
Water heaters	#N/A	#N/A	#N/A	98%
Telephone	#N/A	95%	96%	94%
Home computer (mains-operated, with keyboard)	#N/A	12%	22%	47%
Cellular phone	#N/A	#N/A	#N/A	58%
Water beds	#N/A	#N/A	#N/A	5%
Spa pools and heated swimming pools	#N/A	#N/A	#N/A	5%

Table 12: Percentage of households with amenity 1984 - 2001

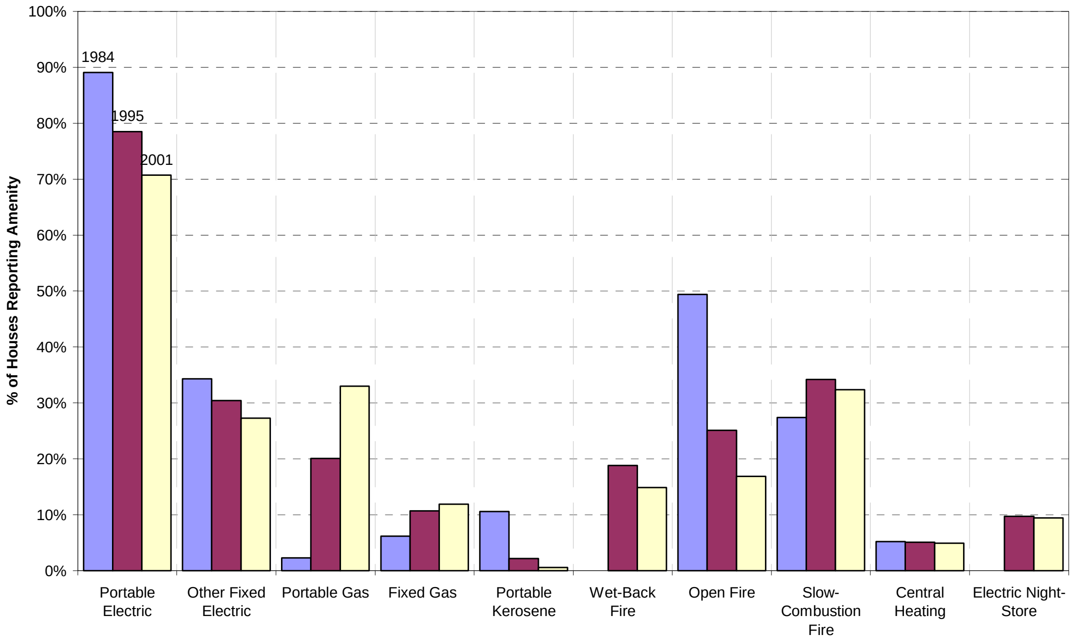

Figure 13: Percentage of NZ households with heating amenities 1984 - 2001

4. MONITORING METHODOLOGY

This section provides a brief background to the documentation held on each house and its appliances in the HEEP sample, the use of a new electricity metering system with some preliminary results on reactive power, and the amenities reported in New Zealand houses.

4.1 Documentation

The large number of houses being monitored by HEEP has required the preparation of detailed documentation to ensure reproducible results are obtained from year to year. In brief, the documentation includes the following areas:

1. **House selection**: Instructions as to the methodology for the selection of house locations for rural and urban areas (See HEEP Yr 6 report – Stoecklein et al. 2001)
2. **Field staff**: Short term staff (often locally based university students) are used in each location to assist with house installations, house measurements and occupant surveyors. A detailed installation guide provides background to the work, and instructions for installation and data collection.
3. **Field specialists**: Detailed installation instructions for field electrician, gas fitter, and plumber.
4. **Data pre-processing**: The method to be followed in preparing data from each of the different types of data loggers for inclusion in the HEEP database.
5. **Database structure**: Documentation of the way each type of monitoring data is included in the database.
6. **Data analysis**: Records of the various processing tools that have been developed for the HEEP work.

The following section provides some examples of the documentation maintained for each HEEP house to ensure the integrity and long term usefulness of the HEEP data.

4.1.1 House data collection

For each house in the HEEP sample, the following information is collected as part of a building audit when the monitoring equipment is installed (unless otherwise noted in the list):

- **house plan** (obtained from household or local council)
- **room type** (e.g. bedroom, kitchen, etc)
- **floor coverings** (e.g. carpet/lino/tiles/etc)
- **window size** (in m² or as estimated % of wall area, if window is inaccessible)
- **shading** (100% is completely shaded, 0% is unshaded)
- **curtains** (indicate with a * by window with thermal drapes)
- **double-glazed windows** (mark with double line and "DG")
- **orientation** (mark 'north' on plan)
- **common walls** (mark with "X" and double line)
- **mould growth** (mark on diagram using wiggly line)
- **position of data loggers**
- **heating type and location**
- **heating schedule**
- **hot water cylinder location**
- **fridge/freezer location**
- **average room height**

Figure 14 and Table 13 provide an example of the data collected for a sample house

Stud height = 2.4 m	
T1 = BRANZ temperature logger T76001	T2 = Tiny Tag logger 29629
SF1 = Enclosed wood burner (logger s/n: 24270)	EUM (s/n: 2525)
F1 = Combination fridge/freezer	
DHW1 = Electric water cylinder 180Ltr	
H1 = 2.4 kW Oil column heater	H2 = 2.0 kW Fan heater

Table 13: Example of house documentation

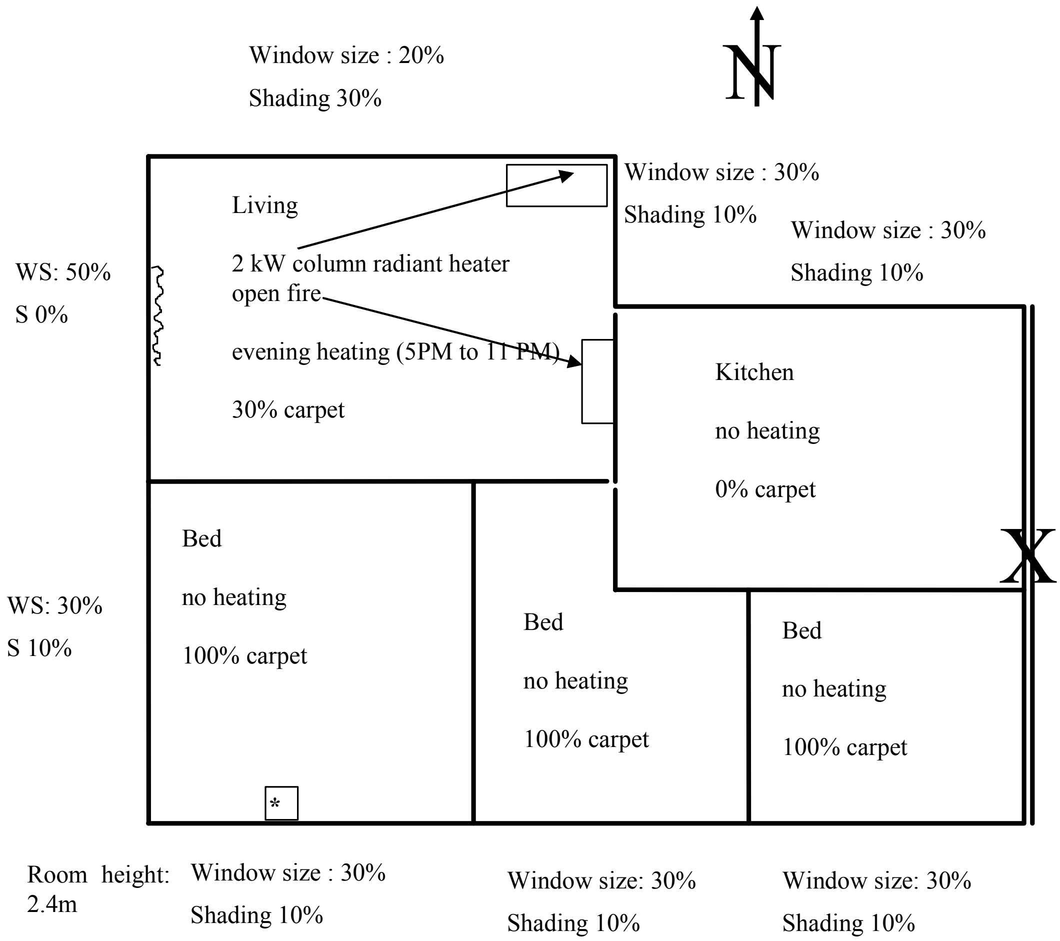

Figure 14: Example of HEEP house plan

4.1.2 Appliance documentation

HEEP is interested in determining where energy is used in houses. In end-use houses it is possible to determine how much of the total electricity load is used by appliances fitted with a transponder; however there are always more than two appliances in the house. In total-load-monitored houses it is not possible to attribute any of the total load to a particular appliance with total certainty.

Table 14 lists the various types of appliances for which information is collected. For those appliances for which 'all' measurements are made, the following information is recorded:

- Appliance type (e.g. "TV").
- Brand name (e.g. "Sony").
- Model (e.g. "XYZ200").

- Serial number (e.g. “0345-2342LVX”).
- Label power rating (e.g. “150W” and/or “234kWh/year”).
- Location (e.g. “Family” room).
- Fixed wiring
- “Standby” power and measured power used for each setting.
- Is the appliance switched on at the wall?
- Photograph.

All measurements including photo:	
• All heaters, including electric blankets and heated towel rails	
• All refrigerators and freezers (MUST get serial number)	
• Entertainment equipment (TV, video, SKY, DVD, stereo, radio, radio cassette etc)	
• Washing machine (MUST get serial number)	
• Clothes dryer (MUST get serial number)	
• Dishwasher (MUST get serial number)	
• Air-conditioner	• Dehumidifier
• Vacuum cleaner	• Microwave
• Computer	• Waterbed
• Electric lawnmower	• Weed eater
• Halogen torchiere	• Hairdryer
• Fax machine	• Heated fish tank
• Fans (inc. extractor and range hood)	• Kiln
Label, make/model, and existence only:	
• All lamps (EXCEPT halogen torchiere)	• Pumps (pool and water)
• Iron	• Security alarm
• Electric jug	• Toaster
All other appliances, existence only:	
• Appliance type, make and model	

Table 14: HEEP appliance measurement documentation

The water flow rate is measured for cold water, ‘warm’ (mixed hot and cold) water and hot water for each shower in the house. Appliance model, size and thermostat setting is recorded for each hot water storage cylinder or instant water heater. A photograph of each hot water appliance is also taken.

4.1.3 Photographs

Extensive photographic records are kept for each house in the HEEP sample. This ensures that visual information on each house will continue to be available regardless of the house location or time since the measurements were made.

Examples of possible future uses include examination of thermal stratification in rooms and temperature zones in the house. In addition the photographs allow consideration of exceptional or unusual monitoring results which could be due to factors such as sun exposure of monitoring sensors, wind exposure or proximity to heated buildings. Under normal conditions the following photographs are taken for each HEEP house:

- **Exterior of house**: from all sides, showing window sizes and shading.
- **Location of all interior temperature loggers**: showing the environment (appliances, windows, general room position) of the loggers.
- **Location of external temperature loggers**: showing the environment.
- **Hot water cylinder**: helps to identify type, size and insulation of the cylinder, and exposure, e.g. in laundry, in closet or outside.

- **Solid fuel burner and LPG heater**: helps to identify the type and efficiency of the burner for later reference and shows the location of the thermocouple monitoring. This may explain time delays between recorded heating start and logger readings and may also give an indication of the sensor placement sensitivity.
- **Electric meterboard layout**: for later review of meter and logger installations.
- **Circuit showing equipment in place**: showing EUM on meter board.
- **Gas logging equipment**: Show meter and logger in place.
- **Transponders in place**: Initial images of appliances. Note the transponders are rotated to other appliances.
- **Appliances**: which have had power measurements made.

4.2 Electricity metering

With the installation of monitoring equipment for a second year in Auckland, three houses are being trialled with new equipment. In these three houses, rather than collecting the total electricity usage and electric hot water usage with a BRANZ pulse logger fed from the pulsed output of two single channelled SAM units (based on a S2AS meter), these houses have been fitted with a TMA3100 integrated three-phase energy meter and interval data logger from Energy intellect Limited (formerly Total Metering Limited)[viii] (shown in Figure 15). Furthermore, these meters have been directly connected to a modem and cellphone so that data on the total electricity usage and the electricity usage of the hot water cylinder for the monitored house can be retrieved without a visit to the site.

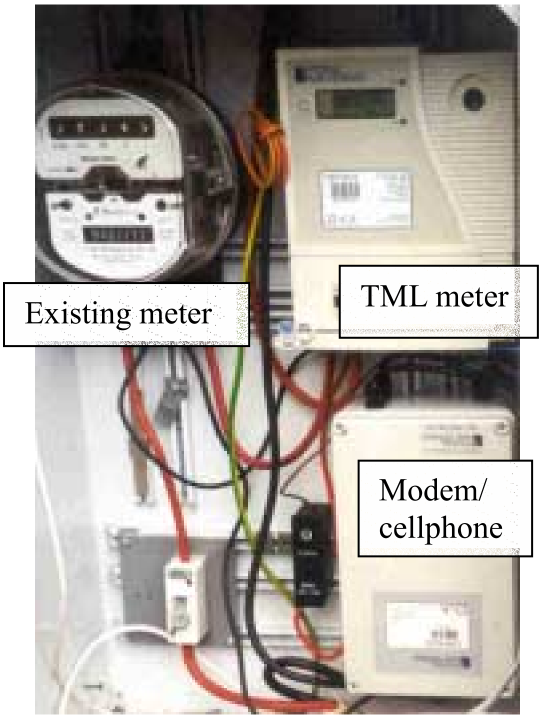

Figure 15: TML meter installation

The inputs to the TMA3000 meter are independent and do not assume a 120° phase-shift between the inputs as would be the case for a conventional three-phase meter. For the HEEP monitoring, one channel is used to record the total electricity usage for the house, another channel is used to record the electric hot water and the third input is currently not used (but is available for house with two phase supply). The TMA3000 has also been set to record at one-minute intervals, similar to the BRANZ logger/Siemens meter setup. The accuracy and resolution of the TMA3000 system are also similar to that of the Siemens S2AS meter. One point of difference is that the TMA3000 meter can also report on the reactive energy, apparent energy and power factor in addition to the real (resistive) energy recorded by the Siemens S2AS meter. While reactive energy data was not available for all three sites at the time of writing, data was recorded for one site for approximately 40 days, and some of the findings for this site are presented in Section 7.2.

[viii] See: www.metering.co.nz

5. HOT WATER SYSTEMS

This section provides an illustration of how HEEP data can be used to quantify the GHG benefits of a selected energy efficiency initiative – in this case the addition of insulation to a domestic hot water cylinder (DHW). the benefits from other energy efficiency opportunities can also be quantified.

This section uses HEEP data to investigate the question:

What would be the 'actual' benefit of insulating existing hot water cylinders to the level required in NZBC H1 2000?

For the purposes of this investigation, any DHW energy efficiency improvement is assumed to have no takeback, so all the 'savings' would be reflected in energy or GHG reductions.

Hot water is a major energy use in the average New Zealand home, as discussed in the HEEP Year 5 report (Stoecklein et al. 2001), using on average 4000 kWh/year/house or about 44% of total energy. The average hot water standing loss is 1000 to 1100 kWh/system/year, representing about 11–12% of total energy use or 25–30% of the hot water heating energy.

Table 15 provides updated summary information for the three types of hot water systems – electric storage, natural gas storage and natural gas instantaneous – monitored by HEEP. The error estimates provided in Table 15 are the estimate of the population standard error in the mean. The reported "Average cylinder operational temperature" is the average temperature of the water in the cylinder, taking account of how long it takes to heat water up from cold. Energy use is gross – i.e. as measured by the gas or electricity meter.

Based on Auckland, Hamilton, Wellington HEEP monitoring	Strata weighted average	Electric storage	Natural gas storage	Natural gas instant
Number of houses in sample	-	80	14	10
Age (years)	15 ± 1	18 ± 2	12 ± 2	3.4 ± 0.8
Cylinder volume (l)	158 ± 4	152 ± 4	150 ± 10	-
Element size (kW equivalent)	-	2.4 ± 0.1	8.3 ± 0.5	35 ± 3.0
Thermostat setting (°C)	60 ± 1	61 ± 1	62 ± 4	47 ± 4
Measured tap temperature (°C)	59 ± 1	61 ± 1	56 ± 2	49 ± 3
Average cylinder operational temperature (°C)	58 ± 1	59 ± 1	54 ± 3	-
Ambient temperature (°C)	19.2 ± 0.3	18.8 ± 0.4	17.8 ± 0.7	-
Standing loss (kWh/day)	2.5 ± 0.2	2.6 ± 0.1	4 ± 0.4	-
Used hot water energy (kWh/day)	7.3 ± 0.6	5.3 ± 0.4	12 ± 2	14 ± 1

Table 15: Household hot water system characteristics

It is interesting to note that both the amount of energy and delivered hot water used for houses with natural gas systems is higher than for electric systems. 75% of the houses have electricity as the main fuel for hot water supply, 15% use natural gas and 10% use instant natural gas (rounded figures).

A few houses have more than one hot water system, but these results are reported on a per house basis. The characteristics per cylinder are very similar to the per-house values, and have not been reported. An average house uses around 485 litres of water per day (Waitakere City Sustainable Home Guidelines 2002), while HEEP measurements suggest around 160 litres of this are taken as hot water per day (Stoecklein et al. 2001) – suggesting around one third of the energy and one third of the water use goes into hot water provision for the house.

Large reductions in energy use and GHG emission can be achieved by upgrading hot water systems, and by reducing hot water consumption. EECA's "Energy Saver Fund" and now the "Residential Grants Programme" have implemented a range of improvements to hot water systems, which include cylinder wraps, pipe insulation and low-flow shower heads. The projects have been run by various interested groups including community groups, local energy trusts and power/lines companies, and commercial companies. The energy reductions claimed are substantial, but no published monitoring is available.

To calculate the change in GHG emissions from upgrading the insulation on the hot water cylinder, a number of factors must be estimated:

- energy use/GHG emissions before upgrade
- energy use/GHG emissions after upgrade
- lifetime of upgrade
- lifetime of system if the upgrade was not put in place.

5.1 Costs

5.1.1 Cylinder wraps

Figure 16: Negawatt cylinder wrap

There are a number of electric hot water cylinder wraps available commercially. The installed price of a cylinder wrap from Negawatt resources is $135 including GST, or $89.95 inc GST for the wrap alone. These prices include 5 m of pipe lagging. This cylinder wrap is wool with a calico backing. Wool pipe lagging is $25 inc GST for 10 metres, which is sufficient to wrap 2 m of pipe.

Other suppliers include Carters which sells a 50 mm thick fibreglass cylinder wrap for $78.26 inc GST. The Warehouse sells a polyester cylinder wrap for $49.99 inc GST. (May 2002). Other products may be available that are not described here.

No doubt lower prices could be negotiated for large purchases, especially if product promotion was also involved.

For the purpose of this analysis an installed cost of $135 has been used.

5.1.2 Electricity

As at February 2002, the national average retail electricity price was 14.4 c/kWh, with prices ranging from 11.24 c/kWh for a Dunedin retailer to 19.20 c/kWh for an East Coast retailer (MED 2002). Price discounts for houses with rippled controlled hot water are around 5%, and for separately metered night rate systems, up to about 50%.

For the purpose of this analysis, it has been assumed that the average electricity cost is 13.7c/kWh.

5.1.3 GHG emissions

The emissions factors for thermal electricity using gas and coal are 0.57 kg CO_2/kWh and 1.28 kg CO_2/kWh respectively. Gas generation outweighs coal generation by 10:1, so the combined emission factor is the weighted average of gas and coal emissions, or is 0.64 kg CO_2/kWh. (Camilleri, 2000a).

5.1.4 Scrap

Older, low pressure, copper hot water cylinders can have significant scrap values. The scrap value of a copper hot water cylinder is about $18 for a 30 gallon (135 litre), and $24 for a 40 gallon tank (180 litre), or slightly more for the copper insert alone (phone inquiry, Wellington Scrap Metals, May 2002).

5.2 Installation

5.2.1 Cylinder wraps

As part of the HEEP data quality assurance, photographs are taken of major household appliances. The examples in Figure 17 illustrate the various types of electric hot water cylinder wrap installation. The quality of the installations varies widely, with some wraps so poorly installed as to be ineffective.

Figure 17: Examples of electric hot water cylinder wraps

It is not known whether these wraps where installed by the occupants, by others or under any external funding programme, such as those supported by EECA’s Residential Grants programmes.

It is critical that cylinder wraps are installed properly to ensure that the maximum savings are achieved, and that these benefits are not rendered ineffective by any later actions of the occupants or tradespeople.

5.2.2 Market description

Electric storage systems make up about three quarters of hot water systems in HEEP houses monitored so far. The overall percentage for New Zealand will be higher, as many areas yet to be monitored have no reticulated gas. Note that installing cylinder wraps on gas storage cylinders is potentially dangerous, and would not be as effective as for electric systems, because the flue and pilot light losses would not be reduced.

Of the electric cylinders, by far the most common cylinder sizes are 135 litre (30 gallon), at 49% and 180 litre (40 gallon), at 39%. For gas cylinders, 23% were 110 litre, and 29% were 135 litre, with a large variety of other sizes. The cost of cylinder wraps appears to be the same for 135 litre and 180 litre cylinders. Energy savings are likely to be higher for the 180 litre systems, so targeting these may be slightly more cost-effective.

Most purpose-installed night-rate systems are already well insulated, so adding cylinder wraps would provide only marginal benefits.

HEEP has found that very few hot water systems of any age or grade have cylinder wraps (4%), or pipe lagging. Pipe lagging is likely to be equally cost-effective on all sizes and types of hot water systems, including gas systems.

Cylinder wraps are most cost-effective on the older, poorer insulated, C or D grade cylinders, and these should probably be the targeted cylinder types. The HEEP information can be used to develop a decision support tool for identifying which houses have C or D grade cylinders before time and money is invested in visiting a house. Wraps are slightly more cost-effective on 180 litre cylinders than 140 litre cylinders, and these might also be targeted.

The strongest indicator of the cylinder grade is age. Based on the age alone, the grade of a cylinder can be corrected identified as either A or B, or C or D, with a 6% misclassification rate.

Unfortunately, at present there are no other single factors of the household that are strongly related to the hot water cylinder properties.

If the age is not known, then by combining other relevant household information such as house age, and household income, into a decision tree, the grade of the cylinder can be grouped as either A or B, or C or D, with a 15% mis-classification rate. This could form the basis for a decision support tool for targeting households for cylinder wraps.

The house age is a useful indicator, as D grade cylinders are predominantly found in houses over 25 years old. Newer houses (post-1986) tend to have higher grade systems, as C and D grade systems were phased out. Older houses have a mix of grades, depending on whether or not the cylinder has been replaced, with about half being D grade systems.

Cylinder sizes appear to be only weakly related to the physical properties of the house. Although the average floor area of houses with 135 litre cylinders is larger than those with 180 litre cylinders, there is such a large range in house sizes that this cannot be used as a single criteria to determine the cylinder volume. The cylinder size appears to be unrelated to the number of occupants in the house. The cylinder size appears to be weakly related to the age of the house.

A decision tree based on the house area and age of house can identify the cylinder as either 135 or 180 litre with a 20% mis-classification rate – compared to a 'random guess' which would give about a 50% mis-classification rate.

The cylinder age appears to be unrelated to the household income, which may suggest that households with higher income are no more or less likely to replace old hot water systems.

The tap temperature appears to be weakly related to the cylinder size, with smaller cylinders more likely to be operated at higher temperatures in order to increase the total volume of hot water available.

5.2.3 Hot water cylinder Stock

The Energy End-Use Resource Assessment (EERA) project has developed a model of New Zealand residential appliance stock. This model has been used to estimate the numbers of cylinders of various grades, and this is given in Table 16. HEEP can help identify regional/household variations. Note that the assignment, given in Table 16, of A and B grades, and C and D grades are sometimes ambiguous. The B grade category may include some A grade systems, and the D grade category some C grade systems.

		EERA (2002 estimates)		HEEP (Preliminary)	
Grade	**Year phased out**	**NZ Total #**	**Proportion**	**Proportion**	**Average age**
A	-	466,000	36%	16%	6 years
B	-	499,000	39%	44%	7 years
C	1986	318,000	25%	4%	15 years
D	1976	0	0%	36%	33 years

Table 16: Hot water system stock

Hot water cylinders are assumed by EERA (Roussouw 1997) to have a life span of 25 years. HEEP has found so far that about 30% of cylinders are more than 25 years old, with the oldest at more than 45 years. Clearly, old cylinders are widespread in New Zealand, with around 40% C or D grade. With an average age of 33 years for D grade electric cylinders (and the youngest 15 years), an age of 40+ years for replacement of old cylinders is probably a better estimate than the 25 years used by Roussouw (1997). The phase-out of B grade cylinders has not yet occurred, as the 2000 revision of NZBC Clause H1 retains B grade as the minimum standard, therefore these will persist in higher numbers then estimated by Roussouw (1997). B grade cylinders will finally be phased out when the Minimum Energy Performance Standard comes into force on 1 February 2003 (Energy Efficiency (Energy Using Products) Regulations 2002).

Mains pressure cylinders are generally not made of copper, using instead lined steel, which reduces the life expectancy to 12 – 20 years. Anecdotal evidence of cylinder failures suggest that many old copper cylinders fail soon after the header tanks are replaced with pressure-reducing valves. Presumably the higher pressure, and greater pressure fluctuation, during use and heating trigger failure.

5.3 Quantifying benefits

Two approaches are available for quantifying the energy benefits of improving cylinder insulation. The first uses the theoretical values used in the EECA Residential Grants Programme and second is based on the measured HEEP data.

Please note that HEEP monitoring has not yet fully covered New Zealand – the results reported here are based only on data from Auckland, Hamilton, and Wellington. It is possible that potential GHG reductions may be larger in the cooler parts of New Zealand – HEEP will be able to provide information as monitoring reaches completion.

5.3.1 Residential grants programme

The current EECA Residential Grants Programme allocates energy efficiency benefits to a range of different retrofit and new fit options. Table 17 documents the expected reductions in standing losses by using an R 1.1 wrap on a cylinder of unspecified size. The size is most likely 180 litres, thus for 135 litre systems the savings would be multiplied by 0.75.

Grade	Annual kWh savings	Annual $ savings at 13.7c/kWh	Carbon cost ($)	Return on investment	Simple payback period @$135 wrap installed
A	170	$23	$1.70	17%	6 years
B	248	$34	$2.50	25%	4 years
C	525	$72	$5.25	53%	2 years
D	640	$88	$6.40	65%	8 months

Table 17: EECA Residential Grants Programme values

GHG emissions for the cylinder wrap are small, as the energy content of a few kilograms of plastic, cloth, wool or glass is low. Installation will involve some transportation, so for example assuming 50 km travel by van would result in a few kilograms of CO_2. However, these emissions are small compared to the potential GHG reductions and energy savings.

The latest Government statement on the Kyoto Protocol has put a cap on CO_2 costs of $25 per tonne[ix]. Assuming more modest carbon costs of $15 per tonne of CO_2, this gives a cost of $0.01 per kWh of thermally generated electricity. Using the values in Table 17, carbon savings of $6.40 per year are significant for the D grade cylinders, though likely inadequate on their own to make retrofitting viable.

Savings for pipe lagging are approximately 120 kWh per year, giving a saving of about $16 per year. Payback ranges from 6-18 months, depending on the cost of lagging.

5.3.2 Cylinder/system standing losses

HEEP can provide statistically valid estimates of cylinder standing losses by cylinder size, grade, and age. The HEEP monitoring results, given in Table 18, show that the average standing losses in actual use are different from the theoretical values. The “Standing Losses” and “Average Cylinder Temperature” are as measured, while the “Normalised Standing Losses” have been normalised a temperature difference of 55.6°C - the same conditions as set out in NZS 4602:1988 (Standards New Zealand 1988).

[ix] Hodgson, Pete (Convenor, Ministerial Group on Climate Change) 17 October 2002 “Government confirms key climate change policies”

Grade	Standing losses (kWh/day)	True standing losses (kWh/day)	Normalised standing losses (kWh/day)	Average cylinder temperature (°C)	Cylinder thermostat temperature (°C)	Ambient air temperature (°C)	HEEP count
140 litre cylinders							
A	1.9	1.7	2.1	60.4	69.9	19.4	2
B	2.6	2.4	2.9	60.6	61.3	16.8	11
C	2.4	2.3	2.8	64.1	65.6	18.2	2
D	3.2	3.1	3.8	61.3	64.2	16.0	18
180 litre cylinders							
A	2.4	2.2	3.1	55.6	59.0	16.6	5
B	2.8	2.6	3.4	57.5	60.5	16.7	16
C	-	-	-	-	-	-	-
D	3.3	3.5	3.9	57.8	64.6	16.6	4

Table 18: DHW cylinder standing losses by size

Of the hot water systems surveyed, very few of any age or grade had cylinder wraps (only 4%), or pipe lagging. Pipe lagging is likely to be equally cost effective on sizes and types of hot water systems, including gas systems. Pipe lagging was used on some pipes in roof-spaces for some Christchurch houses, possibly to prevent freezing of pipes in winter.

Volume (litres)	Grade	Actual losses (kWh/day)	Standard loss (ΔT=55.6°C) (kWh/day)	Standard loss (0.7 for pipes) (kWh/day)	HEEP count
135	B	2.4	3.0	2.5	10
	D	3.4	4.4	3.9	18
180	B	2.5	3.2	2.7	17
	D	5.6	5.7	4.3	5

Table 19: Preliminary standing losses by cylinder grade and size

Table 19 includes data from 2001 monitoring of Auckland houses, but must be used as preliminary as the sample size is still small. There were insufficient A and C grade cylinders in the sample to provide any estimates at this stage. One D grade 180 litre cylinder had an exceptionally high apparent standing loss of 14 kWh per day. This may have been caused by a leak.

Generally, the cylinder standing losses in practice are less than the losses measured according to the New Zealand Standard 4602:1988 (Standards New Zealand 1988). The measured average temperature difference is 45 ± 2°C, and once recharge times are accounted for this reduces to 42 ± 2°C. This is lower than the 55.6°C used for the Standard calculation of standing losses, and is the most likely cause of apparently lower losses.

If the temperatures are normalised to the 55.6°C used in the Standards, the losses are higher, indicating that the thermal performance of the cylinder system is worse than the Standards. Thus the savings that could be achieved by installing cylinder wraps are somewhat less than would be suggested by the Standard standing losses.

5.3.3 Wrap or replace?

Replacing a D grade cylinder with a new A grade cylinder gives greater energy savings and GHG reductions than wrapping the cylinder. Similarly, installing a heat pump, solar water heater, or changing to gas fuel will result in energy and GHG savings.

However, unless the cylinder needs to be replaced (e.g. due to age, house modifications, etc) then cylinder wrapping is by far the most cost-effective measure, as shown in Table 20.

Measure	Cost	Energy savings	Simple Energy Payback	GHG savings
Cylinder wrap	$100	$88/yr	1.1 yr	$6.40/yr
New A grade	~$1200	$100/yr	12 yr	$7.30/yr
Hot Shot heat pump	~$1800	$274/yr	6.4 yr	$20/yr
Solar	$3500+	$356/yr	10 yr	$26/yr
New gas cylinder	~$2000	~$300/yr	6.7 yr	~$25/yr

Table 20: Some alternative measures for D grade 180 litre retrofit

5.3.4 Buyback

Buyback schemes have been run successfully overseas for everything from petrol-powered lawn mowers to halogen torchiere uplights. A buyback or rebate scheme for old hot water cylinders might be cost-effective, and might encourage early replacement with high efficiency 'A' grade systems.

The GHG savings for replacement with an 'A' grade system could be claimed as part of the rebate. Assuming 657 kWh per year for 135 litre and 730 kWh per year for 180 litre, the GHG savings at $0.01 c/kWh are $6.57 and $7.30 per year.

If, for example, a five 5 year premature replacement is assumed, the GHG values are $33 and $37, for a maximum rebate of $51 for an old 30 gallon (135 litre), and $61 for a 40 gallon (180 litre) hot water system.

5.4 Reducing hot water energy use

"*Before project-based activities take place a company needs to develop a methodology to verify and quantify any emissions reductions to evaluate the environmental and investment opportunities of the projects*" (Kessels 2002)

HEEP results can be used to provide useful data, and ultimately a tool, to assist energy companies to assess the GHG benefits of energy efficiency activities.

There are a number of ways to reduce hot water energy consumption, and from there GHG emissions. Table 21 provides examples of achieving this through reducing losses, reducing hot water use and reducing the GHG emissions factors.

Reducing energy losses	• Pipe insulation • Cylinder wrap • Base insulation • Ripple control/timers • Adjusting thermostats • Switching off or turning down cylinders when house vacant • Replacing with new cylinders
Reducing hot water use	• Fixing leaks • Repairing defective pressure-reducing valves • Installing low-flow shower heads • Educating occupants about water use, e.g. clothes washing, baths and showers
Reduce GHG energy factor	• Heat recovery or cold water preheating • Install solar water heater or heat pump • Use solid fuel 'wetback' supplementary water heating • Convert from electricity to gas

Table 21: Methods to reduce hot water emissions

HEEP results permit the cost-effectiveness and takeback of some of these measures to be examined. Unanswered questions include whether the use of mains pressure cylinders encourages higher hot water use, or whether low-flow shower heads do reduce hot water use.

Many households turn the thermostat up high so that they have sufficient hot water. Adjusting thermostats to lower settings to reduce standing losses, which is a common procedure in energy audits, may lead to inadequate water delivery or showers. Consequently, many of these thermostats will be turned up again (Tustin, 1991).

It should be noted that a 135 litre cylinder storing water at 75°C holds the same energy as a 180 litre cylinder with water stored at 55°C, but the higher temperature is clearly unsafe for all users. There are thus very important health benefits if the cylinder temperature can be reduced by increasing cylinder size at the same time as improving the energy efficiency.

HEEP can provide a wide range of information to assist with this process:

- estimates of energy use before and after the upgrade
- selection criteria to maximise benefits from a given upgrade
- technical knowledge to develop methods to maximise GHG (or other) benefits
- capability to undertake specific case studies.

6. LPG HEATER USE

6.1 Background

The number of portable LPG heaters used in New Zealand has increased dramatically over the last 20 years. Section 3.3 (Table 12 and Figure 13) gives results from the Household Economic Survey (Statistics NZ 2002d) on the proportions of households with particular types of heating. The number of households with portable gas heaters has increased from 2% of households in 1984 (the least popular of the eight heating types surveyed at that time) to 33% (452,800) of households in 2001 (second only to portable electric heaters). The increase in the usage of portable gas heaters is closely matched to the reduction in usage of the other two types of portable heaters surveyed: portable electric heaters (reducing from 89% of houses in 1984 to 71% of houses in 2001); and portable kerosene heaters (reducing from 11% of houses in 1984 to 1% of houses in 2001).

The occurrence of portable LPG heaters amongst the current HEEP sample, broken down by region, is shown in Table 22. Overall, 30% of the current HEEP sample have a portable LPG heater. This figure is slightly lower than that found in the Household Economic Survey (33%); however the current HEEP sample is not fully representative of New Zealand, with South Island centres (including Dunedin, Invercargill and Oamaru) as well as many rural areas, yet to be surveyed.

	Households in random HEEP sample			LPG heaters in random HEEP sample	
Region	**Number**	**With portable LPG heater(s)**		**Number**	**Average # per household**
Auckland	97	26	27%	27	0.28
Hamilton	17	7	41%	8	0.47
Wellington	46	17	37%	17	0.37
Christchurch	37	9	24%	9	0.24
Total	197	59	30%	61	0.31

Table 22: Number of portable LPG heaters by monitored region

It is difficult to measure the energy consumption of portable LPG heaters. The flow of gas within a portable LPG is small and equipment to measure such low flows are rare. The method developed for HEEP was outlined in the HEEP Year 4 report (Camilleri, et al, 2000) and involves determining which combination of panels of the LPG heater are on at any one time. The status of each panel of the LPG heater is determined by measuring the temperature in front of each panel with a thermocouple junction. The outputs of all of these thermocouples are fed into a BRANZ logger placed next to the portable LPG heater and panel combinations are determined every five minutes. These combinations of panels are then associated with a particular power level for the heater and a time series of the energy use of the heater can then be created. An example of the response of the thermocouples for each of the settings for one particular heater is shown in Figure 18.

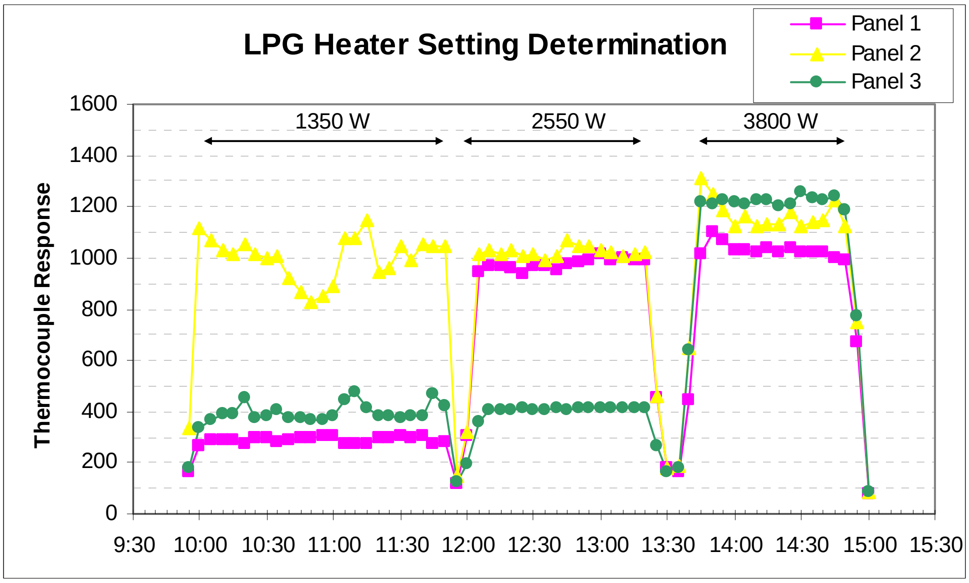

Figure 18: LPG setting determination for one heater

Assigning of settings for each record of the data logger is not without errors. For example, the 1350 W setting in Figure 18 can be identified as those records which have a thermocouple response for panel 2 greater than 800 and a thermocouple response for panel 1 and 3 below 500. If the threshold for panel 1 for this setting is set to 900 (which seems reasonable when examining the responses for the 2550 W and 3800 W settings) then the values around 11:00 would not be classified as the 1350 W setting. Table 23 provides an example of analysis of the classification of the settings of a number of individual download files for a particular portable LPG heater. The shading in Table 23 indicates those settings that can be identified to a particular setting of the heater. From the 'Assign setting' column it can be seen that settings are assigned to a recognised setting for over 99% of the time for this heater.

visit	all off	2nd on	1+2 on	All On	Intermediate (errors)					No. of five minute records	Assign setting	Assign error
	S000000	S101110	S111110	S111111	S111000	S001000	S100000	S101010	S101000			
4	100.0%									1840	100.0%	0.0%
6	96.7%	3.2%				0.0%	0.0%	0.0%	0.0%	8052	99.9%	1.9%
7	92.8%	6.9%	0.1%		0.0%	0.1%	0.0%	0.1%		9986	99.8%	2.9%
8	98.3%	1.7%			0.0%	0.0%	0.0%			9987	100.0%	2.3%
9	99.5%	0.4%			0.0%					6638	99.9%	3.3%
a	99.3%	0.7%			0.0%					7101	100.0%	1.9%
b	100.0%									6960	100.0%	0.0%

Table 23: Setting assignment errors for one heater

Installing thermocouples in front of each panel of an LPG heater can mean dismantling part of the heater, which can take some time. Further time is required to determine the energy consumption for each of the settings of the heater. Previously the specialised heater preparation work (installing the thermocouples and determining the heater settings) was undertaken as a separate task from the general HEEP installation and was undertaken at a centralised site for each of the regions being monitored. As HEEP begins the monitoring of houses from widespread locations around New Zealand (see Section 1.8), the practicalities of maintaining the heater preparation and general HEEP installation as separate procedures become more difficult. A modified approach, including use of data from previously calibrated heaters, has been developed in order to maintain data quality.

6.2 Sample LPG heater use patterns

Figure 19 and Figure 20 provide an exploratory representation of the half-hourly data for a selection of portable LPG heaters used in the houses measured. In these graphs the y-axis gives the day of the year, while the time of day is given on the x-axis. The colours represent the heater power output – the darker the colour the higher the output. Missing data is indicated by the presence of the vertical grid lines. It can be seen that often the missing data is outside the expected winter heating period (e.g. during the summer) and it is thus of limited concern for analysis of the heater use during the cooler months.

While the time between records for electrical energy data is important and is seen to make a difference to the daily energy patterns (Pollard 1999), plotting the 10-minute data in place of the 30-minute data (as shown in Figure 19 and Figure 20) does not produce much of a visual difference in these graphs. However, the 30-minute data is easier to deal with, as it takes less time to process and display, so it was used for this particular display of data.

As with most exploratory graphing techniques, there is much information that can be gained from close examination of Figure 19 and Figure 20. Figure 19 compares the LPG heater usage between house 2 (a low usage house) and house 4 (a high usage house). The heater from house 4 is operated on a low setting over a fairly regular period in the evenings during winter. The day-to-day usage of the heater is also fairly consistent with the heater being used most days over winter (June, July, August). For a relatively short period in July the heater was used during the day. The usage of the LPG heater in house 2 is less predictable. Seldom is the heater used for more than two days in a row. The most popular time of use being during the day; however it is also used in the evenings. The heater is also used at different heating settings with some heating sessions only operated on the low setting and other heating sessions including both medium and low settings.

Figure 20 provides LPG heater usage information from two households with higher usage. Both of the heaters in these homes are predominantly used on higher settings (medium for house 1 and high for house 5). The heater in house 1 is used mainly in the morning and the evening; however the timings are less consistent than for house 4. There is also an extended period of zero usage in August. This was due to a change in the members of household. After this period, the day-to-day usage of the heater appears to be slightly more consistent. It is also interesting to note that there is some usage of the LPG heater during January. The LPG heater used in house 5 is predominantly used on the high setting, with morning being the most popular time of day. Less usage of this heater is seen in the evenings than is the case for the other highly used heaters examined. The LPG heater in house 5 appears to be used fairly regularly on a day-to-day basis except for a period of zero usage in June. The duration of each heating session appears to be shorter than that for the other heaters examined.

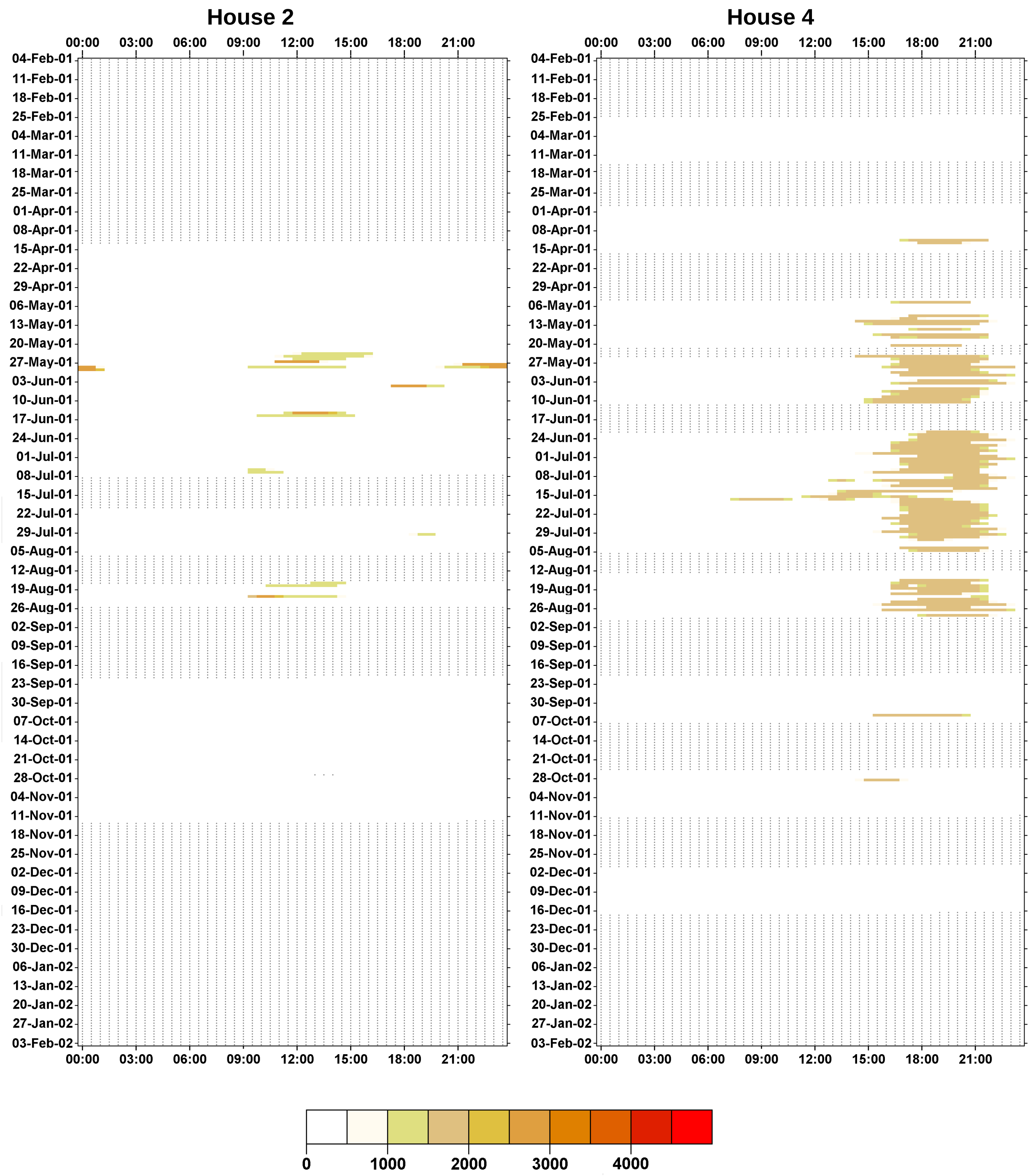

Figure 19:LPG heater use by time of day & day of year (Houses 2 & 4)

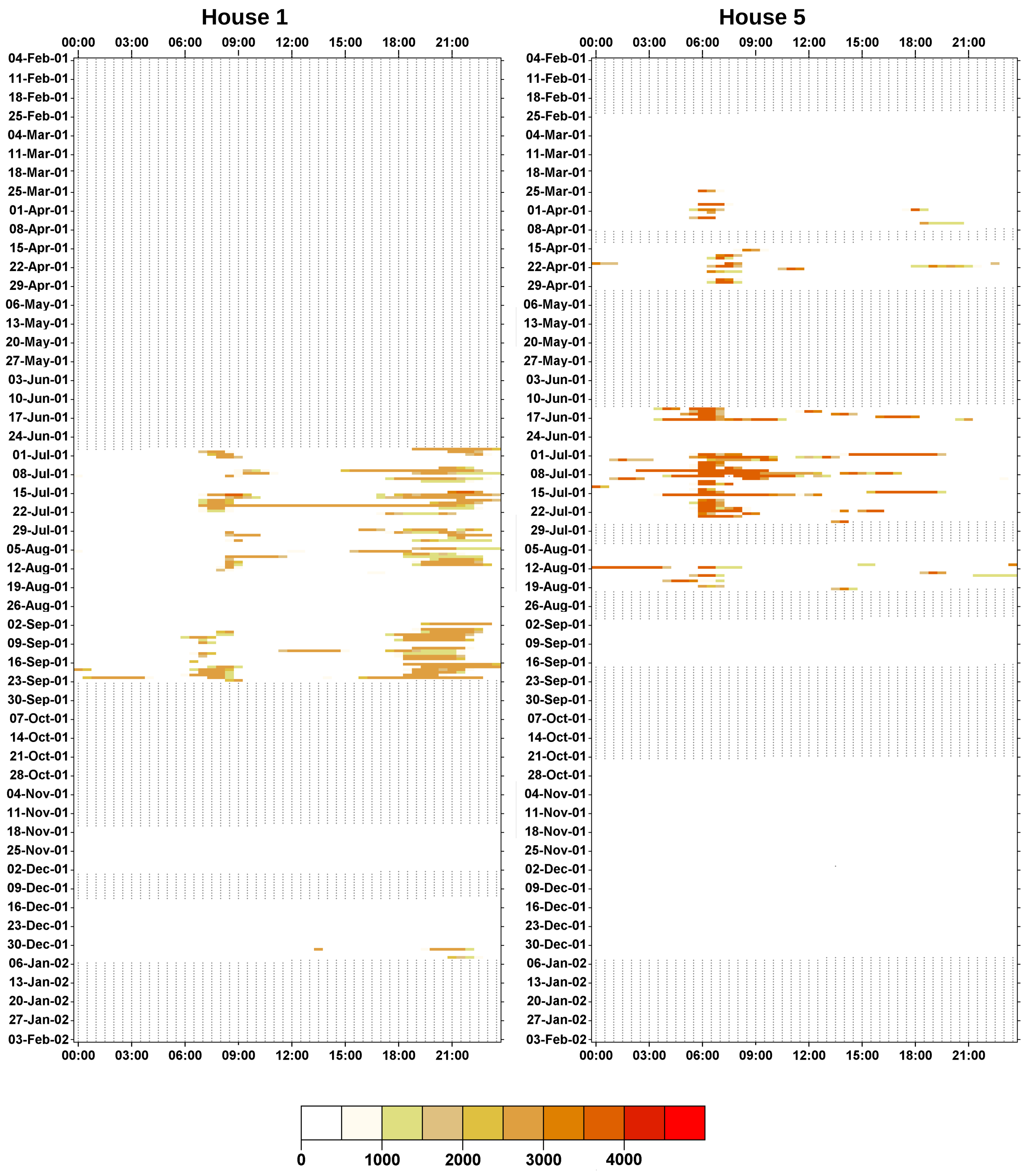

Figure 20: LPG heater use by time of day & day of year (Houses 1 & 5)

Table 24 lists for data on how the heater is used for each of the LPG heaters (for which data is available) from the randomly selected houses in Hamilton (a further 8 LPG heaters were used within a special pensioner housing sample) and the first year of Auckland monitoring information. For each LPG heater the proportion of time it is used in each of the main settings, the number of hours per day it is used during winter (here defined as June, July and August). House number 9 had two separate LPG heaters, so each LPG heater is listed separately. Although the LPG monitoring reported here had higher lost data than would be desirable (often in the non-heating period of the year), the lessons learnt have been applied to the Year 6 monitoring.

House	% of Time at Each Setting: Low (1300 – 1700 W)	Medium (2500 – 2900 W)	High (3600 – 4300 W)	Hours/day Over winter
1	17.8%	81.0%	1.2%	1.6
2	73.2%	26.8%	0.0%	0.5
3	100.0%	0.0%	0.0%	0.5
4	100.0%	0.0%	0.0%	3.8
5	6.2%	11.3%	82.5%	1.4
6	100.0%	0.0%	0.0%	0.3
7	99.2%	0.8%	0.0%	0.5
8	98.9%	0.0%	1.1%	0.5
9 (i)	100.0%	0.0%	0.0%	0.4
9 (ii)	96.6%	3.2%	0.2%	0.9

Table 24: Use of LPG heaters by setting

Table 24 shows that seven of the heaters in six of the nine houses are used for the large majority of the time in the low setting, and of the other three heaters, only one is used for the majority of the time at a high setting. Only three of the heaters are used (on average) for more that one hour per day, and of the other seven heaters, six are used for on average half an hour or less per day over winter. This does not seem to match an expectation that as LPG heaters are capable of higher power outputs than standard '3-pin plug' electric heaters (which are limited to 2.4 kW), they would be used for longer periods of time at higher settings.

Figure 21 provides a plot of the average daily LPG heater profile during winter, (using data from the LPG heaters listed in Table 24). A number of heaters have a high level of usage in the evenings. A smaller number of heaters are used in the mornings. For profiles for other types of heaters see section 4.8 of the HEEP Year 3 report (Stoecklein, et al 1999).

Figure 22 displays the average daily winter profiles of the total LPG heater usage, total electricity usage and reticulated natural gas usage from the houses that contain LPG heaters. An interesting observation from Figure 22 is that for houses that have high evening LPG usage (houses 1,4,9), peaks occur in the total electricity profile before or after the period of LPG usage. A possible explanation is that the occupants are sedentary (such as watching TV) during LPG heater usage and that energy intensive activities occur before or after this sedentary behaviour.

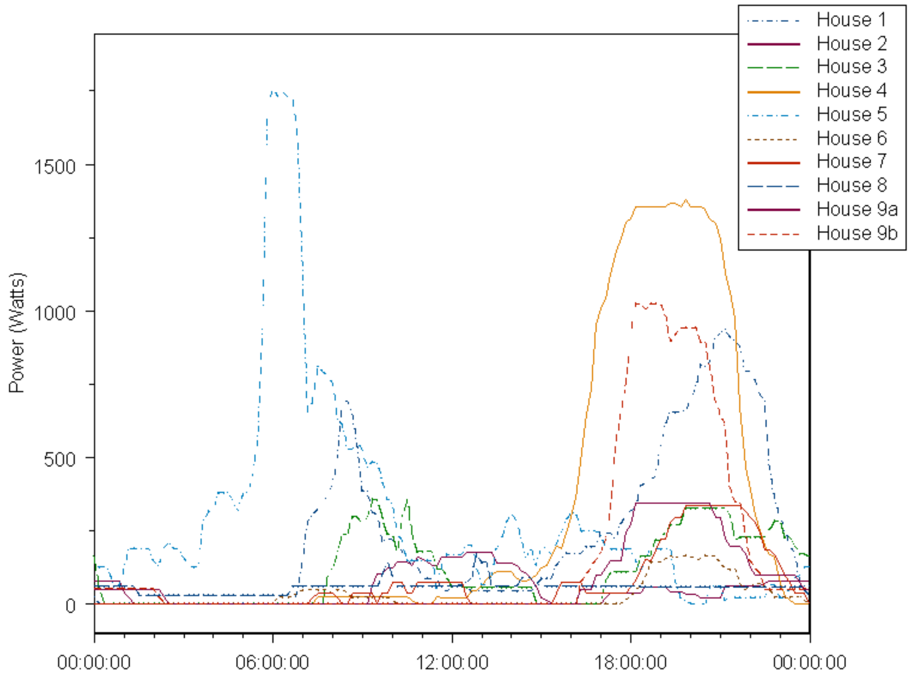

Figure 21: Daily profiles of LPG heater use over winter

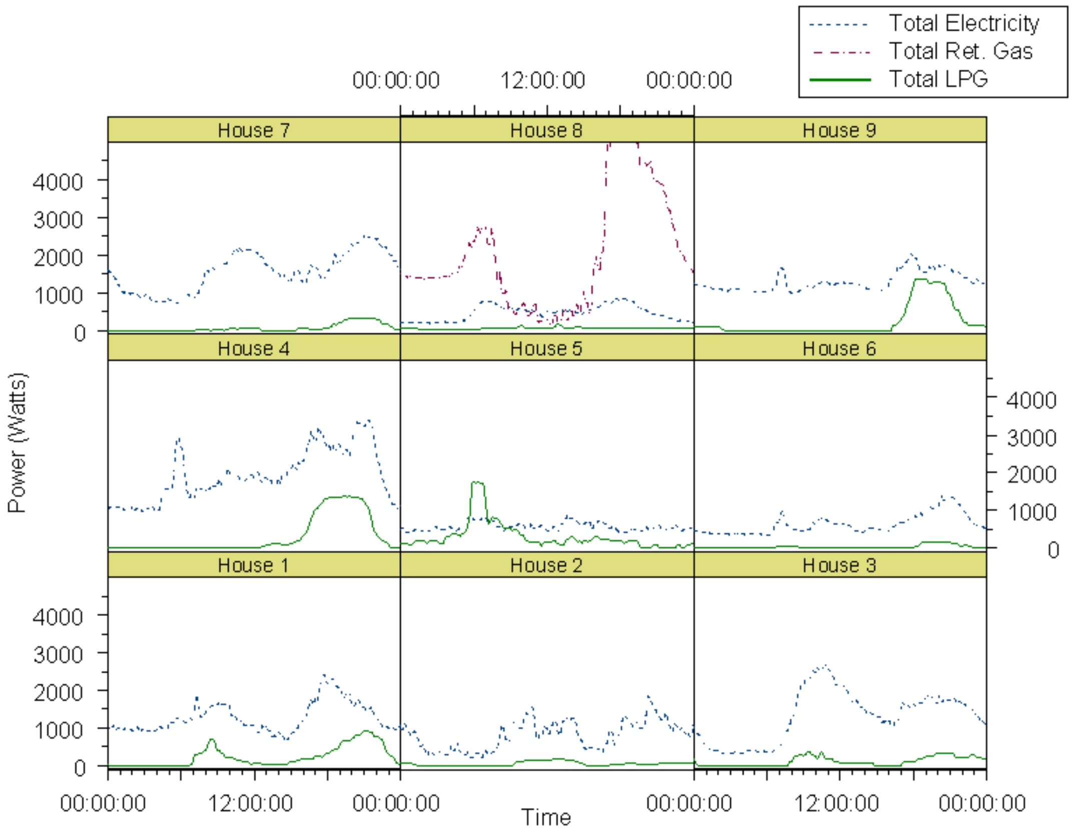

Figure 22: Daily profiles of the electricity, natural gas and LPG winter use

7. APPLIANCE ENERGY USE

This section provides summary data on household appliance energy use – electricity, natural gas and limited analysis of LPG and solid fuel. Pie charts of the electricity and natural gas use for Auckland, Hamilton and Wellington are provided, along with the breakdown of cooking types for Auckland. The use of advanced metering is providing information on reactive, as well as resistive, electricity load. The results for an example house are discussed. Updated values are also provided for baseload and standby electricity, with information on the distribution over the HEEP houses.

7.1 Appliance energy use

Mean annual power consumption has been calculated for the various appliance groups for Auckland (Year 1 only), Hamilton, and Wellington, and their weighted average.

Description	Component
Total	Electricity and gas
Refrigeration	Freezer Fridge/freezer Refrigerator
Range	Hobs Oven Range
Other cooking	Bread-maker Crockpot Electric coffee maker Electric frying pan Electric jug Electric juicer Microwave Rangehood Toaster
Heaters/Air conditioners	Air conditioner Central heating Electric resistance heating Gas heater
Other climate control	Dehumidifier Electric blanket double Electric blanket single Fan (internal) Heated towel rail
Lighting	Compact fluorescent - portable Halogen or similar - portable Incandescent - portable
Washing machines	Washing machine
Dryers	Dryer
TV/computer	TV Computer/games
Large miscellaneous	Pool pump Water pump
Small miscellaneous	Dishwasher Electric fence Electric power tools Guitar amplifier Iron, iron press Sewing machine
	Vacuum cleaner Weed eater
Hot water	Storage, instant

Table 25: Appliance group coverage

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.

The combinations of different appliances used for each appliance 'group' are given in Table 25.

As the analysis has progressed, the composition of the groups has been re-defined, so for Wellington and Hamilton not all the groups have estimates of the average power yet. Difficulties can arise in the analysis when apparently logical groupings put together appliances that may have very different energy consumptions.

For example, for the Auckland analysis the standard deviation for the 'Other climate control' group grew to 38 ± 129 W due to a single appliance. Only in hindsight can these effects be minimised. These groups will be re-applied to the Hamilton and Wellington data, and discussed in the HEEP Year 7 report.

It is interesting to note that there are no significant differences between the total energy use for Auckland, Hamilton and Wellington, being 1156 ± 85W, 1280 ± 162W, and 1172 ± 105W respectively, as shown in Table 26.

There is a marginally significant difference between the hot water energy use in Auckland and Wellington. This is expected as the air and cold water temperatures in Wellington are about 2°C cooler than Auckland.

Further analysis of other appliances energy use on a per household basis will be undertaken for later reports. Standby power estimates for common appliances are provided in HEEP Year 5 report, Section 3.5.4 (Stoecklein et al. 2001), and these will also be updated in later reports.

Description	Estimated Watts per-	Auckland (2001)	Hamilton (2000)	Wellington (1999)	Strata weighted
Refrigeration	Appliance	75±5	69±7	68±6	73±4
	House	128±16	113±17	146±33	131±13
Range, oven, hobs	House	51±9	80±27	67±24	59±9
All other cooking	Appliance		6±2		
	House	42±8	29±10		
Microwave	Appliance	10±3			
	House	9±3			
Electric jug	Appliance	22±6			
	House	22±6			
All cooking	House	93±12	109±29		
Heaters & air conditioners	House	382±203	177±72		
Other climate control	House	38±129	12±7		
Lighting	House (Plug)	21±6	9±8		
	House (Fixed)	170±48	95±19	109±31	147±32
	House (All)	192±50	105±21		
Washing machines	Appliance	4±1	10±2		
	House	4±1	10±2	6±3	5±1
Dryers	Appliance	42±15	14±5	37±19	38±11
	House	42±15	11±4	32±17	36±10
TV/computer	Appliance	10±2	19±3		
	House	43±11	49±9		
Large miscellaneous	House	49±45	7±5		
Small miscellaneous	House	6±5	7±5		
Dishwasher	Appliance	36±10		22±12	
	House	22±8		16±9	
Hot water, electric	Per system	324±23			
Hot water, gas	Per system	529±80			
Hot water (All)	House	386±29	428±93	462±43	409±24
Total (inc gas) [x]	House	1156±85	1280±162	1172±105	1173±63

Table 26: Appliance average power estimate by location

Hamilton has a higher number of solid fuel heaters which are intensively used. Table 27 provides an initial estimate, which suggests overall heating energy use is comparable between the three locations.

Figure 23, Figure 24, Figure 25 and Figure 26 provide the proportions of energy (electricity and natural gas only) by end use for each of Auckland (Year 1 monitoring only), Hamilton, Wellington as well as a strata weighted average over the three locations. These figures update the pie chart (Figure 7) presented in the HEEP Year 1 report (Stoecklein et al. 1997). Wellington heating energy use (Figure 25) is included in the 'assigned' category due to processing issues.

[x] "Total (inc gas)" includes LPG heaters only in Auckland, but not the other centres.

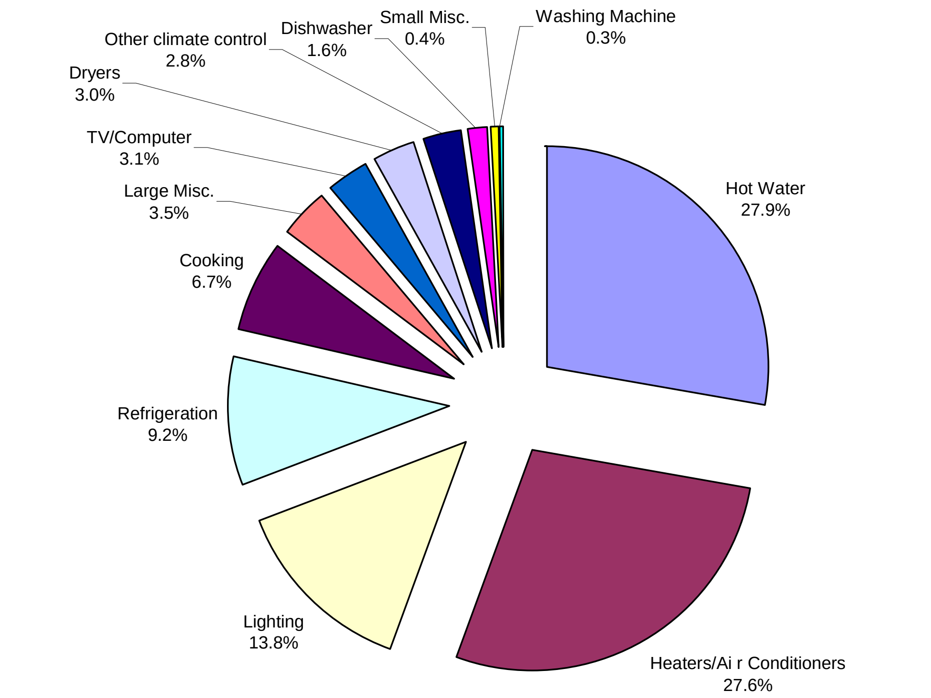

Figure 23: Auckland mean annual electricity & gas-use breakdown

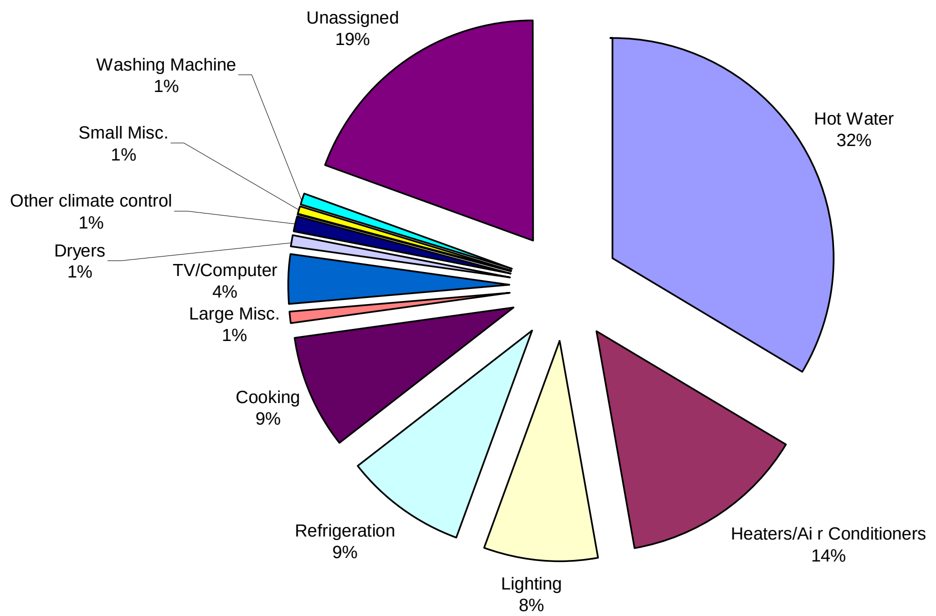

Figure 24: Hamilton mean annual electricity & gas-use breakdown

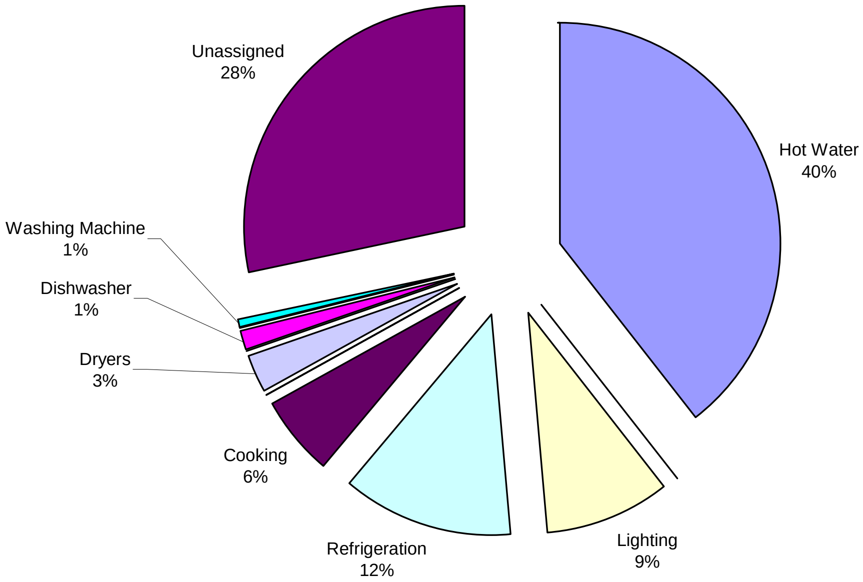

Figure 25: Wellington mean annual electricity & gas-use breakdown

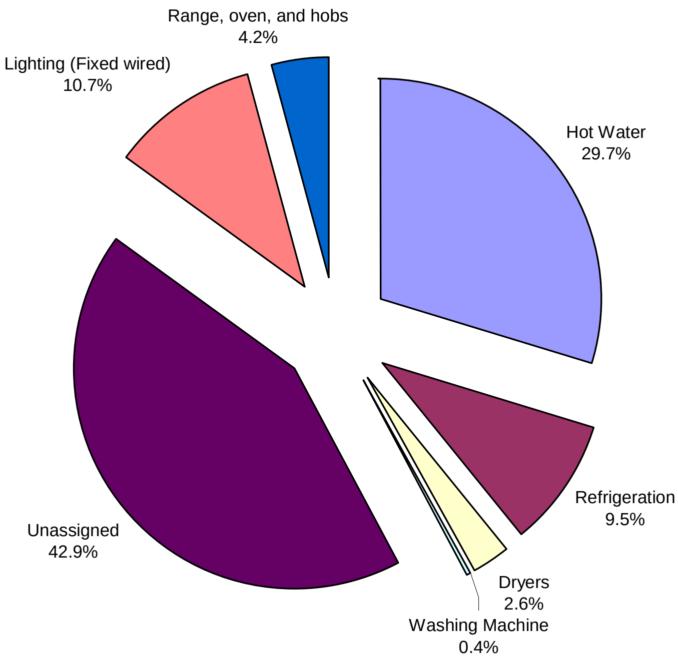

Figure 26: Mean annual electricity & gas - strata weighted average

Figure 27 provides an average power breakdown by the different use of cooking appliances for Auckland (first year of monitoring only).

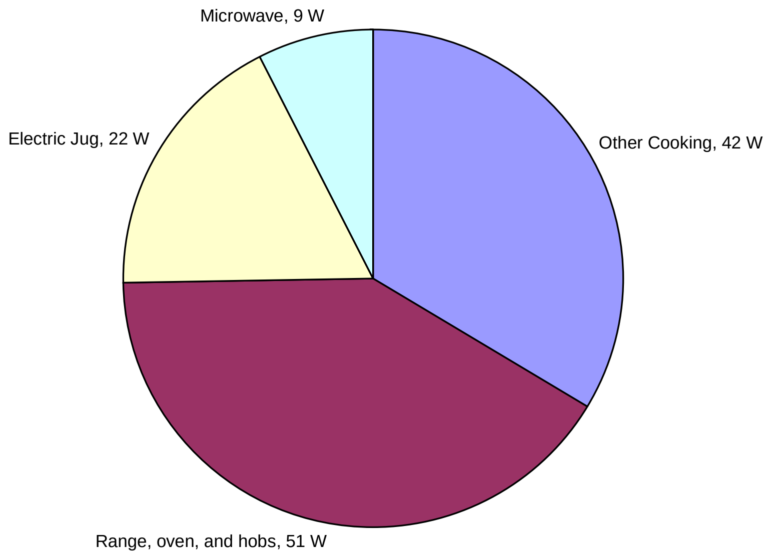

Figure 27: Cooking electricity & gas-use - Auckland

7.1.1 Likely importance of LPG and solid fuel use

As LPG data was not available for Hamilton and Wellington, and solid fuel energy is not yet incorporated, there was the possibility that this would result in sizable changes to the total house energy estimates in future years.

To investigate the scale of this issue, the surveyed heating use (hours of heating, months heated etc) were analysed and rough estimates of average energy use calculated. Table 27 shows that even with these rough estimates included, there are no significant differences between average annual energy use between these three cities. Note that for the analysis reported LPG use is included only for Auckland.

Estimates based on survey responses	Estimated Watts per-	Auckland (2001)	Hamilton (2000)	Wellington (1999)
LPG [xi]	House	12	40	24
Solid fuel	House	118	218	77
Total	House	1266 ± 85	1498 ± 162	1249 ± 105

Table 27: LPG, solid fuel and total average power estimates

Assumptions made in the preparation of Table 27 were:

- **LPG**: 2 kW average heat output for the hours-per-week and months-per-year reported used.
- **Solid Fuel**: 2 kW average heat output per room heated for the hours-per-week and months-per-year reported used.

[xi] Actual measured value for Auckland

7.2 Reactive energy for one residential building

The load on the electric distribution network is often thought of as resistive, for example as would be caused by using a number of electric heaters. However, many common household appliances now use motors, electronic power supplies and electronic controls which have reactive (inductive or capacitive) components to the load.

The ratio of the reactive (frequently inductive) load to the resistive load is termed the 'power factor'. If the load is purely resistive the power factor will be unity (1.0) but if the load is reactive (inductive or capacitive), it will be less than one.

Energy is required to supply both the resistive and reactive loads of appliances. This has been an issue for commercial and industrial organisations which are charged not only for the 'real' power (kW) but also for the reactive power (kVAr), and hence have a financial incentive to minimise their use of reactive power. However, households do not pay for reactive power, and there are no controls on the power factor of the appliances that can be purchased. Thus it becomes an issue for the local lines company to manage.

Reactive power information was available for one Auckland house for about 40 days from the TML meter (see Section 4.2). The real power (kW), reactive power (kVAr), apparent power (kVA) (the vector sum of real and reactive power) and power factor (PF) were recorded every minute.

The monitored house was a five-year-old, two-storey house of about 175 m², occupied by a family of five. Reticulated natural gas is used for hot water and some space heating. Amongst the appliances are one medium-sized refrigerator/freezer and one old large vertical freezer.

The daily profiles for this sample house over a one-month period (based on data averaged to 10-minute intervals) across the month for the real, reactive and apparent power, as well as the power factor (to the scale on the right of the graph), are shown in Figure 28.

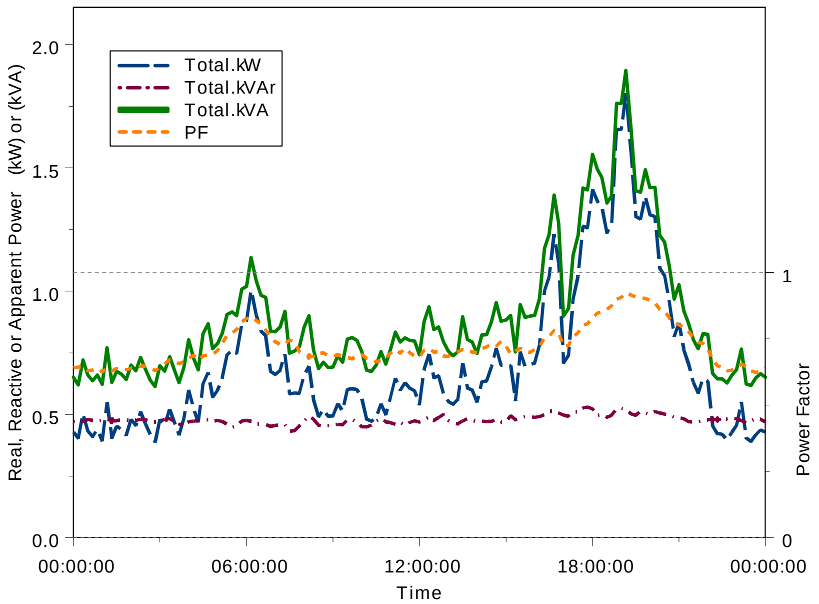

Figure 28: Sample daily power profiles and power factor

Overall, the mean of the real power was 0.71 kW, with peaks around 6am and around 7pm. The reactive power was more consistent over the day and had a mean value of 0.48 kVA. The mean power factor was 0.72, with the power factor increasing at peak times as more resistive load is switched on.

Figure 29 gives a histogram of the power factor showing there is a peak in the value of the power factor at around 0.6. For 25% of the time the power factor is below 0.62 and for 50% of the time is below 0.68.

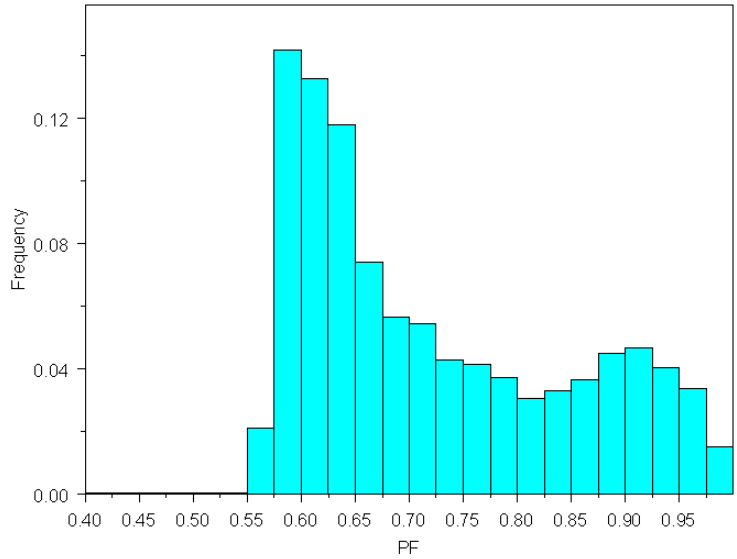

Figure 29: Histogram of the power factor (PF) over one month

The power factor is also time-dependent, as shown in Figure 30. Figure 30 divides the day into six parts, and provides a histogram of the power factor for each. The mean energy consumption (resistive) along with the mean power factor for each period of the day are given in the top right hand corner of each graph. For the midnight to 4 am time period, the lower power factor values predominate. During this time the resistive energy consumption is low and presumably the only appliances on are baseload appliances, such as refrigerators, freezers, microwaves, TV, stereo, clock radios etc. Even in the period of highest consumption (4 pm to 8 pm), for 25% of the time, the power factor is less than 0.72.

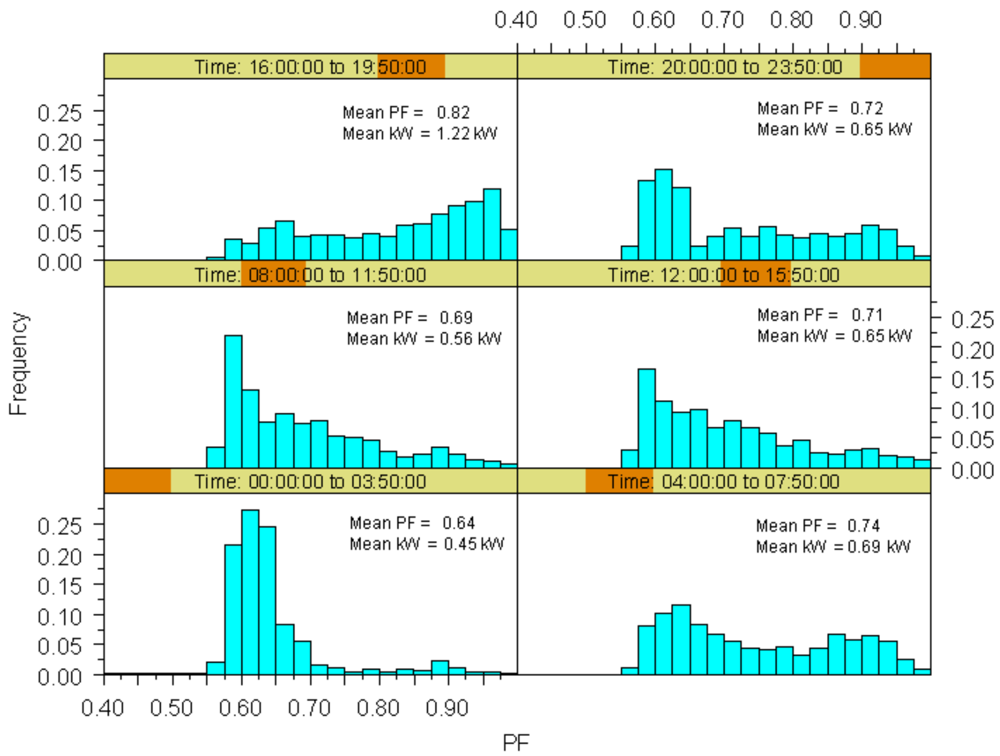

Figure 30: Power factor distribution by time of day

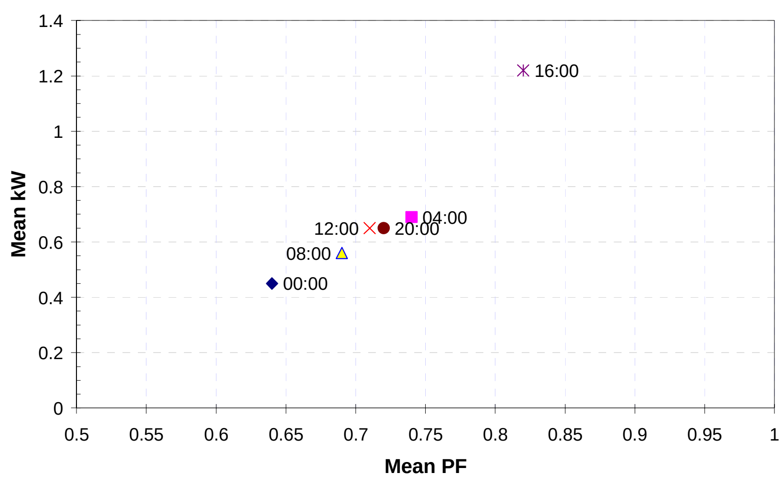

Figure 31: Power factor vs. kW load by time of day

Figure 31 plots the mean power factor and kW loads, as given in Figure 30.

It can be seen that the worst power factors occur at periods of low resistive energy use.

Information on the relationship between the real and reactive power is shown in Figure 32, which plots the real versus reactive power for the sample house over a one-month period at 10-minute intervals. The least-squares line of best fit has an intercept of 0.45 kVA and a slope of 0.044 kVA/kW. Note the y-axis (reactive) scale is magnified as compared to the x-axis (real) so that the slope is exaggerated.

The two components of the best fit line (the slope and the intercept) are determined by two different features of the appliances in the household. The intercept is associated with the reactive power demands of the baseload appliances (those continuously on), whereas the slope is associated with reactive power associated with discretionary appliances that are operated by the occupants. For this particular house, the reactive energy from baseload appliances is greater than that from the discretionary appliances used in the house. However, as discretionary appliances are used at times of network constraint (times of peak load) the additional reactive energy of these appliances may be as important to generators and transmissions providers as the reactive energy requirements of the baseload appliances.

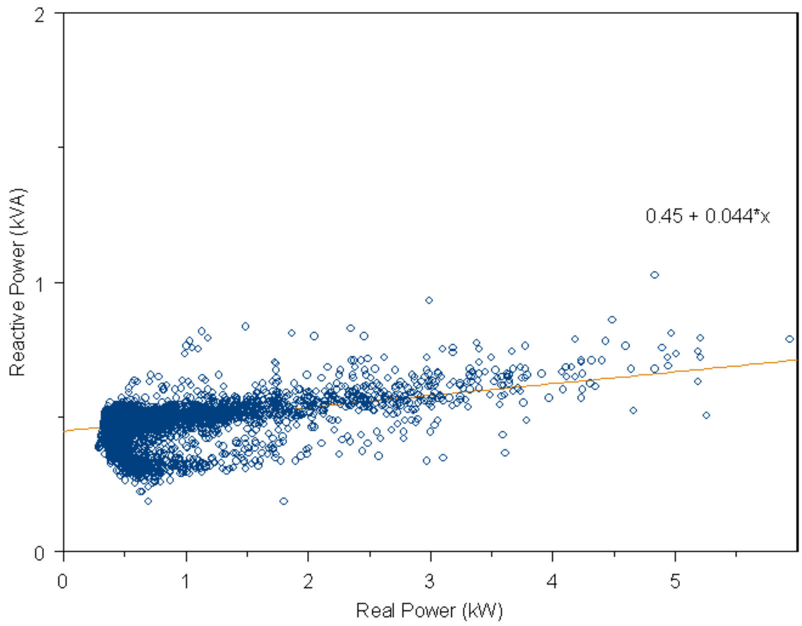

Figure 32: Real vs. reactive power for the sample house

As more appliances are produced that use electronic controls and have electronic power supplies, household reactive energy may be expected to increase.

Refrigerators and freezers, with their use of compressor motors, have historically had a large reactive baseload energy demand. Minimum Energy Performance Standards (MEPS) for refrigerators and freezers were introduced for New Zealand from 1 July 2002. MEPS requires that refrigerators and freezers sold must achieve a minimum level for energy efficiency (a minimum number of stars on the Energy Label which have also become mandatory for refrigerators and freezers since 1 April 2002). It is intended to introduce stricter energy efficiency targets in the 2004 revision of MEPS for refrigerators and freezers.

As energy efficiency plays an important role in refrigerators, manufacturers are looking to improve the performance of their appliances (Roke 2002). One improvement that can be made to the performance of refrigerators and freezers is to use higher efficiency compressor motors (which make use of run capacitors). A by-product of some of these technologies is that the reactive energy demand for the motor can be significantly reduced.

The reactive energy of a house may be a sizable load on the electricity networks. Appliances with large reactive loads (due to electronic controls, electronic power supplies, transformers, electric motors, etc.) are on the increase. How these new appliances are contributing to the reactive power demand may be better understood by comparing graphs similar to Figure 32 for a range of houses. This data will be available for a small sample of HEEP houses. One way to reduce the impact of additional reactive energy is to require appliances to have good power factors (low reactive energy use). Appliance efficiency improvements to refrigerators and freezers likely to also result in improved power factors for these appliances in the future.

7.3 Baseload and standby electricity

HEEP has been instrumental in bringing the issues of baseload and standby electricity to the attention of New Zealand. The HEEP Year 3 report (Stoecklein et al. 1999) provided the first estimates of the scale of this facet of energy use, and the HEEP Year 5 report (Stoecklein et al. 2001) provided more detailed estimates for a wider range of appliances. As the HEEP sample increases in size it will be possible to further refine these estimates.

The HEEP Year 5 report (Section 3.5.5) reported that for the randomly selected Wellington and Hamilton households the baseload and standby for the totalled 103 ± 10 W, with 90% of households in the range of 15 to 205 Watts. Over all the houses it was found that the largest five contributors to the household baseload are (from highest to lowest):

- fridge and fridge/freezer
- television
- video
- washing machine
- microwave.

In an individual house, the heated towel rail may have a higher baseload.

A full revision of the analysis of the standby and baseload electricity loads has not been undertaken for this report. The HEEP database has been used to develop an improved estimate and some descriptive sample statistics.

Analysis of the randomly selected Wellington, Hamilton and first year Auckland houses (102 houses) currently in the HEEP database gives a stratum weighted average baseload of 122 ± 27 W – this is not statistically different from that given in the HEEP Year 5 report.

Table 28 provides sample minimum, average and maximum electricity demand, along with the baseload electricity as a percentage of the total electricity. The spread between the sample minimums and maximums are wide, and the following figures provide additional insights. The sample mode of the baseload as a percentage of total electricity is 11%.

Power	Baseload electricity	Non-baseload	Total Electricity	Baseload % of total electricity
Sample maximum	586 W	2125 W	2561 W	53%
Sample average	117 W	804 W	921 W	13%
Sample minimum	14 W	159 W	311 W	2%
Sample skew	2.3	1.2	1.4	1.7

Table 28: Sample electricity demand

Figure 33 shows for each house in the sample the baseload electricity power, the total electrical power and the baseload as a percentage of the total electricity (note the percentage scale is on the right). For any given baseload, there is a wide range of the total electric load, and the baseload as a percentage of the total load. There is a weak correlation between total energy use and baseload. A high percentage of baseload does not necessarily mean a low total electric power demand, or vice versa.

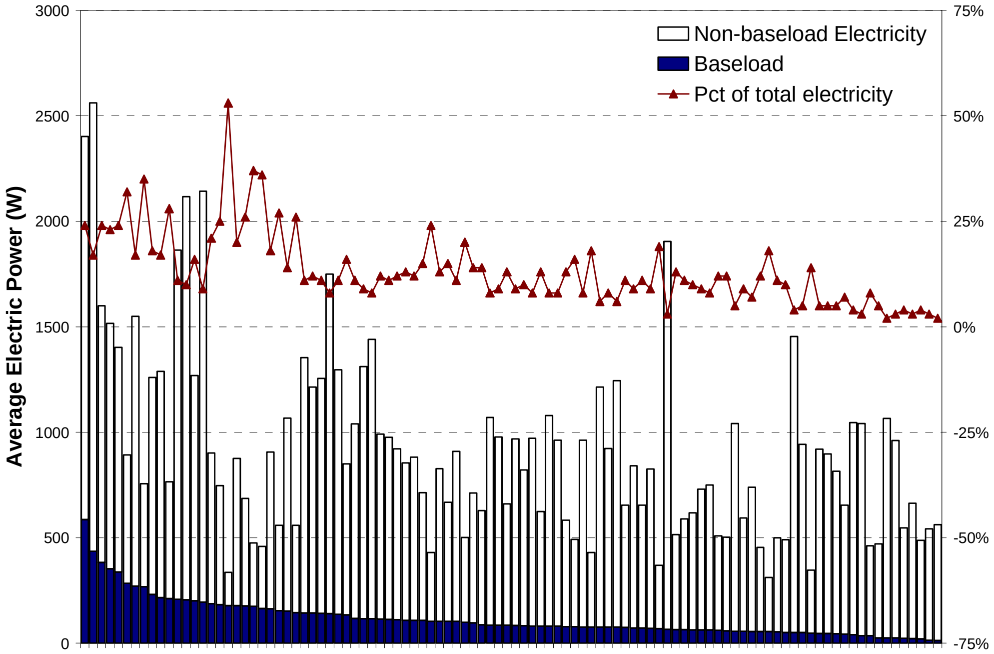

Figure 33: Proportion of baseload power by sample house

Figure 34 provides a histogram of the average baseload from the sample. The distribution is skewed to the left, with a long tail to the right, with the top 10% having 14 houses with a 250 W or higher baseload.

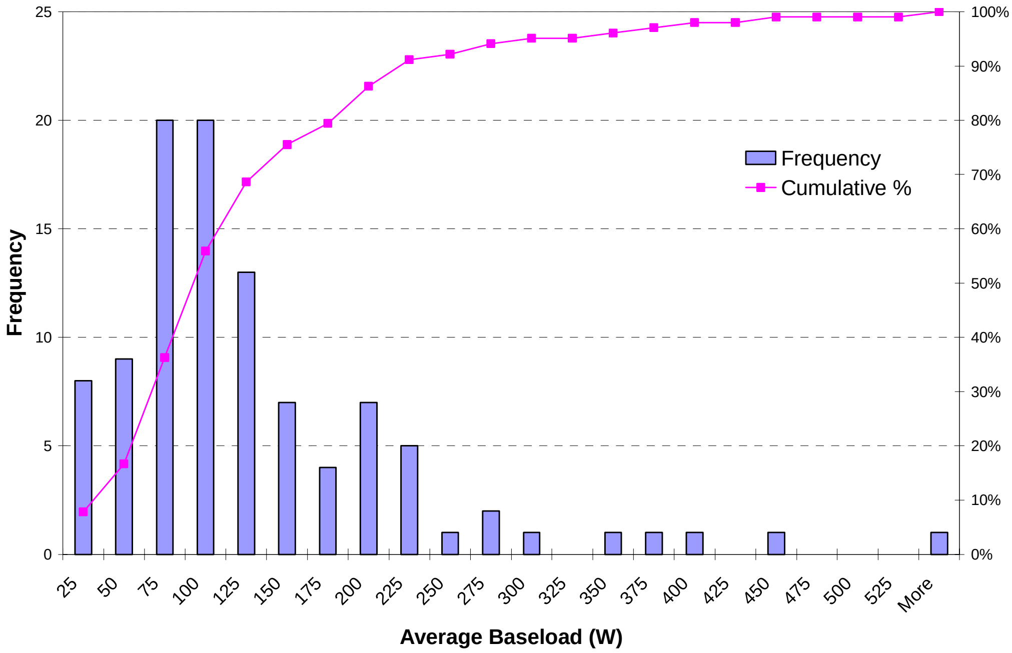

Figure 34: Sample average baseload power

Figure 35 provides a histogram of the sample total electricity use. The distribution is less skewed than the baseload, but still has a tail of high-using households stretching to the right, with four houses reporting a total average electricity demand of over 2,100 W (2.1 kW).

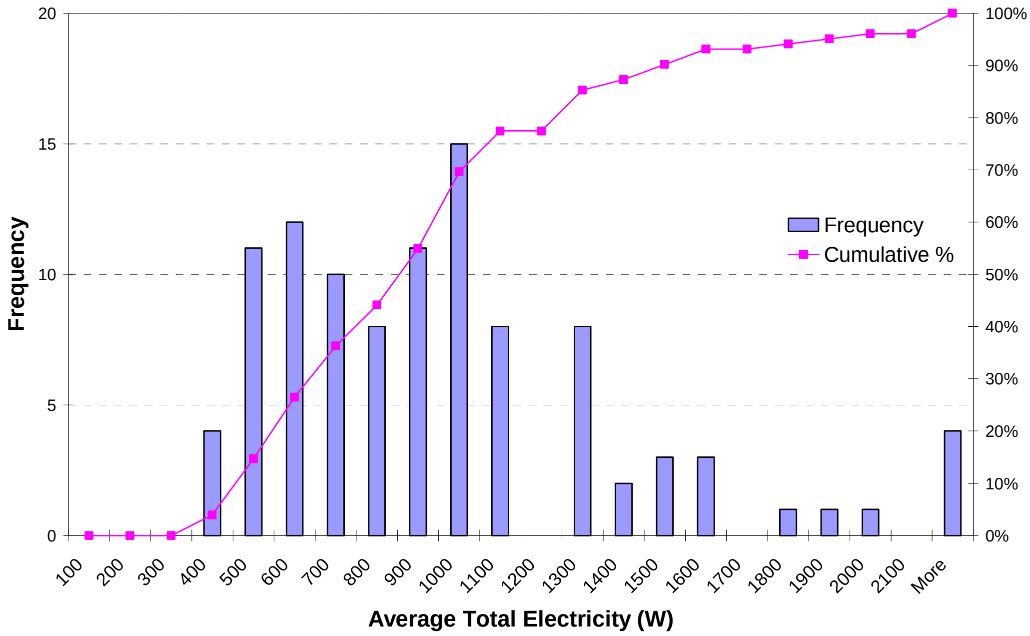

Figure 35: Sample average total electricity

Figure 36 shows the baseload as a proportion of the total electricity load. In the majority of the sample households the baseload is less than 20% of the total electricity load, but there are 16 houses which have a greater percentage. The reasons for this are many – in some cases other fuels are used for space and water heating, resulting in the electric standby becoming of greater importance, in others a large number of appliances with high standby and/or baseload power demands are the cause. These issues will be investigated in later HEEP reports.

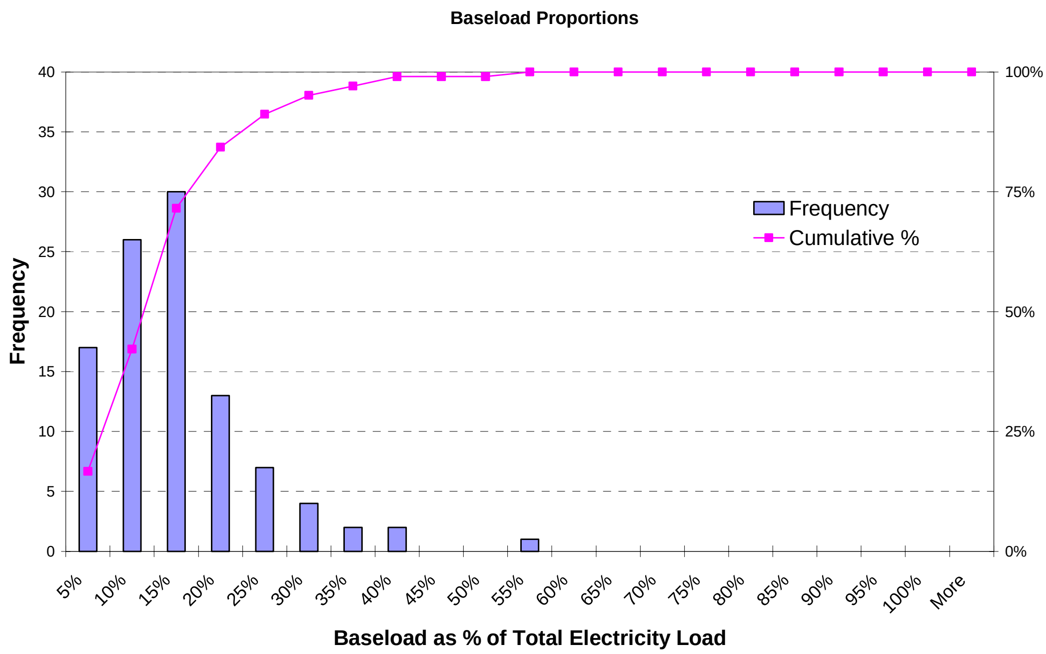

Figure 36: Sample baseload as percentage of total electricity

8. SOLID FUEL CONSUMPTION

Previous HEEP reports have used Artificial Neural Networks (ANNs) to investigate patterns of energy use. This section examines the use of solid fuel through the use of ANNs.

During the past year the HEEP team has updated its ANN software, moving to "NeuroSolutions 4.2". This is a highly graphical neural network development tool for Windows 95/98/NT/2000/XP. It provides both stand-alone and Excel-integrated ANN tools. It combines a modular, icon-based network design interface with an implementation of advanced learning procedures and genetic optimisation[xii].

8.1 Artificial Neural Networks (ANNs)

Artificial Neural Networks (ANNs) are mathematical structures consisting of interconnected nodes. The features of individual nodes and their connections are generally very simple and the ability and flexibility of the network arises from the interaction of a large set of interconnected nodes.

The connection between each node is weighted. The weighting of the connection modulates the signal passed between the nodes. Weighting factors can be positive or negative. The net input signal to node *i* can be written as:

$$net_i = \sum_{j=1}^{n} w_{ij} o_j \qquad \textbf{Equation 2}$$

with w_{ij} representing the weighting factor of the connection which runs from the node *j* to the node *i* and o_j the activation level of node *j* as shown in Figure 37.

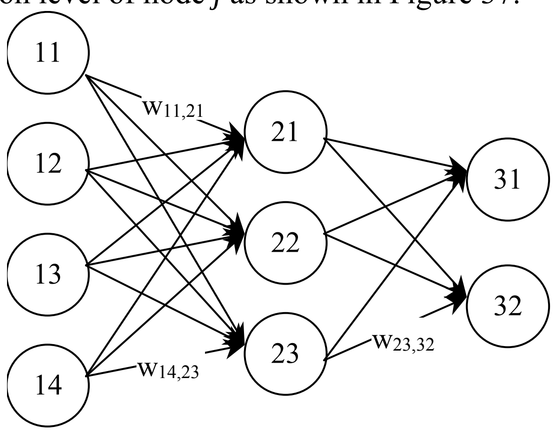

Figure 37: ANN nodal connections

Each node in the network is characterised through its activation function. Whenever the node receives signals through its incoming connections the activation status of the node is determined by applying the activation function to the incoming signals.

$$o_i = f_i(net_i) \qquad \textbf{Equation 3}$$

The node is then able to pass its activation value on to connected successor nodes.

The nodes of a neural network are generally arranged in 'slabs' or 'layers'. All neural networks have at least an input and an output layer. The input layer is used to feed

[xii] NeuroDimension Inc. see www.neurosolutions.com

information into the network, the output layer shows the activation levels of the output layer nodes for the presented input pattern. The activation pattern of the output layer is determined by the weighting factors of the interconnections of the network. Most network architectures use only one additional layer of nodes between the input and output layer. Since these intermediate layers are often not externally interrogated they are often termed 'hidden layers'.

The characteristic of the neural network to perform tasks lies in its ability to adapt the weighting factors of the connections according to defined paradigms. The automatic adjustment of the weighting factors is often referred to as 'learning'.

Multi-layer perceptrons (MLPs) are layered feed-forward networks typically trained with static back-propagation. These networks have found their way into countless applications requiring static pattern classification. Their main advantage is that they are easy to use, and that they can approximate any input/output map. The key disadvantages are that they train slowly, and require lots of training data (typically three times more training samples than network weights).

In recent years, ANNs have been used successfully for a number of pattern recognition tasks. Typical applications are the recognition of handwriting, stock market trends or product failure features in production processing plants:

- Mihalakakou et al (2002) have used artificial neural networks very successfully to predict residential load profiles for a building in Athens, Greece.
- Farinaccio & Zmeureanu (1999) have applied neural networks to disaggregate load profiles into their end-use components.

Because of the flexibility of ANNs they seem to offer a useful method to disaggregate the 'household level' energy profiles into their 'end-use level' components. The following section briefly describes the structure and processing method of ANNs.

8.2 HEEP application of neural networks

'Household level' profiles consist of the sum of all the individual 'end-use level' profiles in the household. When visually inspecting the 'household level' profiles it becomes obvious that there are a number of contributing end-uses, which lead to very characteristic patterns in the profile. Figure 38 shows such a typical 'household level' profile. Characteristic patterns are caused by hot water heaters, fridges, as well as cooking and heating appliances. While it is comparatively easy to spot these characteristic patterns visually, sophisticated algorithms are required to automatically identify and extract the individual 'end-use level' profiles. This use of neural networks will be further investigated in the coming year.

A similar problem exists for the determination of solid fuel energy consumption. Although it is visually quite easy to identify times of high heating energy use from temperature profiles measured within the building, completing this task in an automated way is rather complex.

HEEP monitors the use of solid fuel heating appliances using thermocouples (temperature sensors), which are attached to the surfaces of the heating appliances. This logging provides accurate measurements of the time of use of the solid fuel heaters; however, the amount of heating energy supplied to the room cannot be easily deduced from these measurements.

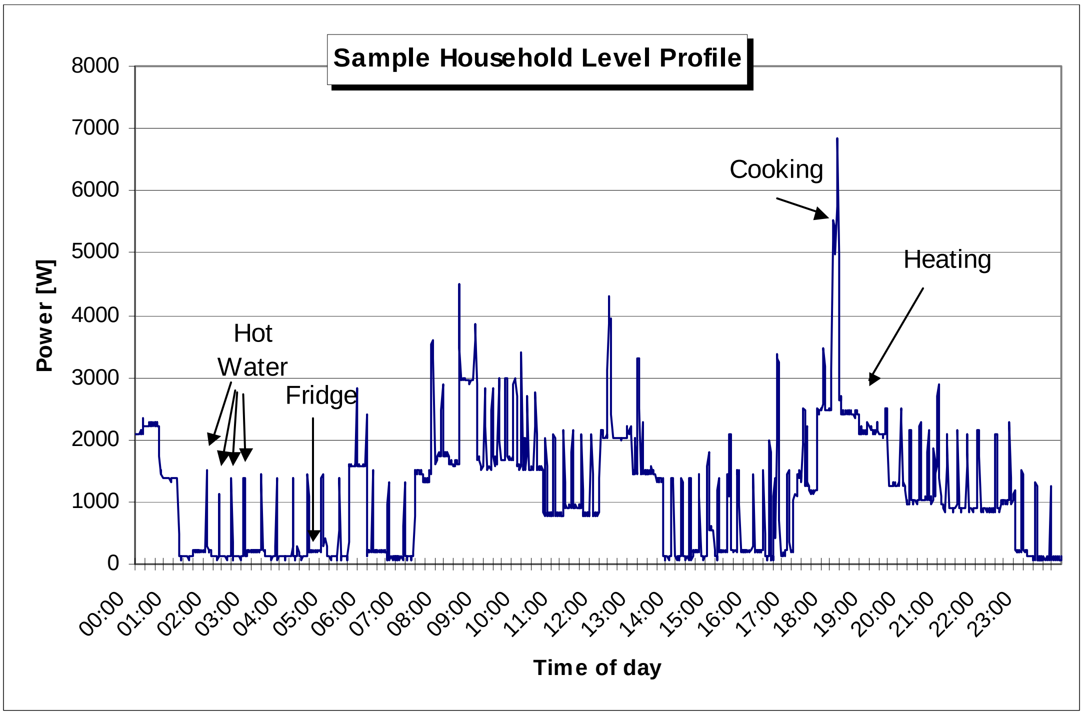

Figure 38: 'Household level' with characteristic 'end-use level' profiles

In order to deal with this issue, the room in which the fireplace is situated is treated as a de-facto calorimeter. The thermal characteristics (heat loss and thermal mass) are then determined through neural network simulations. Once the characteristics are established and a neural network model is defined for the house, the heat output of the solid fuel heater can be determined.

The first step in this approach is the establishment of a thermal model of the room. This has been done using a generalised feed-forward neural network. (For a detailed description of neural network architectures please refer to Freeman & Sakura 1991). Generalised feed-forward networks are a generalization of the Multi-layer Perceptron such that connections can jump over one or more layers. Generalised feed-forward networks often solve the problem much more efficiently than simple Multi-layer Perceptrons. For a common test example, a standard MLP requires hundreds of times more training epochs than the generalised feed-forward network, which contains the same number of processing elements.

8.3 Pattern representation

The representation of input and output patterns presented to the neural network will determine the success of the network performance. Each input pattern may consist of very different parameters. In the HEEP example the input patterns consist of temperature and solar radiation parameters and also of parameters describing the time of day at which the specific pattern occurred.

The appropriateness of the pattern representation depends of factors such as the nature of the data source, the range of the parameters, the relationship between the parameters and the relationship between the patterns.

8.3.1 Input pattern representation

One of the most complex aspects of creating an appropriate data representation is the question of how to represent temporal data. This is the case in the HEEP task where the precise temporal relation of the whole energy consumption in the time series contains a significant amount of information. This can then be used for the characterisation of the particular end-use, i.e. heating energy consumption becomes so 'typical' through its delayed response in internal temperatures. If the data representation did not account for the temporal aspect of the pattern, it is unlikely to be able to identify heating or any other appliances.

In order to take account of the network's ability to recognise time-series pattern features a node has been implemented with an integrated time-delay structure, i.e. a certain number of input values from previous time steps is being retained. The further the input data lie in the past the more the data are attenuated. Such a node is called a Gamma-Axon. The Gamma-Axon provides a recursive memory of the input signals past.

	Parameter
sin(TOD(t))	Sine of time of day
cos(TOD(t))	Cosine of time of day
To(t)	External temperature at time t
R(t)	Solar radiation at time t

Table 29: Pattern features input to ANN

Table 29 lists the pattern features which have been used as input variables for the network to predict total energy consumption.

Using these input variables the network has learned to predict the internal family room temperature to a sufficiently high accuracy.

Figure 39 shows a section of the neural network prediction of the internal family room temperature (blue) against the actually measured temperature (red). The data used for establishing the network did not include periods of heating. The graph in Figure 39 shows a good general match.

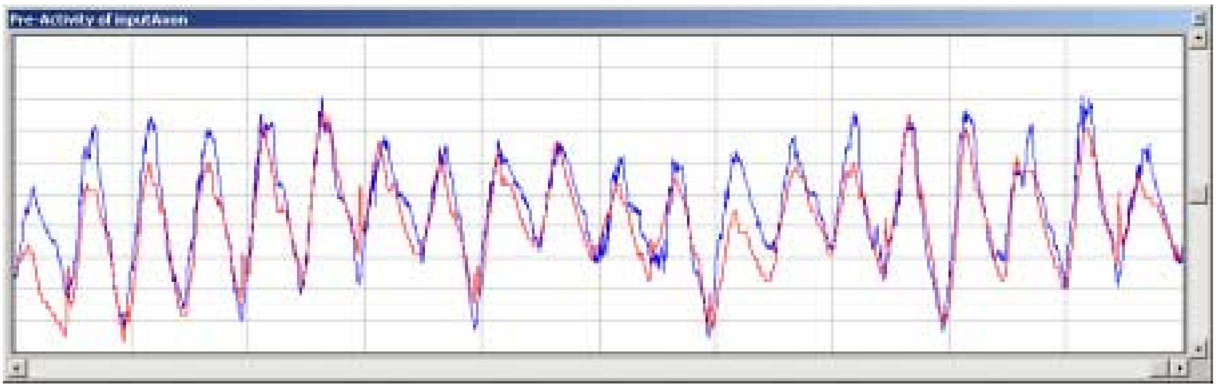

Figure 39: ANN prediction vs. actual family room temperature

The next step will be to apply this network to times during which heating was applied. As discussed previously measuring the surface temperature of the solid fuel heaters allows heating times to be determined. It is expected that for these times the neural network predictions will deviate from the actual measurements, i.e. the actually measured temperatures will be higher than the network predictions. These deviations will give a measure of the heating energy applied to the space. Work on this analysis step is currently under way, and will be reported in a later HEEP report.

9. INDOOR TEMPERATURES

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 30 compares the results of the HEEP monitoring with the 'lounge' temperatures by region from 1971/72 Household Electricity Survey (Statistics 1976). Note that after data checking, the Wellington and Hamilton temperatures were revised compared to previous HEEP year reports.

Temperatures °C	HEEP Wellington 1999	Southern North Island 1971	HEEP Hamilton 2000	HEEP Auckland 2001	Northern North Island 1971
Living room:					
Mean temperature	15.5	16.6	16.6	16.5	17.7
Standard deviation	1.3	-	1.2	1.7	-
95% confidence interval	14.9 - 16.0	-	16.0 - 17.2	16.0-17.0	-
External:					
Mean temperature	9.4	11.0	9.2	12.7	12.0
Internal - external temp.	6.1	5.6	7.4	3.8	5.7

Table 30: 1999/2000 temperatures and 1971 temperatures

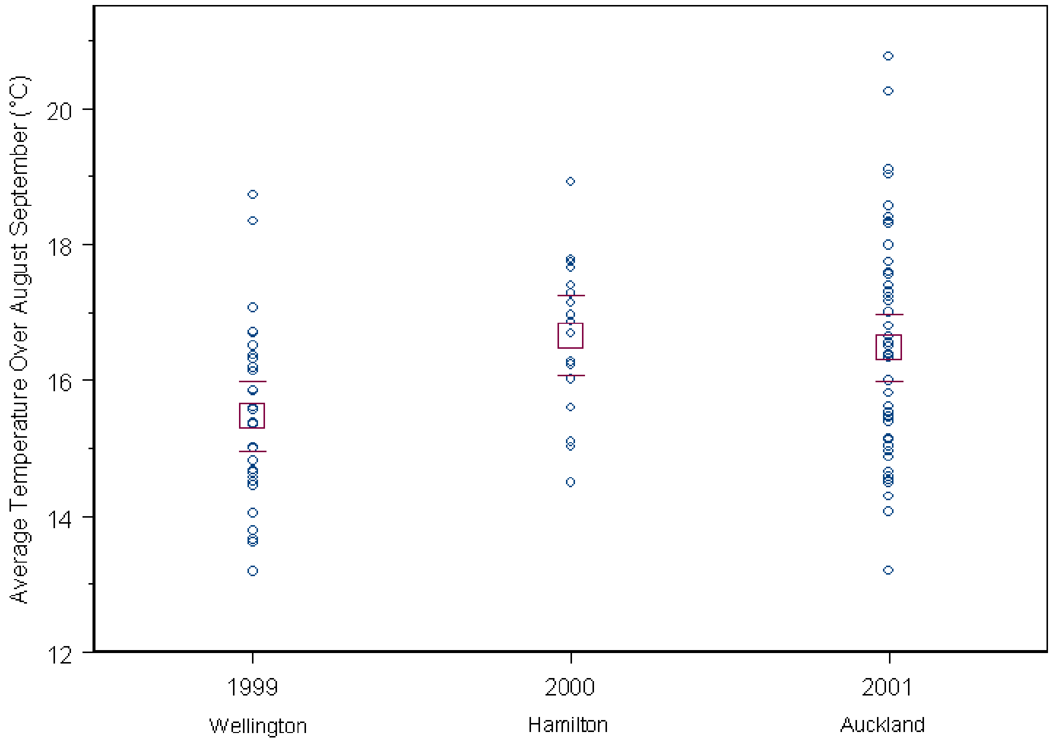

Figure 40: Mean temperatures August - September by location

Figure 40 shows the temperature distribution (each point is one house) and the mean temperature with 95% confidence interval for Wellington, Hamilton and Auckland. Figure 40 can be compared with Table 30 which shows the wide distribution of temperatures and hence the size of the standard deviation of the sample.

For the analysis discussed in this section, the HEEP database contained full years of data from sample households in Wanganui, Wellington, Hamilton and the first year of Auckland logging (2001/02). Some of the analysis was conducted on all available houses and some on a sub-set containing only the randomly selected houses.

Winter evening temperatures were calculated by first determining the most common heating season, based on the occupant survey response to questions about the first and the last month when heating is used (question B.5.1) Table 31 and Figure 41 give the number of houses reporting the given start or finish month.

Month	Number start	Number end
January	1	
February		
March	4	
April	29	
May	43	
June	20	
July	4	2
August	1	15
September		43
October		33
November		6
December		1

Table 31: Reported heating season

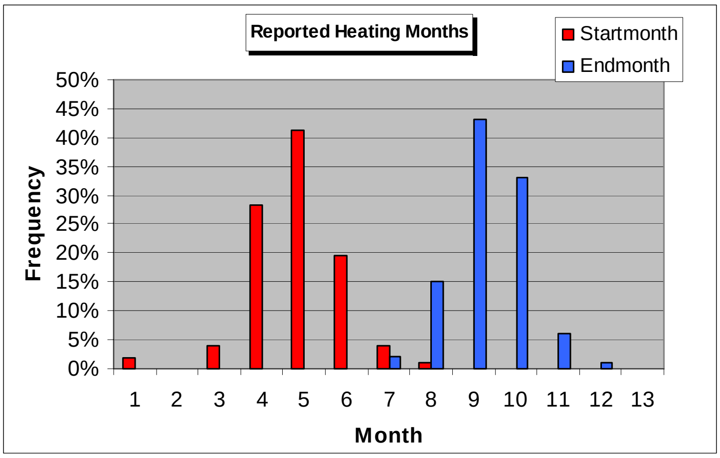

Figure 41: Reported heating season start and finish

Figure 42 (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. Note that there is only one house that reports starting heating in January, and continuing heating for the entire year.

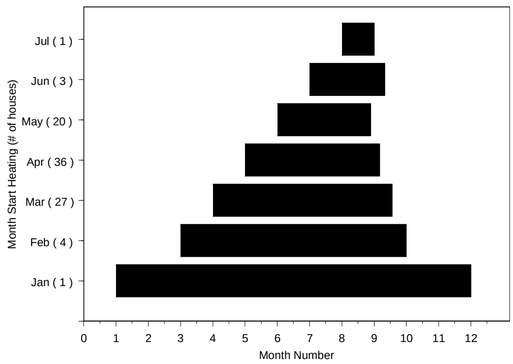

Figure 42: Length of reported heating season

Region	Start month	End month	Length	Length SD
Auckland	5.0	9.0	4.0	0.2
Hamilton	4.9	9.8	4.9	0.6
Wellington	4.8	9.4	4.7	0.2

Table 32. Average heating season by region

Table 32 shows that the average starting and finishing heating seasons do not show statistically significant variations by region; however the length of the heating season does vary by region, with Auckland having a shorter average heating season than Hamilton or Wellington. (p=10%).

The starting month of the heating season is weakly related to the average winter evening living room temperatures, so 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[xiii].

Figure 43 gives the winter temperature profiles for Auckland, Hamilton, Wellington and a simple (unweighted) average of all three regions. It reveal some interesting patterns:

- Hamilton houses are the warmest, followed by the Auckland houses. The Wellington houses are the coolest of the sample.
- Peak living room temperatures occur at 7 pm in Hamilton, 8:30 pm in Auckland, and 9:30 pm in Wellington. This effect may be related to the house occupants' schedules, as the average bedtimes are 10:00pm, 11:10pm, and 11:00 pm, respectively (see Figure 44). 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.

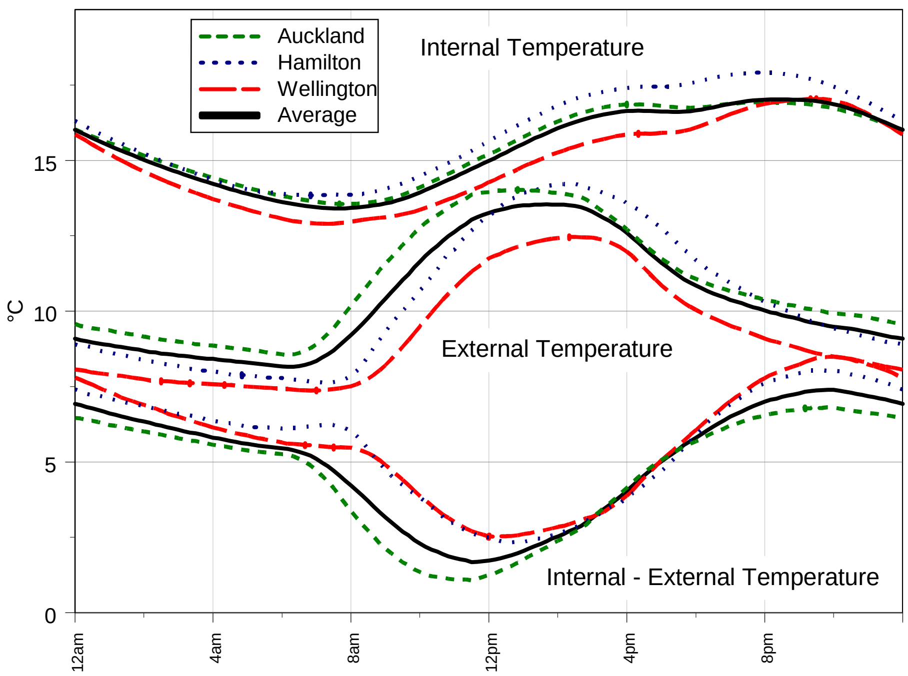

Figure 43: Winter temperature profiles

The temperature profiles were examined to determine the times that heating was applied. The 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 indicates that, on average, houses are being heated. The end of heating is more difficult to determine, but the method chosen was to find the point at which the temperature returned to

[xiii] No account was taken of logger heights and representativeness or consistency between different households. However, because loggers are in general 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.

the same as that of the start period. This is not adequate, and an improved method will be developed for future HEEP reports – possibly based on energy records.

An examination of the data showed that 90% of the monitored households have a bedtime of 9 pm or later. Figure 44 gives the results of the analysis of the monitored temperature profiles, giving the average time over the winter period that heating was started and finished, as well as the "average bedtime" based on analysis of electricity use for the house. While the monitored Auckland and Wellington houses had similar average "bedtimes" (11 pm), Hamilton bedtimes appear to be one hour earlier (10 pm). Heating also started earlier in Hamilton, and finished earlier in the evening. These effects will be investigated further in later HEEP reports.

	Auckland	Hamilton	Wellington
Heating Time (hr)	4:15	4:40	6:59
Start Heating	5:45 PM	4:30 PM	5:00 PM
Avg Bedtime	11:10 PM	10:00 PM	11:00 PM

Figure 44: Estimated heating periods by region

9.1 Heating schedules

The survey also asks householders about their heating schedules in three areas of the house: living areas, bedroom, and utility areas. The schedules are "Morning 7 – 9 am", "Daytime 9 am – 5 pm", "Evening 5 – 11 pm", and "Night 11 pm – 7 am". Table 33 and Table 34 provide statistics from the survey.

Most (~90%) households reported heating living areas in the evening. About 25% of households heat the bedrooms in the morning. The heating pattern changes from weekdays to weekends, with daytime heating becoming more common, evening heating becoming less common, and overnight and morning heating showing no change.

The most common heating schedule for living areas is evening only, with 49% and 33% of households heating living areas on weekdays and weekends respectively. Most households (71%) report the same weekday and weekend living room heating schedule. Of those that change heating schedules in the weekend, most extend it to include an additional period – most often daytime heating. The most common change is to increase from evening only to the daytime/evening heating, which is used by only 3% of households during weekdays, but 13% during weekends.

19% and 13% of households heat living areas on weekdays and weekends respectively during the morning and evening only. Many households switch to 'all day' heating during the weekend.

About 10% of households heat living areas 24 hours a day. 9% do not heat during the evening, and of these 7% and 10% heat 'all day' (all but the 'night' time) on weekdays and weekends, with many households shifting to this pattern at the weekend.

Other rooms are less likely to be heated than the living room. More than 50% of households do not heat bedrooms, and most (86%) have the same heating pattern during weekdays and weekends. Only 19% of households heat bedrooms overnight.

The schedules are weakly related to household occupancy. Houses are usually only heated during the day if someone is at home (8 of 9 households heated during the day), but most houses that have people at home during the daytime (75%) are not heated during the daytime.

Most households do not heat utility rooms. These results suggest that household heating is strongly zoned.

Room	**Living**		**Bedroom**		**Utility**	
Weekend/Weekday	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
Evening	49	33	25	20	13	5
Morning and evening	19	13	10	7	0	0
24 Hours	10	11	6	6	5	0
All day	7	14	0	4	0	0
None	3	6	40	46	71	84
Morning only	3	4	6	4	0	1
Daytime/evening	3	13	1	3	2	2
Night only	1	1	4	4	1	0
Night/morning	2	2	1	1	4	2
Evening/night	3	2	7	5	1	0
Not daytime	1	0	0	0	3	5
Not morning	1	2	0	1	1	2

Table 33: Percentage of households using various heating schedules

		7 am - 9am	9 am - 5 pm	5 pm - 11 pm	11 pm - 7 am
Bedrooms	Weekdays	25%	9%	48%	19%
	Weekends	25%	16%	47%	19%
Living areas	Weekday	43%	19%	91%	15%
	Weekends	44%	39%	86%	16%
Utility areas	Weekdays	15%	10%	26%	7%
	Weekends	18%	15%	20%	8%

Table 34: Percentage of households reporting heating by location & time

Figure 45 provides an overview of the winter (June through August) evening (5 pm to 11 pm) living room average temperatures in the randomly selected houses. As the curve shows, this follows the normal (bell shaped) distribution, with an average temperature of 17.3°C and a standard deviation of 2.1°C. Thirty percent of the average temperatures are below 16°C.

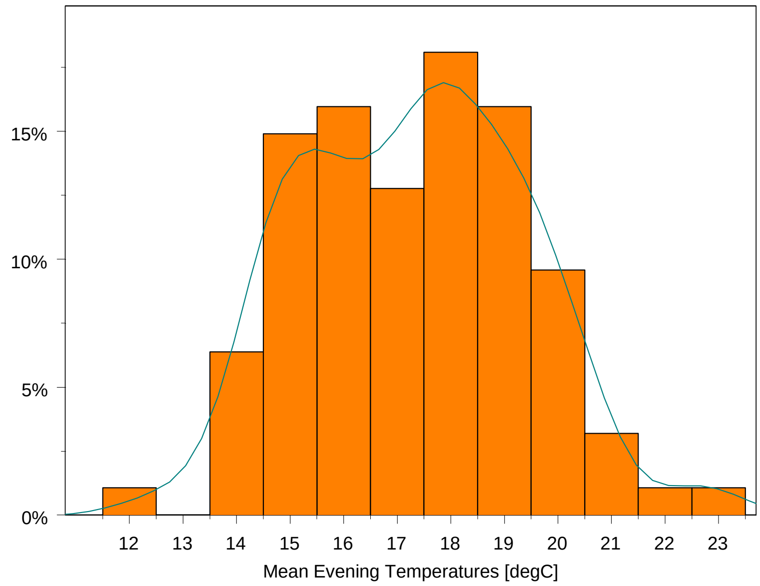

Figure 45: Winter evening living room average temperature distribution

9.2 Descriptive statistics

The following section provides descriptive statistics of the monitored houses, based on occupant responses to the HEEP survey.

9.2.1 Incomes

Table 35 provides the HEEP income groupings. (Note that this is based on the Census 1996 division and not the Household Economic Survey decile divisions used in Table 42.)

Code	Annual income	Weekly income	Code	Annual income	Weekly income
1	up to $5,000 per yr	less than $96	8	$40,001 - $50,000;	$769 - $961
2	$5001 - $10,000;	$96 to $191	9	$50,001 - $60,000;	$962 - $1153
3	$10,001 - $15,000	$192 - $287	10	$60,001 - $80,000;	$1154 - $1538
4	$15001 - $20,000;	$288 - $384	11	$80,001 - $100,000,	$1539 - $1923
5	$20,001 - $25,000;	$385 - $480	12	over $100,000	$1924 or over
6	$25,001 - $30,000;	$481 - $576	13	wouldn't say	
7	$30,001 - $40,000;	$577 - $768			

Table 35: HEEP Survey income groups & codes

Figure 46 gives the income distribution for all houses.

Income	Percentage
up to $5,000 per yr	0
$5,001 - $10,000	1.3
$10,001 - $15,000	1.9
$15,001 - $20,000	4.5
$20,001 - $25,000	3.9
$25,001 - $30,000	2.6
$30,001 - $40,000	5.0
$40,001 - $50,000	15.6
$50,001 - $60,000	14.2
$60,001 - $80,000	17.4
$80,001 - $100,000	14.1
over $100,000	15.1
wouldn't say	4.5

Table 36: HEEP income distribution

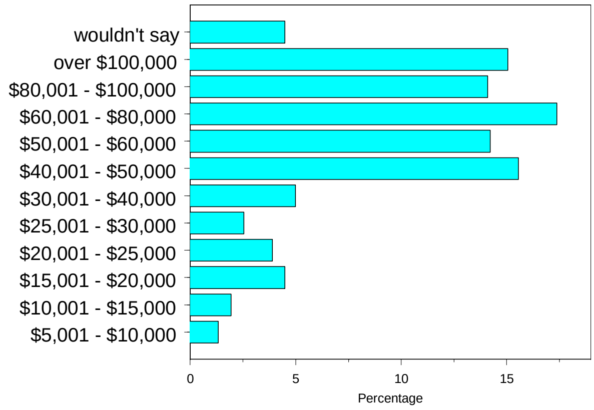

Figure 46: HEEP income distribution to date

9.2.2 Household type

Table 37 lists the coding used in HEEP for the different household types, and the proportions of each family type from the 2001 Census (Table 8, Statistics 2002b). There were a total of 1,344,270 households included in the 2001 Census. The HEEP sample currently has a higher proportion of one-family households (with or without others), and a lower proportion of one-person households than found in the Census. Figure 47 provides a histogram of the percentages of each type for randomly selected HEEP houses.

HEEP – Auckland, Hamilton, Wellington			2001 Census - All NZ		
Code	Household Description	%	Household description	%	Count
1 & 2	1 family	83%	1 family (with or without others)	69%	909,084
3	>1 family household	4%	>1 family household	2%	28,440
4	Non family	7%	Multi-person household	5%	70,434
5	1 person	6%	One-person household	23%	307,635
			Not identified		28,677

Table 37: Household composition – HEEP and 2001 Census

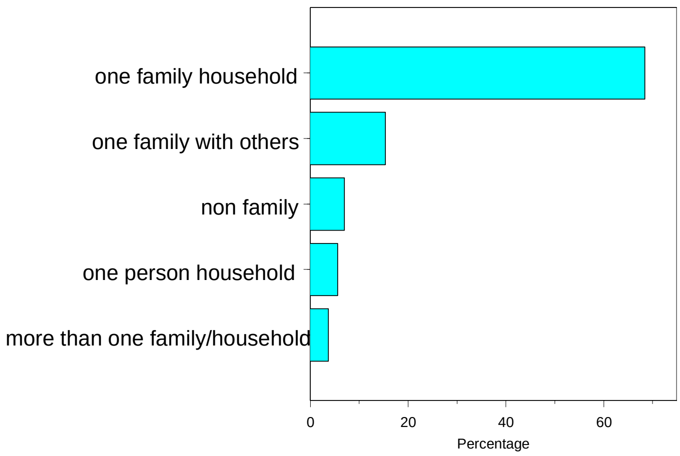

Figure 47: HEEP household types

9.2.3 Tenure

Table 38 lists the survey house tenure codes with the HEEP and 2001 Census proportions. These codes are used in Table 39 to describe the tenure distribution across the current sample of the randomly selected HEEP houses monitored up to 2001, which includes Wellington, Hamilton, and the first year of Auckland monitoring. The HEEP house numbers have been scaled by the appropriate regional strata weightings (derived from the 1996 Census) so that the figures are directly comparable to those from the Census. Note that Manukau and Waitakere have lower rates of mortgage-free ownership than the other locations.

HEEP code	Description	HEEP Strata weighted	2001 Census
1	Occupants own dwelling with mortgage	54%	34%
2	Occupants own dwelling without mortgage	23%	31%
3	Occupants rent/lease dwelling	23%	31%
4	Other	0%	5%

Table 38: HEEP Occupancy for completed houses with complete surveys

HEEP Code	Auckland Region	Auckland City	Manukau City	North Shore City	Waitakere City	Hamilton	Wellington
1	56%	47%	67%	45%	75%	53%	48%
2	20%	26%	0%	36%	12%	29%	29%
3	24%	26%	33%	18%	12%	18%	24%

Table 39: HEEP house occupancy by city/region

9.2.4 Number of people home during the day

Figure 48 gives the number of adults at home during the day and Figure 49 gives the number of children home during the day, in the HEEP houses.

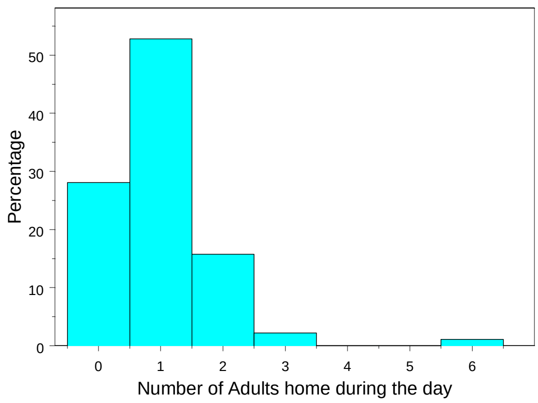

Figure 48: Adults home during the day

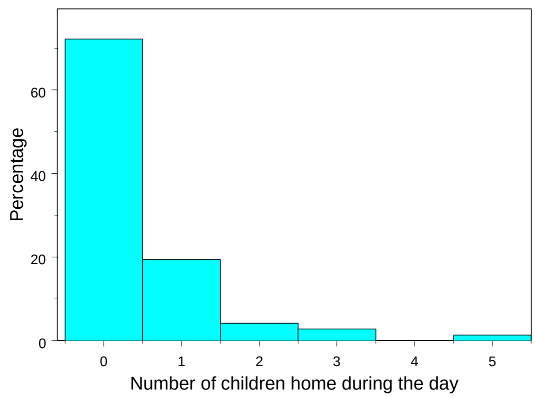

Figure 49: Children home during the day

9.2.5 Year houses were built

Figure 50 gives the decade that the house was built, based on the HEEP survey results. This is not dissimilar in distribution to the total NZ housing stock, except houses from the 1970s and 1980s are under represented.

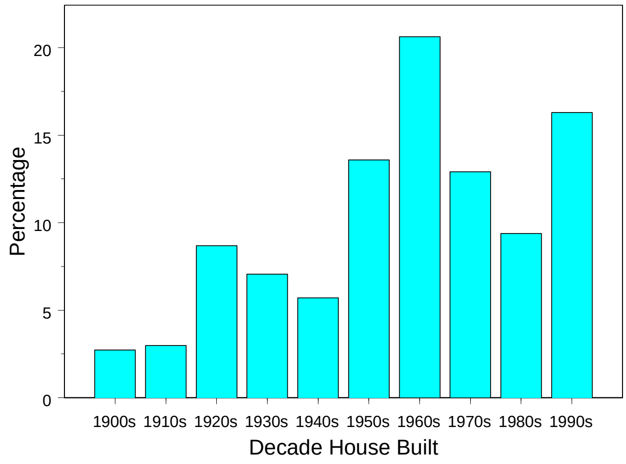

Figure 50: Decade of building (all houses)

9.3 Correlations

There are significant correlations between mean winter evening temperatures and:

- the region,
- the house age, and
- presence of insulation.

No correlation has been found between the winter evening temperatures and:

- household income, or
- the house floor area.

9.3.1 Region

Figure 51 shows that the Hamilton temperatures are significantly higher than either the Auckland or Wellington. The differences in average temperatures between the regions are significant at the 95% confidence level (Anova model: F statistic 4.7 on 2 and 94 degrees of freedom, Pr(F) = 0.012).

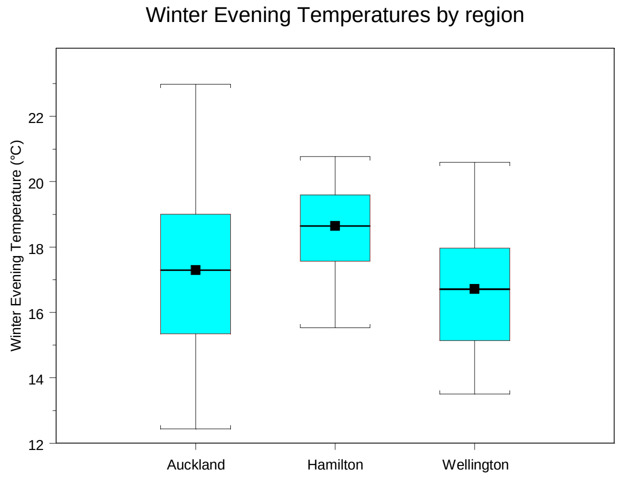

Figure 51: Mean temperatures by region

9.3.2 House Age

There is a very strong relationship between the age of the house and the winter temperatures. Figure 52 shows this relationship by the decade the house was built. Older houses tend to be colder, with an average rate of 0.33±0.08°C per decade. This result has a very high statistical significance (F-statistic: 15.5 on 1 and 93 degrees of freedom, the p-value is 0.00016).

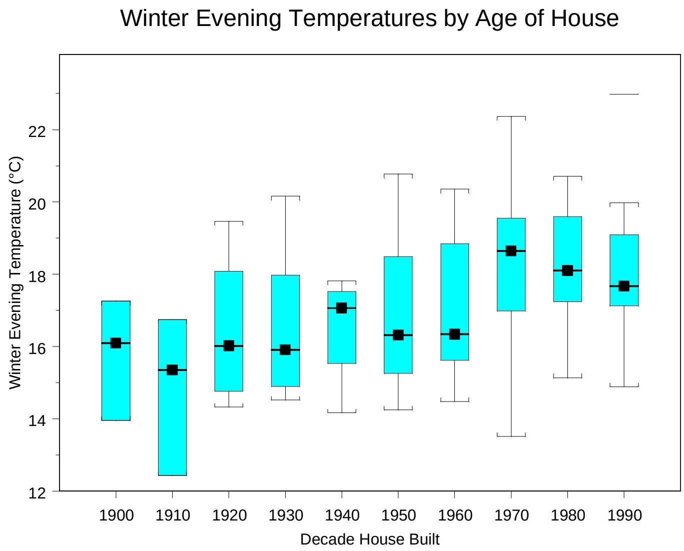

Figure 52: Winter evening temperatures by year house built

Houses built after 1978 were required to exceed a minimum level of insulation, whereas older houses were not required to have any insulation at all. Figure 53 shows how the winter temperatures vary in houses built between the pre-1978 (no insulation), and post-1978 (insulated) requirements.

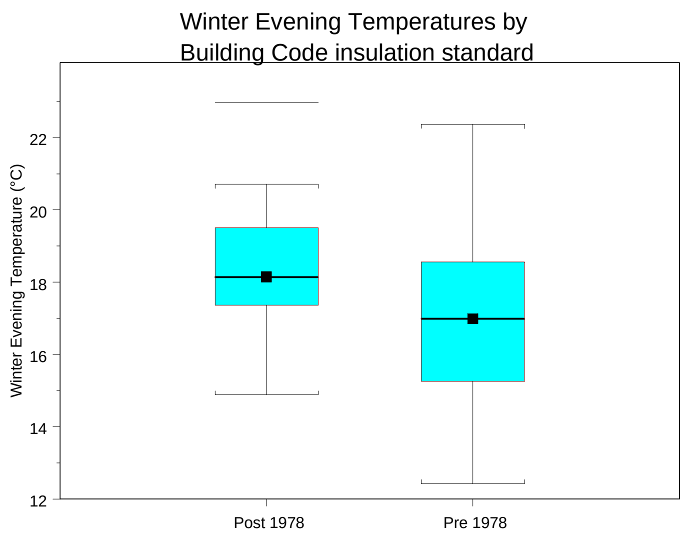

Figure 53: Winter evening temperatures by insulation requirements.

The temperature, energy (excluding solid fuels) means and population standard deviations are tabulated in Table 40. These indicate that there is a highly significant difference between the temperatures in pre-1978 and post-1978 houses, with the older houses being on average 1.4°C colder.

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, 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 not statistically significant with the current analysed sample size of approximately 100 houses.

Insulation group	Average winter evening temperature	Winter evening energy use
Pre-1978	17.0 ± 0.2°C	1070 ± 280 W
Post-1978	18.4 ± 0.4°C	1130 ± 150 W

Table 40: Winter evening temperatures and energy use by insulation level

Currently, we can conclude that post-1978 houses are 1.4°C warmer on average and that their winter evening energy use is not significantly different from the pre-1978 houses.

9.3.3 Income and floor area

There was no correlation found between household income and winter evening temperatures (Figure 54), or between winter evening temperatures and house floor area (Figure 55). It should be noted that while there is no correlation between these factors, other factors could mask a possible correlation.

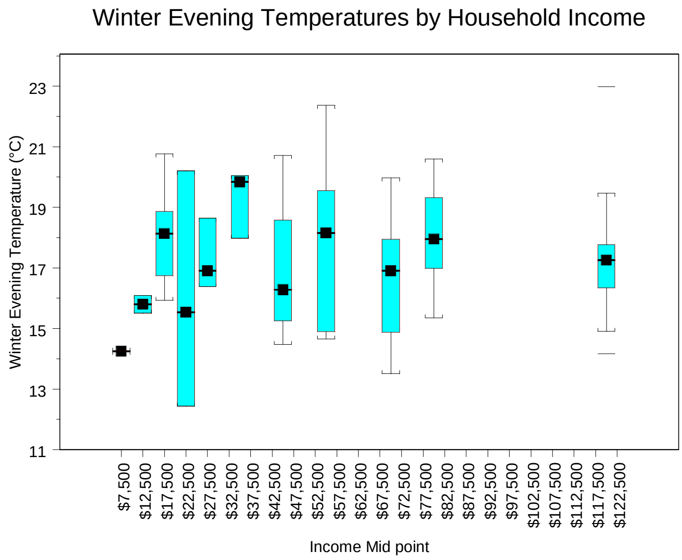

Figure 54: Winter evening temperatures by income midpoint

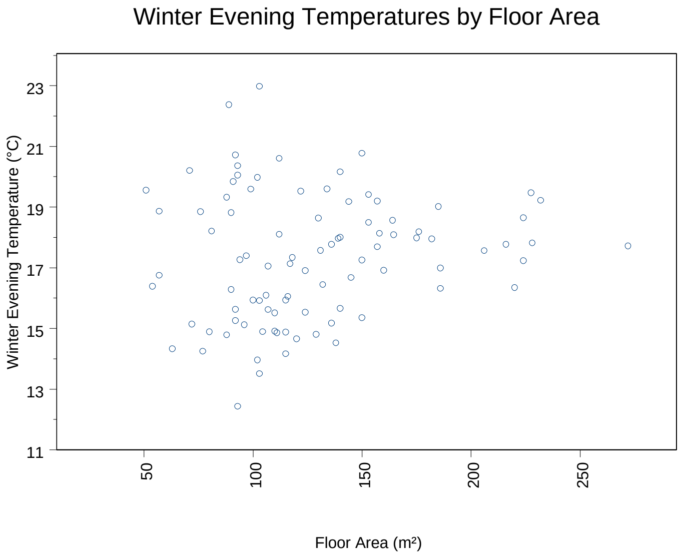

Figure 55: Winter evening temperatures vs. floor area

9.3.4 Presence of insulation

Houses with floor insulation are 0.9°C warmer than those without (Figure 56). Houses with roof insulation are 0.9°C warmer than those without (Figure 57). Both of these effects are significant at the 95% confidence level.

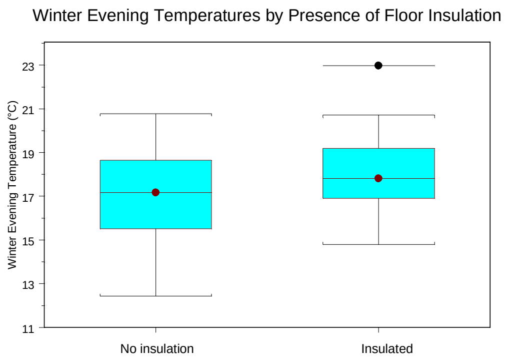

Figure 56: Winter evening temperatures by presence of floor insulation

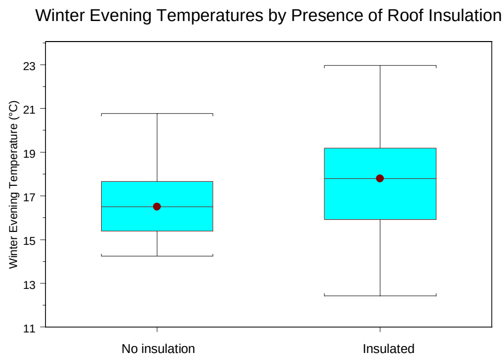

Figure 57: Winter evening temperatures by presence of roof insulation

10. EXPENDITURE AND TEMPERATURES

It has been argued that energy prices in New Zealand are too low to encourage interest in energy efficiency. This section examines the cost of energy in New Zealand and, through analysis of Statistics NZ's regular "Household Economic Survey", the patterns of expenditure on energy in comparison to other household costs. A brief international survey of household expenditure on energy provides further comparison. The results of this analysis will then be compared to the preliminary results of the HEEP monitoring in the next section.

This section builds on an earlier paper which examined the HES 1987 - 1997 (Isaacs 1998).

10.1 New Zealand energy costs

Official statistics (MED 2002) and political statements (e.g. Franks 2001[xiv], Hodgson 2002[xv]) regularly re-enforce the belief that New Zealand has amongst the lowest electricity prices for both industrial and residential users in the main OECD countries.

Figure 58 (MED 2002) provides a price comparisons in New Zealand dollars per GigaJoule (1GJ = 278 kWh). Of the eight countries, New Zealand is ranked 5th for gas and 6th for electricity costs. It should be noted that the data in Figure 58 is not necessarily all for the same year, and that product specifications and statistical methodology vary across the different countries. The data for Australia and Japan is for the 1997 calendar year.

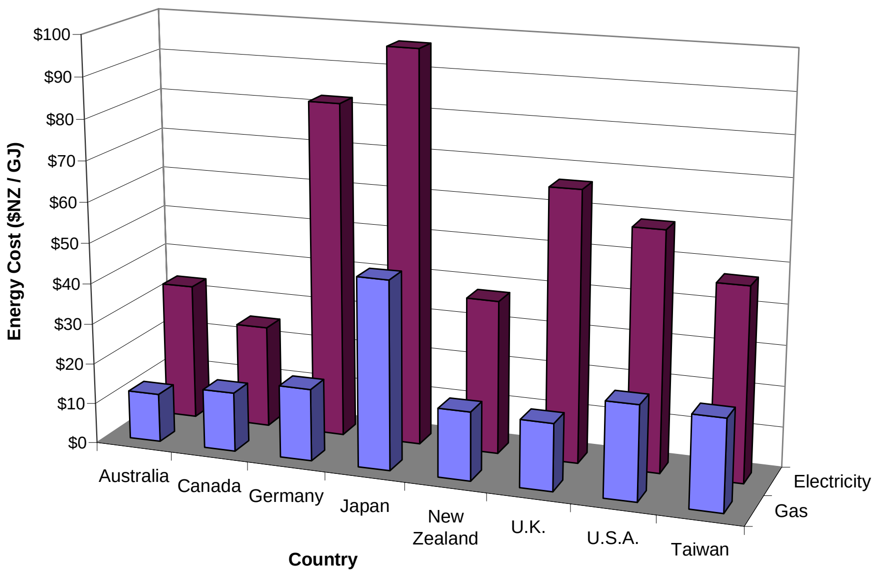

Figure 58: International comparison of domestic energy prices

But does a relatively low cost for energy necessarily result in high energy use? To find out it is necessary to examine the patterns of expenditure in New Zealand houses.

[xiv] "…a market which doesn't reward consumers for saving scarce power, is no market at all"

[xv] "One of New Zealand's competitive advantages over other developed nations is cheap electricity, but – probably because it is cheap – we have not been very efficient with it. Under the Kyoto Protocol our power will still be cheap, but there will be new incentives to make more efficient use of it."

10.2 Household expenditure

Statistics NZ has carried out a regular Household Economic Survey (HES) since 1973, although the name has changed over the years (Statistics NZ 1997). Although originally intended to provide statistics on the expenditure patterns of private households, it has expanded to cover the fields of household income, and social and demographic information. From 1 July 1973 to 1998 the HES was conducted annually, switching to an April-March year from April 1975 until 1997/98. It has now moved to a three-yearly cycle, and reverted to a July-June year, starting with the 26th survey undertaken in the 2000/01 year (Statistics NZ 2001a).

Data for this report have been obtained from the Statistics NZ INFOS database (Statistics NZ 1998), pre-prepared tables in electronic form for 1997/98 (Statistics NZ 1999) and the electronic version of the 2000/01 printed report (Statistics NZ 2001a, 2001b). Unless stated otherwise, all values refer to the 2000/01 HES.

10.3 Household Economic Survey

The HES provides data on a wide range of household expenditure, grouped into eight commodity "parent" groups, as listed in Table 41. Data on up to 2,316 items, along with information on the household, are collected through a detailed survey interview and a householders' diary. The diary is completed by each household member over 15 years of age, and includes all expenditure for 14 consecutive days, major expenditure from the previous 12 months, and income and employment data.

Commodity group	Items	Sub-group examples	Sample error
Food	606	Fruit, vegetables, meat	3%
Housing	160	Rent, capital, mortgage, rates	5%
Household operation	358	Energy, appliances, furniture, supplies	3%
Apparel	218	Clothing, footwear	7%
Transportation	159	Public, overseas, vehicles	6%
Other goods	410	Tobacco, alcohol, pets, leisure	4%
Other services	259	Health, education, legal, savings	6%
Refunds, sales and trade-ins	120	Refunds, sales, trade-ins	NA

Table 41: HES coverage 2000/01

Table 41 also provides the 'Sample Error' for each commodity grouping. In general, the higher the percentage of surveyed households which contributed to an expenditure statistic, the more statistically reliable that expenditure statistic. This is an issue for "Housing", where in some sub-groups a small proportion of households report expenditure, e.g. in the 2001 survey, 30% of all households reported expenditure on rent and 31% on mortgage payments.

The HES does not provide estimates of response errors or other non-sampling errors; although it is known that expenditure on some items (such as tobacco, alcohol, meals away from home, and food such as ice-cream) tend to be understated. GST, which was introduced in 1986 at 10% and increased to 12.5% in 1989, is included in all expenditure statistics.

Incomes reported to the HES may also be understated, as not all income is necessarily reported. The Family Support tax credit was introduced in 1986, and along with other tax-based support payments, has been changed at various times in the period 1986/67 to 1996/97.

The results from the HES can be analysed using a range of different socio-economic variables. The household 'Income' is defined as the total gross regular income reported by the household, while the 'Expenditure' is made using after-tax income. Income can be negative or zero (e.g. more money went out of the house than was received in that year), and includes wages, salaries, self-employed income, social welfare benefits and investment income. Income groups are based on tenths (deciles) of the total number of households — approximately one tenth (10%) of all households will be in each income decile.

Decile	2000/01 income	Decile	2000/01 income
1	Under $14,900	2	$14,900 to $20,699
3	$20,700 to $25,899	4	$25,900 to $32,399
5	$32,400 to $40,599	6	$40,600 to $51,099
7	$51,100 to $62,299	8	$62,300 to $76,699
9	$76,700 to $101,099	10	$101,100 or more

Table 42: 1996/7 Household income deciles

Table 42 provides the income decile ranges for the 2000/01 HES. It can be seen that both the bottom (1st decile) and the top (10th decile) income groups are not bounded. Careful adjustment of self-employed income can also result in households with a comparatively high real income falling into the lowest income decile. Thus, for the purposes of the following sections, analysis is mainly based on the 2nd and 9th income deciles.

10.4 Expenditure over time

As the HES is conducted on a regular and consistent basis, it is possible to compare changes in expenditure patterns over time. Although the analysis reported in this paper has been carried out for the 14-year period 1986/87 to 2000/01, comparisons are only made between the end periods. The differences which are examined for these two end-periods can be traced through the annual HES to show that there is a real trend rather than a simple anomaly.

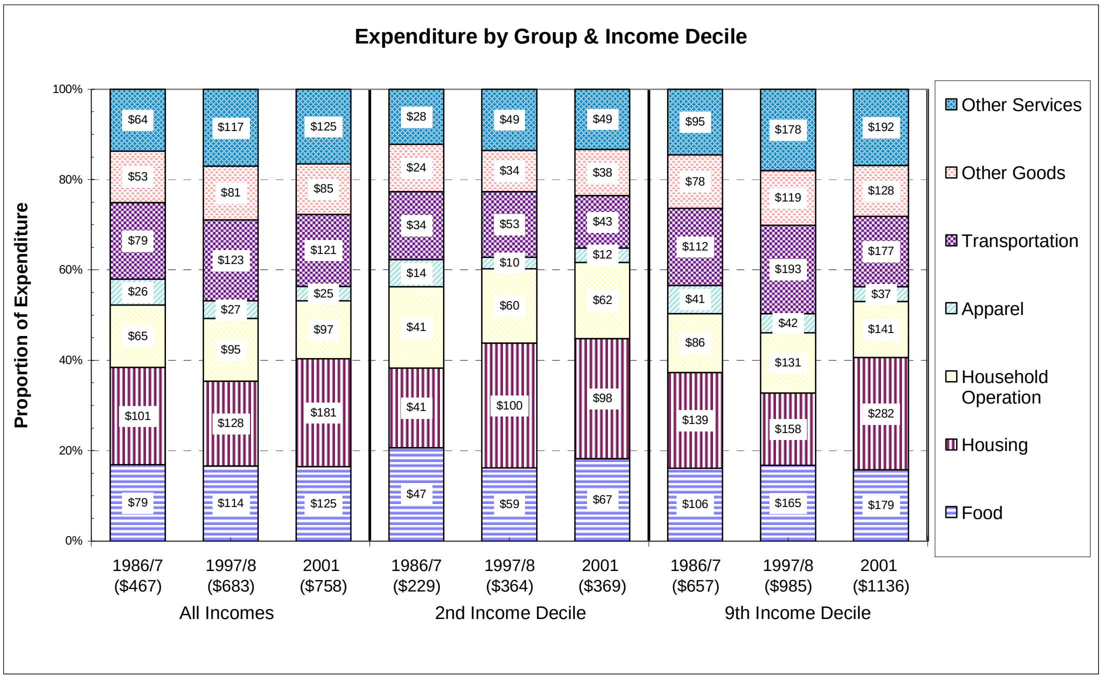

Figure 59: Household expenditure by commodity group & income

Figure 59 compares expenditure by commodity group for the 1986/87, 1997/98 and 2000/01 HES for the summary of all 10 income deciles, the 2nd decile and the 9th decile. The total weekly expenditure is given in dollars-of-the-day (in brackets) below year.

Table 43 shows that across all incomes, the proportion of expenditure spent on each of the major groups has remained largely constant except for:

- **Housing** which fell from 22% in 1986/7 to 19% in 1997/8 and has risen to 24% in 2000/1
- **Apparel** which fell from 6% (1986/7) to 4% (1987/8) and down to 3% in 2000/1
- **Other services** which increased from 14% (1986/7) to 17% for both 1987/8 and 2000/1.

	All incomes			2nd decile			9th decile		
Commodity group:	1986/7	1997/8	2000/1	1986/7	1997/8	2000/1	1986/7	1997/8	2000/1
Food	17%	17%	16%	21%	16%	18%	16%	17%	16%
Housing	22%	19%	24%	18%	28%	27%	21%	16%	25%
Household operation	14%	14%	13%	18%	16%	17%	13%	13%	12%
Apparel	6%	4%	3%	6%	3%	3%	6%	4%	3%
Transportation	17%	18%	16%	15%	14%	12%	17%	20%	16%
Other goods	11%	12%	11%	10%	9%	10%	12%	12%	11%
Other services	14%	17%	17%	12%	14%	13%	15%	18%	17%
All groups	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 43: Proportion of expenditure by group and income decile

Table 43 also shows that a slightly different picture emerges with the changes for the 2nd and 9th deciles over the 14-year period:

For the 2nd income decile:

- Decreases: **food** has decreased from 21% to 18%, **apparel** from 6% to 3%, and **transportation** from 15% to 12%.
- Constant: **household operation** (-1%), **other goods** (0%) and **other services** (+1%).
- Increases: **housing** increased from 18% to 28%.

For the 9th income decile:

- Decreases: **apparel** has decreased from 6% to 3%.
- Constant: **food** (0%), **household operation** (-1%), and **transportation** (-1%), **other goods** (-1%) and **other services** (+2%).
- Increases: **housing** increased from 21% to 25% (although there was a fall of 5% between 1986/7 and 1997/8).

The overall group expenditures are based on a weighted average of all expenditures reported in each income decile. For example, in 2000/1 nearly all (98%) households reported expenditure on the housing group, but only 30% reported expenditure on the rent sub-group, and 31% on the mortgage sub-group. Thus, the HES average house is unlikely to be matched to any real household. In order to understand the changes occurring in expenditure, it is necessary to limit the analysis to those households actually reporting the specific expenditure.

Household energy is included in the HES “fuel & power” sub-group, and is included in the “household operation” group. The other “energy” related aspect of household expenditure is “Fuel for road vehicles” which is included in the “Transportation” group.

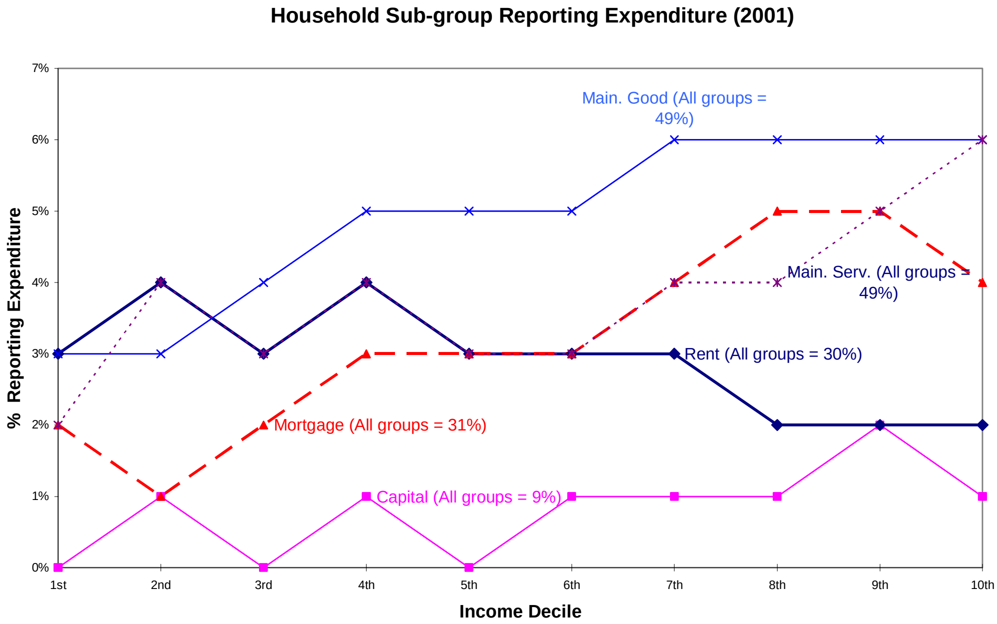

Figure 60: Housing sub-group reporting expenditure by income decile

Figure 60 shows the proportion of households reporting expenditure by expenditure decile for selected housing sub-groups, and in brackets shows the proportion across the entire sample, e.g. 49% of all households report maintenance expenditure (an average of 4.9% per decile). However, only 2% in decile 2 report this expenditure whereas 6% of households in decile 10 report this expenditure. In each year almost all houses in each decile (i.e. 10%) report expenditure on energy, and thus this is not given in Figure 60.

For example, Figure 60 shows that as income **increases**, the proportion of households reporting expenditure on rent **decreases**, but the proportion reporting expenditure on mortgage **increases**.

These proportions have remained within the rounding error (a reported 1% is rounded from actual proportion of between 0.5% and 1.5%) over the period, i.e. there does not appear to have been a sizeable increase or decrease in the proportions for the different deciles. For the purposes of analysis, deciles reporting expenditure of 1% or less in any sub-group are excluded from analysis.

The HES data are reported as an average over the specific decile. Thus, unless the sub-group is the subject of expenditure in all of the houses in a particular decile (i.e. if 10% report expenditure), it is necessary to use the proportion reporting to calculate the average expenditure in the houses which do make that expenditure. For example, in both the 2nd and 9th deciles "Energy" expenditure is reported in all houses, but as shown in Figure 60, "Rent" expenditure is reported in 3% of the 2nd decile but in only 2% of the 9th decile. The HES for 2000/1 reported "average weekly" rent expenditure of $52.10 for the 2nd decile and $42.90 for the 9th decile. This appears to suggest that lower income houses actually spent more on rent than higher income households. However, if only the households that actually spent money on rent are considered, their average expenditure was $130.30 and $214.50 respectively – this fits with the expectation that higher income households would more expensive rental accommodation.

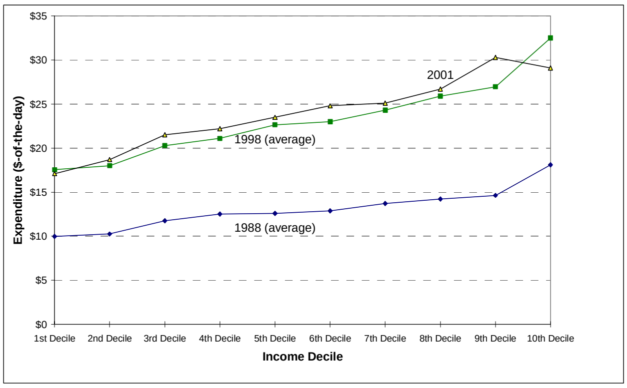

Figure 61: "Fuel & power" expenditure

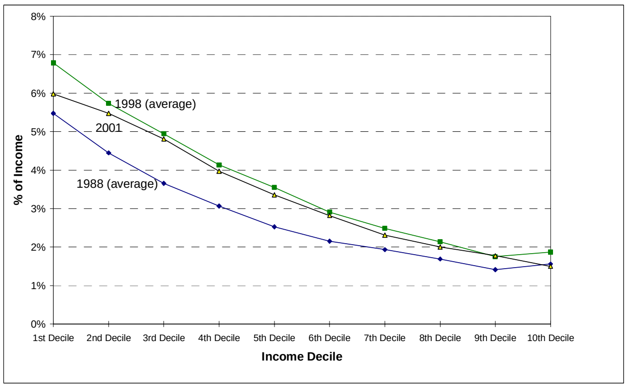

Figure 62: "Fuel & power" as % of income

In the period June 1987 to June 2001 the Consumer's Price Index increased by 45%, and thus it would be expected that dollars-of-the-day expenditure on the various aspects of household operation would also increase, all other things being equal. In order to avoid this issue, the analysis presented here is based on the proportion of expenditure, as this is always calculated from the dollars-of-the-day.

Figure 61 presents the "fuel & power" component of household expenditure, the expenditure per week in dollars-of-the-day (i.e. including inflation) by income deciles. For the purpose of the graph, the points for 1988 are the average of 1986/7 & 1987/8, and for 1998 are the average of 1996/7 & 1997/8. It can be seen that expenditure does increase from 1987 to 2001, but the increase is smaller for the higher income deciles.

Figure 62 compares the proportion of expenditure spent on "fuel & power", and again although the proportion has increased for all deciles, the greatest increase (and absolute proportion of expenditure spent on energy) is for the lower deciles.

Table 44 compares expenditure for the 2nd and 9th income Deciles between the 1986/7, 1996/7 and the 2001 surveys. Examination of the time-series data showed that although there was a consistent trend over the period, the small proportions of households reporting some expenditures results in fluctuations between years. Table 44 weekly expenditures by sub-group are thus based on the average over two years (i.e. 1985/86 and 1986/87, and 1995/96 and 1996/97 respectively).

	Energy			Rent			Mortgage			Maintenance goods			Maintenance services		
	1987	1998	2001	1987	1998	2001	1987	1998	2001	1987	1998	2001	1987	1998	2001
Expenditure in $-of-the-day / week (averaged over 2 year for 1987 & 1997 only)															
2nd decile	9.80	18.00	18.70	51.90	142.50	130.30	61.52	120.50	113.00	13.30	14.80	16.00	23.27	41.30	54.00
9th decile	14.00	26.95	30.30	83.11	169.75	214.50	104.77	240.00	396.80	26.27	47.30	51.70	54.26	120.50	166.00
Ratio 2nd:9th	1.4	1.5	1.6	1.6	1.2	1.6	1.7	2.0	3.5	2.0	3.2	3.2	2.3	2.9	3.1
Expenditure as proportion of expenditure															
2nd decile	4.4%	5.7%	5.5%	23.6%	45.2%	38.2%			37.2%	6.0%	4.7%	5.9%	10.6%	13.1%	10.5%
9th decile	1.4%	1.8%	1.8%	8.4%	11.1%	12.6%	10.6%	15.6%	16.3%	2.6%	3.1%	2.6%	5.5%	7.8%	6.2%
Proportion of total sample reporting expenditure															
2nd decile	10%	10%	10%	3%	4%	4%	1%	1%	1%	4%	4%	3%	3%	3%	4%
9th decile	10%	10%	10%	2%	2%	2%	6%	5%	5%	8%	7%	6%	5%	5%	5%

Table 44: Expenditure and income

The ratios between the expenditures for each sub-group given in Table 44 allow a comparison to be made of the proportion of expenditure spent on each HES group (or sub-group) between the income groups across time (without the need to adjust the expenditure for inflation).

For the 2nd income decile over the 14-year period 1987 to 2001:

- Constant: **maintenance goods** proportion of expenditure remained constant, and although over the entire period **maintenance services** was constant, there was an increase from 10.6% in 1987 to 13.1% in 1998, falling back to 10.5% in 2001.
- Increases: **energy** increased from 4.4% to 5.5% of income and r**ent** increased from 23.6% to 38.2%.

For the 9th income decile:

- Constant: **energy**, **maintenance goods** and **maintenance services** remained constant**.** However, as in 2nd income decile, **maintenance services** showed an increase from 5.5% in 1987 to 7.8% in 1998, falling back to 6.2% in 2001.
- Increases: **rent** and **mortgage** both showed an increase in the proportion of expenditure.

Please note that the small numbers of households (1% or less) in the 2nd decile reporting expenditure on **mortgage** limits the comparisons possible for this expenditure sub-group. In the 9th decile, one half of the houses (5%) report expenditure on a Mortgage.

Over the 14 years, the proportion of expenditure spent on **energy** increased in the 2nd income decile, but not in the 9th income decile. For all other of the expenditure areas considered in Table 44 the proportion of expenditure increased in the same direction for the 2nd and 9th decile, except for **maintenance services.** Spending in this sub-group remained constant for the 2nd decile while the 9th decile expenditure as a proportion of expenditure increased from 5.5% to 6.2%.

Table 44 also shows that while household energy expenditure increases with income, the size of the increase in expenditure does not match the size of the increase in income. Table 45 gives the annual income for the 2nd and 9th decile for the 1987, 1998 (not averaged) and 2001 HES, along with the weekly expenditure on energy.

	Annual income mid-point			Weekly expenditure on energy		
Year	**2nd decile**	**9th decile**	**2nd :9th**	**2nd decile**	**9th decile**	**2nd : 9th**
1987	$11,500	$51,000	343%	$9.80	$14.00	43%
1998	$16,900	$82,350	387%	$18.00	$26.95	50%
2001	$17,800	$88,900	399%	$18.70	$30.30	62%

Table 45: Proportion of expenditure spent on energy by income decile

Table 45 shows that in 2000/1 the 2nd Decile income averaged $17,800 (see Table 42 for the range), with a weekly energy expenditure of $18.70, while the 9th Decile income averaged $88,900, with weekly energy expenditure of $30.30 - a 400% increase in income but only a 60% increase in energy expenditure.

Table 45 also shows that although the ratio between the 2nd and 9th income deciles has widened by 56% over the 14 years, the ratio between the energy expenditures has increased by only 19%. In 1986/7 there was a 340% increase in income between the 2nd and 9th deciles and a 40% increase in expenditure on energy. By 1997/8 the difference in incomes was 390% but the energy expenditure was 50% greater, and in 2000/1 the income difference was 400% with energy expenditure 60% greater.

As noted in Section 1.3 (page 3), HEEP is a 'snap-shot' study, which looks at each individual household for a maximum of one year. The HES is also a 'snap-shot' study, examining each individual household in the sample for approximately two weeks. There are currently no New Zealand longitudinal studies of energy use that could show whether changing income results in changed energy expenditure.

From a building research viewpoint, this difference in levels of expenditure on household maintenance also raises concern. The BRANZ House Condition Survey (Page et al. 1995) was first carried out in 1993/94. It found that houses each had on average over $3,800 of outstanding maintenance - but as with any average there will be many houses with more or less maintenance required (Page et alia. 1995). The 1999 House Condition Survey (Clark et al. 2000) found an average of $4,000 worth of outstanding maintenance, with house owners spending less than half that amount - around $1,500 per year – on maintenance. For comparison, the 1997/8 HES reported that for all households reporting expenditure on **maintenance goods** the annual expenditure was $1,517 and for **maintenance services** $4,781 per year.

10.5 International comparisons

The previous section has examined household expenditure in New Zealand, with a particular focus on energy expenditure. How does New Zealand compare with selected other countries?

10.5.1 Household energy use

Table 46 gives the household energy use per household, and it can be seen that the wide range is not solely related to temperature. Each country varies considerably in the amount of energy each person uses at home. This variation is a combination of many factors, such as climate, house size, household size, comfort levels, energy efficiency and energy prices.

Country	GJ/house	Year	Energy data reference
New Zealand	43	2000	EECA (Pers. Com. 2002) (see Figure 3)
Australia	59	1993/4	ABS 1997
UK	80	2000	DTI 2002
US - average	96	1997	EIA 1999
Canada	143	1997	CREEDAC 2001

Table 46: Household energy per house – international comparison

Figure 63 shows the household energy use per person for OECD countries[xvi], and ranks New Zealand 25th out of 30 countries.

[xvi] IEA data in DTI 2002b - "Section 10. International comparisons of energy production and use."

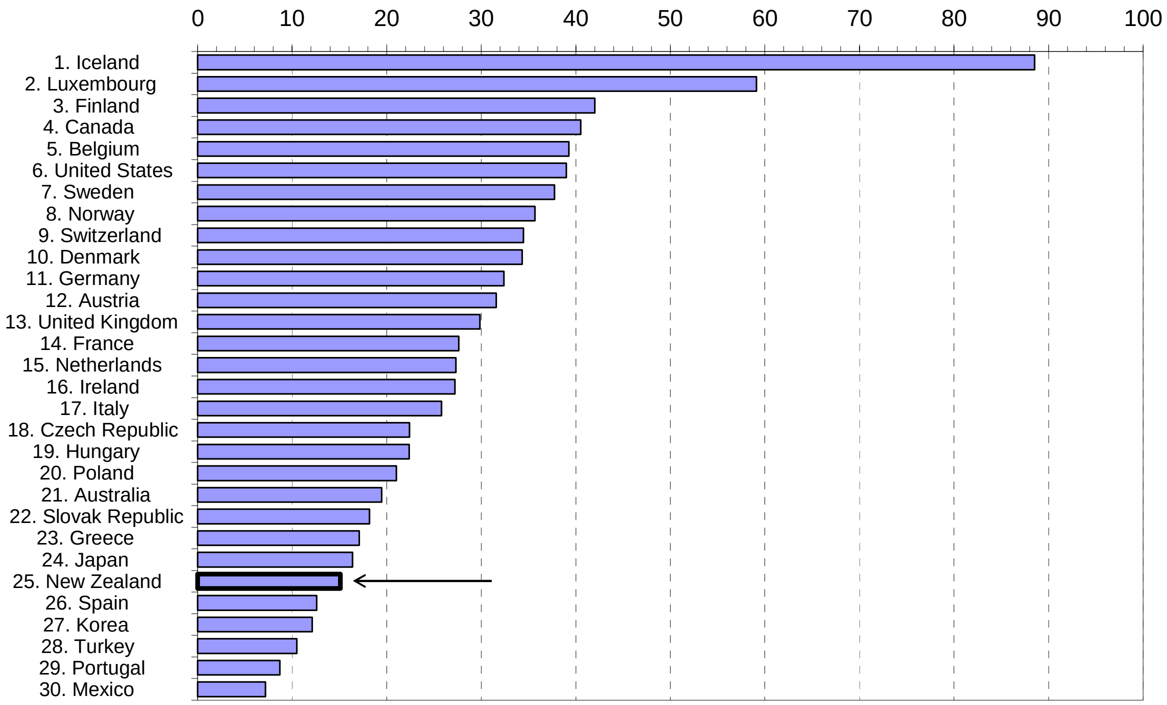

Figure 63: Household energy use per person for OECD countries

Figure 64 compares the household energy use per person (excluding transport) for the G7 major industrialised countries and New Zealand over the period 1980 to 1999[xvii]. Among the G7, those countries with the lowest levels in 1970 have seen increases in energy use per person, most noticeably in Japan and France, as average comfort levels have risen. In contrast the USA and Canada have seen declines in average energy use as energy efficiency measures have taken effect. New Zealand household energy use has slightly increased, although as noted by Schipper (2000), this is most likely due to the low levels of space heating compared to other countries.

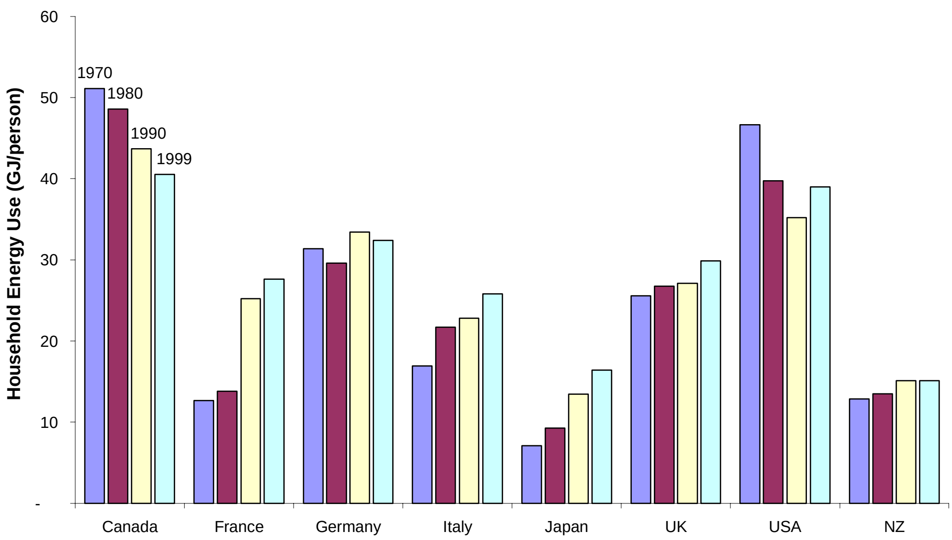

Figure 64: Household energy use per person 1980 to 1999

[xvii] IEA publication "Energy Balances of OECD countries 1960-1999" quoted in DTI 2002b - "Section 10. International comparisons of energy production and use."

10.5.2 Household energy expenditure

The previous section examined New Zealand household energy expenditure as reported in the Household Economic Survey. Similar surveys are carried out for many countries, and this section discusses a limited number of countries for comparison.

It should be noted that the data collection and analysis varies from country to country, and thus the results presented here should be subject to further research. Of particular interest is the way different government-support-mechanisms are handled in the reporting of household expenditure in different countries. For example in the UK, expenditure on ‘housing’ is included in the total household expenditure net of any ‘housing benefit, rebate and allowances received’. It is not expected that government support for individual households is an issue with respect to energy expenditure in any of these countries.

Table 47 compares the proportion of total household expenditure (average weekly or annual) by income decile (10%) or quintile (20%) for the following four countries:

- New Zealand (Statistics NZ 2001a) – by decile for the ‘domestic fuel and power’ sub-group which is part of the “housing operation” expenditure group
- United Kingdom (ONS 2001) – by decile for the ‘fuel and power’ expenditure group
- Australia (ABS 2000) – by quintile for the “domestic fuel and power” expenditure group
- United States of America (Bureau of Labor Statistics 2001) – by quintile for the expenditure items “natural gas”, “electricity” and “fuel; oil and other fuels” which are part of the “utilities, fuels, and public services” expenditure group.

For those countries which do not report the proportions, the percentage of expenditure was calculated from the expenditure on light, heat and power (i.e. stationary, non-transport energy expenditure) compared to the total expenditure for that decile or quintile as appropriate.

In addition, Table 47 gives the annual (all households) proportion of expenditure on “water, fuel and electricity” (part of the “shelter” expenditure group) for Canada for those houses reporting expenditure (Bureau of Statistics – Northwest Territories 2000). 88.9% of Canadian houses reported expenditure, and of those houses which reported expenditure it averaged $CDN 1,712 per year out of a total expenditure of $CDN 51,362. An interesting comparison is that for Yellowknife the proportion spent on “water, fuel and electricity” is 3.7% ($CDN 2,999 out of $CDN 81,105) and for all the Northwest Territories the proportion is 3.5% ($CDN 2,492 out of $CDN 71,196).

For all five countries, the proportion of expenditure on stationary energy (i.e. excluding transport energy) is within the range 2.6% to 3.5%, even for countries expected to require greater indoor temperature control – either due to hot or cold external temperatures. The reasons for this apparently similar proportion of expenditure have not been investigated, but could be due to a range of factors, including energy pricing policies, house thermal performance, occupant expectations or even the expenditure survey methodology. This should be investigated further.

Country	Description	Deciles 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	All households
New Zealand	Domestic fuel & power	6.0%	5.5%	4.8%	4.0%	3.4%	2.8%	2.3%	2.0%	1.8%	1.5%	3.4%
UK	Fuel and power	6.5%	6.7%	5.5%	4.2%	3.6%	3.2%	2.9%	2.6%	2.4%	2.0%	3.1%
		Quintiles										
			1st		2nd		3rd		4th		5th	
Australia	Domestic fuel & power		3.7%		3.3%		2.7%		2.3%		2.0%	2.6%
USA	Nat. gas, elect, fuel oil etc		4.9%		4.4%		3.6%		3.0%		2.4%	3.5%
Canada	Water, fuel, electricity											3.3%

Table 47: Proportion of expenditure on light, heat & power

Figure 65 present the values from Table 47 as a graph. In all four countries the proportion spent on energy decreases with increasing income, with New Zealand and UK showing the largest different (4.5%) between the lowest and highest income groups. This wider range may be due to the use of deciles rather than the larger quintiles.

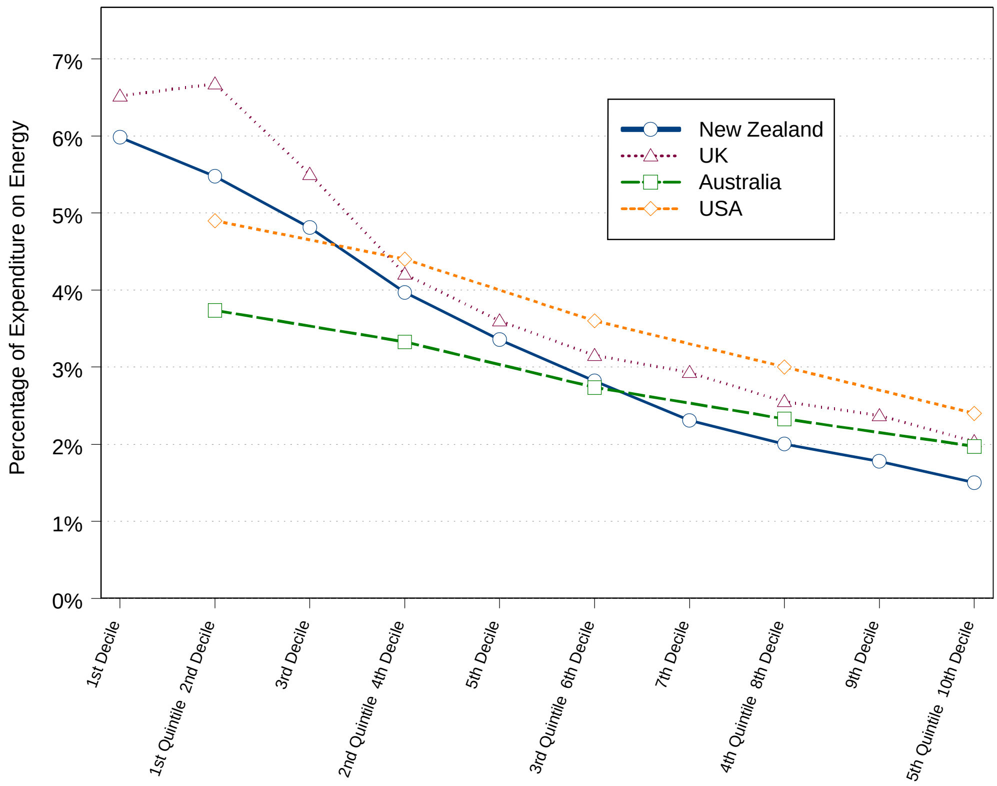

Figure 65: Household energy expenditure percent by country & decile

It is difficult to make comparisions when two of the countries report expenditure in deciles and two in quintiles, so Figure 66 compares only the UK and New Zealand, while Figure 67 combines the decile proportions by simple averaging into quintiles (1^{st} and 2^{nd} decile to give the 1^{st} quintile, etc) to compare the four countries.

Figure 66 compares UK and New Zealand expenditure on energy by income decile. In both countries the proportion of expenditure decreases as income increases.

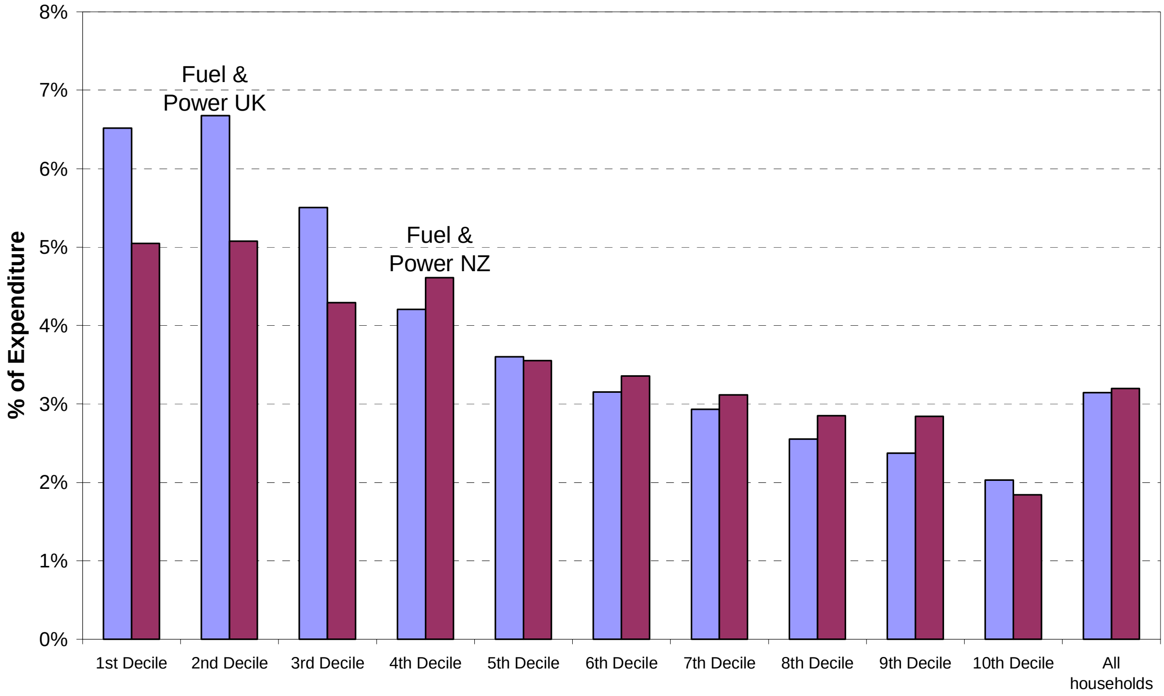

Figure 66: UK & New Zealand percent of expenditure on energy by decile

Figure 67 compares the expenditure for each country by quintile compared to the first quintile. In order to provide a comparison without currency conversion, the calculations were made in the reported currency for each country, as given in Table 48.

Table 48 also gives the expenditure converted into New Zealand dollars, using the average exchange rate for the particular year. When converted to New Zealand dollars, the New Zealand expenditure lies between Australia and the UK.

Country	1st quintile	2nd quintile	3rd quintile	4th quintile	5th quintile	All households
New Zealand (2000/1)	$17.90	$21.85	$24.15	$25.90	$29.70	$23.90
Australia (1998/9)	$6.62	$9.17	$12.46	$16.40	$22.52	$13.44
UK (1999/2000)	£8.80	£10.05	£11.10	£12.20	£14.65	£11.30
USA (1999/2000)	$17.12	$22.37	$24.29	$27.31	$33.65	$25.29
	Convert expenditure to $NZ based on average exchange rate for year[xviii]					
New Zealand (2000/1)	$17.90	$21.85	$24.15	$25.90	$29.70	$23.90
Australia (1998/9)	$7.79	$10.80	$14.68	$19.32	$26.52	$15.83
UK (1999/2000)	$27.25	$31.12	$34.37	$37.78	$45.37	$34.99
USA (1999/2000)	$32.91	$43.01	$46.70	$52.51	$64.71	$48.63

Table 48: Household energy expenditure in local currency & $NZ

Figure 67 shows the greatest range between the lowest and highest income groups occurs in Australia, with New Zealand tracking reasonably closely to the UK, as shown in Figure 66.

xviii Conversion rate data: www.oanda.com/convert/fxhistory. Averaged exchange rate over March year.

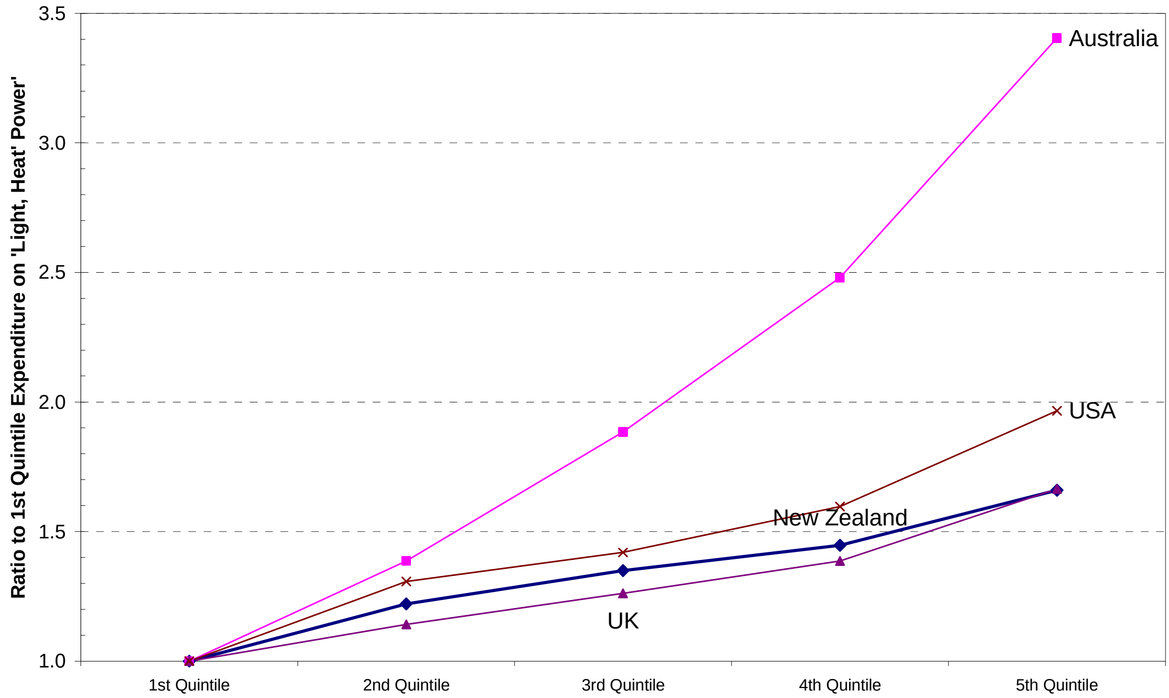

Figure 67: Ratio of expenditure to lowest quintile by country

10.5.3 Fuel poverty

The UK is placing considerable social policy emphasis on 'fuel poverty'. A fuel-poor household is one that cannot afford to keep adequately warm at reasonable cost – defined as needing to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard of warmth (21°C in the living room and 18°C in the other occupied rooms). The UK Fuel Poverty Strategy was launched on 21st November 2001 (DTI 2001). It sets a target for vulnerable households to ensure that by 2010 no older householder, no family with children, and no householder who is disabled or has a long-term illness need risk ill health due to a cold home.

In 1998 approximately 3.3 million households in England were in fuel poverty - more than 1 in 6 households, and over 1 in 30 households were in severe fuel poverty (that is, households which need to spend over 20% of total expenditure on fuel to keep warm). It has been estimated that the number of fuel poor in England has fallen by half a million households between 1998 and 2000 when changes in income and fuel prices are considered. (DTI 2002b)

Income group	1970		1980		1990		1999/00	
	Food	Fuel	Food	Fuel	Food	Fuel	Food	Fuel
Lowest	30.5%	13.0%	28.5%	12.0%	24.1%	10.8%	21.4%	6.6%
Low-mid	28.1%	7.6%	26.4%	7.9%	21.3%	6.5%	19.9%	4.8%
High-mid	26.0%	5.9%	23.5%	5.5%	17.3%	4.1%	16.9%	3.0%
Highest	20.1%	4.6%	18.7%	3.6%	14.4%	2.9%	13.5%	2.0%
Ratio Lowest/highest	1.5	2.8	1.5	3.3	1.7	3.7	1.8	3.7

Table 49: UK percentage of expenditure on food & fuel 1970 - 2000

Table 49 provides information on the proportion of expenditure on food and fuel for UK households divided into income quartiles (DTI 2002b)[xix]. Over time the percentage of

[xix] Data Source: 'Family Expenditure Survey', Office of National Statistics.

expenditure on both food and fuel has fallen for lower income households, the ratio between expenditure on food has remained fairly flat but the fuel ratio has increased.

Directly comparable statistics to Table 49 for New Zealand are not available, although Table 44 provides expenditure relationships between the 2nd and 9th deciles for energy. For New Zealand the ratio has steadily increased for “Energy” (1987: 1.4, 1998: 1.5 and 2001: 1.6). For the “Food” sub-group the comparable ratios are for 1987: 2.2, 1998: 2.8 and 2001: 2.7.

11. DISCUSSION

HEEP offers a comprehensive treasure trove of data on New Zealand households. The data can be used in a wide range of ways to assist in dealing with many different types of problems. The HEEP database allows the use of a wide range of energy-using appliances to be evaluated using socio-economic and physical house variables, e.g. the number of heaters of using any fuel type compared with income and house age. Two examples are given here – one investigating opportunities to deal with air-pollution problems, and the other with peak-demand patterns due to a specific appliance type.

11.1 Reducing air pollution

Air pollution from domestic space heating is becoming an increasingly important issue throughout New Zealand. Table 50 provides a selection of recent winter headlines for Blenheim, Timaru, Nelson, Christchurch and region, Upper Hutt, and the Waikato.

Blenheim: "A new report shows Blenheim's air quality has reached the "alert" level." (**Firing debate on smog**, The Marlborough Express 22 July 2002.)
Timaru: "Timaru has breached Ministry for the Environment air pollution guidelines eight times between July 1-18 {2002} (ten times since May 22)". (**Working towards clean Timaru air by 2016,** The Timaru Herald 20 July 2002.)
Nelson: "The new figures, published on Saturday, show that Nelson's smog is exceeding Environment Ministry guidelines far more often than is the case in Christchurch." (**Tackling the smog,** The Nelson Mail 22 July 2002.)
Christchurch, Timaru, Rangiora, Ashburton and Kaiapoi: "Our major winter air pollution is suspended particulate (or simply PM10) – very small particles in the air. In Christchurch, 90% of it comes from burning wood and coal to heat homes. Fireplaces and other "domestic solid fuel burners" (log and coal burners) are also the main cause of winter air pollution in other Canterbury towns and cities, including Timaru, Rangiora, Ashburton and Kaiapoi." (www.ecan.govt.nz/Air/Air-Monitoring/air-monitoring.asp, 24 July 2002.)
Upper Hutt: "The increase in domestic fire use during the recent cold snap has led to air pollution problems in Upper Hutt, says Wellington Regional Council". (**Cold snap leads to air pollution problems,** Press Release 5 July 2001. www.wrc.govt.nz)
Waikato: "The four major sources of air pollution in the Waikato Region are home fires, industry, livestock farming and motor vehicles." (www.ew.govt.nz/ourenvironment/air/big4/index.htm)

Table 50: Causes of NZ winter air pollution – selected extracts

HEEP offers the first opportunity to understand how, why and where space heating is used in New Zealand houses, and from there provides the necessary basis for action. HEEP results work in conjunction with more common market research. Rather than relying on the inventory and occupant-reported use of heating appliances, HEEP provides data on how the appliances are actually used, and shows the critical interaction between the appliances, the house occupants and the physical structure of the house.

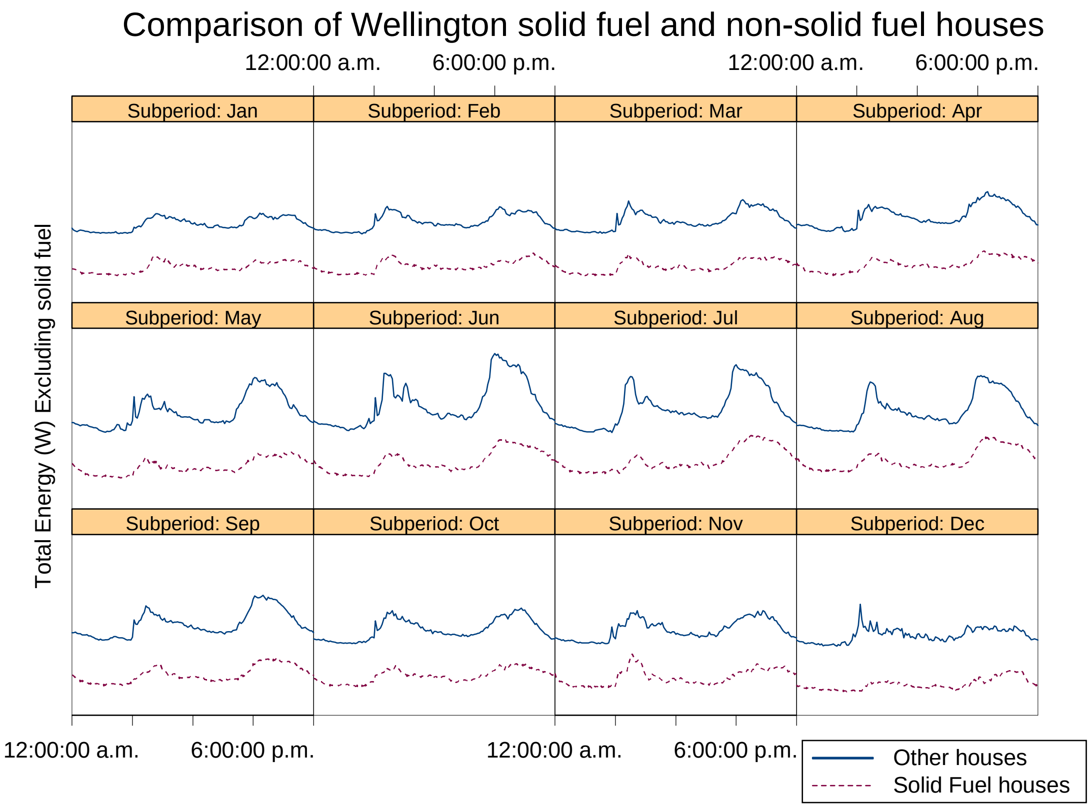

Figure 68: Power profiles – solid fuel & non-solid fuel in Wellington houses

HEEP can provide considerable detail on patterns of energy (electricity and natural gas) use – as an example Figure 68 provides for each month electric power profiles for houses with and without solid fuel burners. Note the scales and baselines for the two house types have been shifted to provide a clear view of the profiles. The profiles of the houses that use solid fuel do not have the pronounced morning and evening peaks in electrical energy consumption, and have a much smaller increase from summer to winter. More detailed analysis of the HEEP database would show whether these differences are statistically important, and whether the relationships differ by climate or other variable.

These issue may be of concern for a number of locations around New Zealand. The Transpower "System Security Forecast 2002"(SSF) is a 10-year (2002-2011) security forecast and assessment of security issues affecting the New Zealand power system (Transpower 2002). The SSF identifies where new investment may be required to maintain security and quality of supply over the 10-year forecast period. According to the CEO of Transpower, a number of important regional security issues are highlighted in the SSF. In the North Island, supply across the Auckland Isthmus, supply into Auckland and supply into the Bay of Plenty are particularly significant issues. In the South Island, the focus is on power transfer from the Waitaki Valley to the Christchurch area (Thomson 2002).

11.2 Hot water systems

A HEEP client requested hot-water electricity profiles for selected locations. Figure 69 provides an example of the type of output that can be provided from the HEEP database. It is possible to select specific appliance types, fuel types and exclude houses with certain characteristics in order to develop specific analysis.

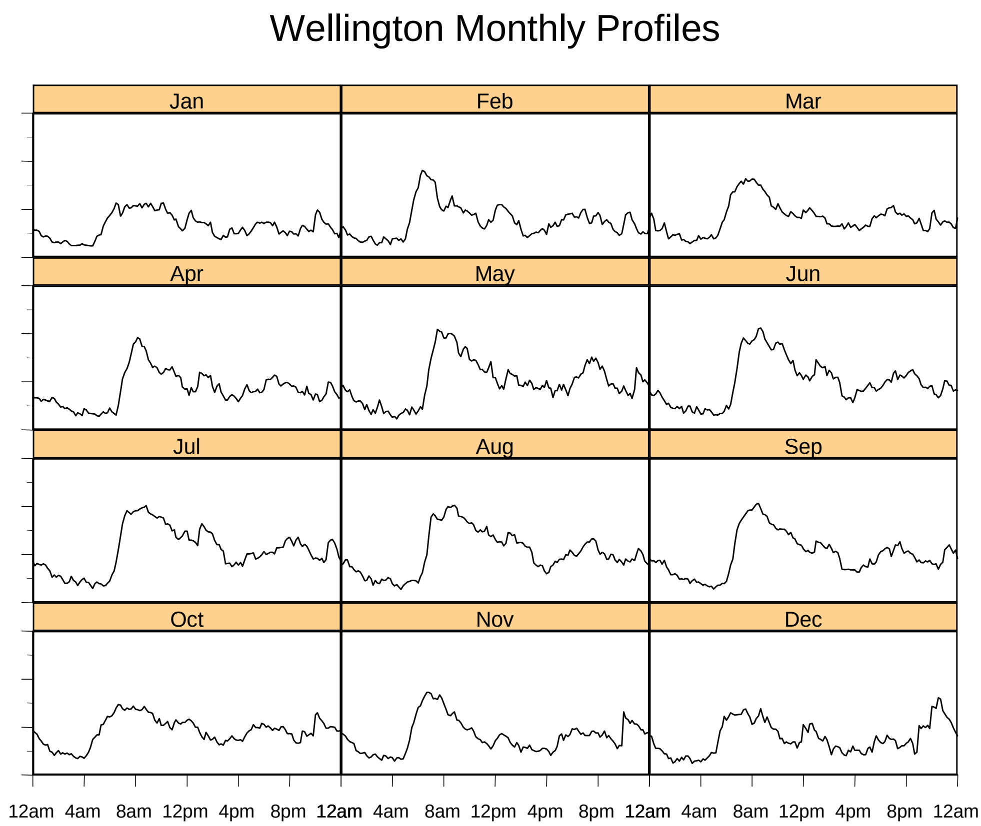

Figure 69: Monthly hot water profiles for Wellington

12. CONCLUSIONS

This sixth annual HEEP report, has described the current state of the HEEP monitoring, provided some analysis of the HEEP database, set out some ideas for other uses of the database, and discussed plans for the final two years of monitoring.

The need for high quality, empirical data on how, why, where and when energy is used in New Zealand homes has never been as urgent. It is needed in order to meet the goals of the National Energy Efficiency and Conservation Strategy (NEECS) and to meet the requirements of New Zealand's obligations under the Kyoto Protocol. It is needed to support the revision of the New Zealand Building Code Clause H1 Energy Efficiency, and it is needed to ensure all New Zealanders have the opportunity to live healthy lives.

HEEP is a 'snap-shot' study – looking at energy use in existing houses while making no interventions. There has been, and is currently, no sizeable New Zealand longitudinal study of impact on households of changing energy efficiency (although an example was provided of other research which showed that improving the insulation of a house resulted in improved indoor temperatures rather than a reduction in energy use). The current health and housing study which is modifying the energy efficiency of a number of houses to explore the health impacts was also described (Section 1.3).

As in previous HEEP reports, the data has been used to explore different aspects of how energy is used in houses – these results are not intended to be representative of the entire stock of houses, but rather to explore some critical issues. These include the following areas:

- The use of LPG heaters was examined in nine houses, and it was found that they were used for less time and with lower settings than could have been expected. In many cases they could be replaced by lower power output heaters.
- The resistive and reactive power use was examined for one house, and it was found that power factors were far from ideal, although closer to one during the times of highest power use.
- Artificial Neural Networks were used to examine solid-fuel heater use, and this work will be continuing in the coming year.

The whole HEEP database was also explored, including the following areas:

- Baseload and standby power consumption was re-evaluated with the larger database, but no statistical difference was found from previous HEEP estimates.
- Different heating schedules were identified in Auckland, Hamilton and Wellington. The existence (or non-existence) of differences will be further explored in the coming year for Christchurch, Waikanae and the full Auckland sample.

A number of key assumptions about New Zealand energy use patterns have been examined, preliminary answers provided, and further questions raised:

- New Zealand has low energy prices which lead to high energy use – **untrue**.
    - New Zealand household energy use per person ranks 25th out of the 30 OECD countries (Figure 63), and energy use per house is considerably lower than in Australia, UK, US and Canada (Table 46).
    - New Zealand energy unit costs rank around 6th out of major economic powers (Figure 58).

- Energy is a minor component of New Zealand household expenditure – **true**.
  - New Zealand households spend about the same proportion (about 3%) on non-transport energy as UK, USA, Australia and Canada (Table 47).
- New Zealand households are cooler in winter than those in other countries – **true**.
  - Average temperatures in New Zealand houses do not appear to have increased since the 1970s, although this conclusion may change as further HEEP temperature measurements become available in the coming years (Table 30).
  - UK houses have seen a steady rise in the use of central heating (to about 90% of houses) and average temperatures (increasing from 13°C in 1970 to 17°C in 1996) (Figure 11).
- Higher incomes lead to higher temperatures in New Zealand houses – **untrue**.
  - The proportion of expenditure spent by lower income houses on energy has increased more rapidly than the proportion spent by higher income households (Figure 62).
  - Lower income households spend a higher proportion on energy than high income houses in both New Zealand and the UK (Table 47)
  - There is no correlation between winter evening temperatures and income in New Zealand houses (Figure 54), or winter evening temperatures and house floor area (Figure 55).
- Insulated houses are warmer – **true**.
  - There is a good correlation between warmer winter evening temperatures and houses built since the mandatory requirement for thermal insulation was introduced in 1978 (Table 40).
  - Currently, we can conclude that post-1978 houses are warmer by an average of 1.4°C, and that their winter evening energy use is not significantly different from that of the pre-1978 houses.

These results are important, as for the first time they start to quantify these issues. They raise many more questions than they answer – such as:

- Do New Zealand house occupiers place such a low value on winter warmth?
- Why do New Zealanders only heat part of their homes for comparatively short periods?
- What role does the house play in the provision of low winter temperatures?
- What are the implications for future policy – not only Kyoto, but also health?

As the HEEP database grows in size, the answers to these questions will become clearer.

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13.1 HEEP Reports

Electronic (PDF) copies of all HEEP annual reports are available from the BRANZ web site www.branz.co.nz. Limited numbers of hard copies are available from BRANZ at the addresses given in Section 1.9 (page 13). The 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 Four 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 SR 111 Judgeford.

13.2 HEEP *BUILD* articles

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

Stoecklein, A., 2001 **Year five results of the household Energy End-use Project (HEEP)** *BUILD* 67 Nov/Dec pp 38-39

Stoecklein, A., 2001 **Confessions of a researcher** *BUILD* 67 Nov/Dec p 40

Camilleri, M., 2001 **NZ homes 'leak' $120 Million of electricity each year** *BUILD* 64 May/June pp 44-46

Pollard, A., 2001 **Getting into hot water** *BUILD* 63 Mar/Apr pp 58-61

13.3 HEEP Conference Papers

A number of the papers presented over the years by the HEEP team are available on the BRANZ web site under "Publications". They can be downloaded (at no charge) in PDF format, or hard copies purchased from BRANZ:

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

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 Conf. 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 Conf. 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)

Pollard A.R. 1999 **The Measurement of Whole Building Energy Usage for New Zealand Houses** in *Proc. IPENZ Technical Conference*, Auckland, July 11-12, 1999. (BRANZ Conference Paper 69)

Stoecklein A.A., Pollard A.R and Bishop S. 1998 **Energy End-Use in New Zealand Houses** in *Proc ACEEE Summer Study*, Asilomar, Monterey, CA, USA, August 1998 (BRANZ Conference Paper 57)

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Stoecklein A., Pollard A., Isaacs N., Bishop S., James, B., Ryan G., & Sanders I. 1998 **Energy End-use and Socio/Demographic Occupant Characteristics of New Zealand Households** *Proc IPENZ Conference Vol. 2* pp51-56 (BRANZ Conference Paper 52)

Stoecklein A.A. and Pollard A.R. 1998 **Occupant And Building Related Determinants On The Temperature Patterns In New Zealand Residential Buildings** in *Proc. IPENZ Conference*, Auckland, New Zealand, 1998 (BRANZ Conference Paper 49)

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