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Energy Use in New Zealand Households

Report on the Year 5 Analysis for the Household Energy End-use Project (HEEP)

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ENERGY USE IN NEW ZEALAND HOUSEHOLDS

Report on Year Five for the Household Energy End-use Project (HEEP) – June 2001

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ABSTRACT

This report covers the activities of the fifth full year of the **Household Energy End-use Project (HEEP)**. The project was established in late 1994, with monitoring commencing the following year. It is a long-term research activity aimed at creating and making available a scientifically and technically rigorous, up-to-date and public knowledge base of energy use and end-uses, energy services provision, and key occupant, building and appliance determinants in New Zealand residential buildings.

This report is limited to some of the monitoring and analysis aspects of the last year. More in-depth customised analysis of the information is available to financial supporters of the HEEP investigation.

Acknowledgements

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

BRANZ, and the Building Research Levy
Energy Efficiency and Conservation Authority (EECA)
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PowerCo, Wanganui
TransAlta New Zealand Ltd, Wellington
TransPower New Zealand Ltd
WEL Energy Trust, Hamilton

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

Energy Use in New Zealand Households
Report on Year 5 of the Household Energy End-use Project (HEEP)
June 2001

Executive Summary

This report covers the activities of the fifth full year of the **Household Energy End-use Project (HEEP)**. The project represents a major commitment by a number of funding and research organizations to develop, and make available, improved knowledge about the actual energy use of real New Zealand houses occupied by real families.

HEEP was established in late 1995 as a long-term research activity to create a scientifically and technically rigorous, up-to-date public knowledge base of energy use and end-uses, energy services provision and key occupant, building and appliance determinants of energy use in residential buildings.

Energy consumption is analysed both in terms of time-of-use across the day and over the year in order to examine daily and seasonal patterns. Focus is not solely on the technical aspects of energy use, but also on the physical and social characteristics of the house and occupants. The objective is to build a model based on the main drivers that determine household energy consumption patterns 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 used*
- **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*

The project has been designed to suit a wide range of possible participants, with particular analyses able to be tailored towards specific needs. For example, this year a group of 12 pensioner households in Hamilton has been monitored as a special study for the WEL Energy Trust. At the same time, all the data collected will contribute towards the overall understanding of the energy performance of households.

The first few years of the project focussed on the development and implementation of large-scale monitoring and data analysis methodology for the types of energy used in households, and other specific monitoring tasks. The areas of methodology investigated or underway since the beginning of the project are:

	Systems investigated or underway
1996: Year 1	*Electrical end-uses only*
1997: Year 2	*Solid fuel burners*
1998: Year 3	*Reticulated gas appliances*
1999: Year 4	*Random house selection monitoring*
	Total level monitoring
	LPG trials
2000: Year 5	*Refining of solid fuel monitoring and analysis techniques*
	LPG monitoring
2001: Year 6	*Remote logging development*
	Development of methods for solar and wetbacks

This work involved a series of selected households as pilot studies, as well as specific case studies that concentrated on particular areas or household types such as this year's pensioner

study. Including these, selected households now total 66. Random selection of households started in 1999, with progress to date as follows on the target sample of 400:

1999: Year 4	*43 houses completed in Wellington*
2000: Year 5	*17 houses completed in Hamilton*
	48 underway in Auckland

Taken together with the non-random households completed to date, the total HEEP database now includes 126 households, with another 48 currently being monitored in Auckland. The randomly selected households completed in Wellington and Hamilton are now statistically representative of approximately 13% of New Zealand's households. When the current monitoring of households in the Auckland region is completed at the beginning of 2002, the HEEP sample will be representative of 340,000 households, or 27% of the country. Monitoring the remainder of the Auckland households will optimise the statistical validity for that area.

The following highlights some of the more interesting parts of the Year 5 work:

Broad Level Statistics:
The 1971/72 electricity survey [1] generated data which has not been able to be questioned since that time. Since that study, it has been commonly held that hot water used about 33% of total energy, while lighting used about 8%. Some broad level statistics are now available from this project, which can be compared to the figures commonly used for the past 30 years.

These new results are based on the random houses monitored to date, and future reports will update and add to these as more households are monitored and more results available for analysis. However, these findings can still be considered as indicative of future results, despite still being preliminary at this stage as they are based on Hamilton and Wellington households only.

- ***Total energy***: Average overall total (excluding LPG) — 9000 kWh/year /house
  - Gas only — 2400 kWh/year /house
  - Electricity only — 6700 kWh/year /house
- ***Hot water***: Average energy used for hot water heating — 4000 kWh/year /house
  - % of total energy for hot water heating — 44%
    (compared to past estimates of 33%)
  - % of electricity used for electrically heated hot water — 42%

  Average hot water standing loss — 1000-1100 kWh/system /year
  - % of total energy — 11-12%
  - % of hot water heating energy — 25-30%
- ***Lighting***: Average energy used for lighting circuits — 740 kWh/year/house
  - % energy used for lighting — 8%
    (same as past estimates of 8%)
- ***Standby & baseload power*** — 920 kWh/year/house
  - % electricity used by standby & baseload — 10%

The interesting point arising from the limited findings relates to the relative importance of hot water heating energy compared to the total energy used by households. This appears to play a significantly greater part in domestic energy consumption than has been traditionally assumed, which is an important factor to take into account when considering future emphasis in regard to energy conservation initiatives.

Standing Losses from Electric Hot Water Cylinders

Hot water systems in New Zealand are generally not very efficient, with merely an estimated 5% of hot water cylinders meeting "A" Grade specifications. Consequently the potential for national energy savings, and Greenhouse Gas emission reductions, from improvements in hot water systems is likely to be large. Previous estimates of the electric hot water cylinder standing losses of about 30% appear to be confirmed by a random sample of HEEP households, which have an average standing loss of about 25-30% of hot water energy use. Standing losses for all of New Zealand's electric hot water cylinders could amount to as much as 5 PJ.

New performance requirements under NZBC Clause H1, which became mandatory on 29th December 2000, will improve the overall performance of electric hot water cylinders in new homes, as will retrofitting of insulation wraps to existing cylinders. The application of Minimum Energy performance standards (MEPS) and energy labelling will result in improvements in existing homes as old cylinders are replaced.

The HEEP survey shows that about 20% of New Zealand houses sometimes run out of hot water. The reasons for this include small cylinder size for the household hot water use, which can only be resolved by fitting a larger cylinder. The early results are also suggesting that improving the cylinder and piping energy efficiency along with improved thermostat controls should help provide a better hot water service.

Influences on Hot Water Demand

Hot water demand is driven by a number of factors and work is still being undertaken to examine these. The water heating information from the HEEP database was examined against a number of potentially demand-influencing factors such as the ages of the occupants, type of hot water system, and the reported shower and bath usage. At this intermediate stage, the number of female teenagers appears to be an important influence on demand for hot water.

Hamilton Pensioner Case study: overall energy consumption

Energy consumption of pensioner and non-pensioner households are as follows:

- Yearly total energy per person
  - Non-pensioner — 1900 kWh
  - Pensioner — 2200 kWh
- Yearly hot water energy per person
  - Non-pensioner — 930 kWh
    - *Hot water % of total* — *48%*
  - Pensioner — 820 kWh
    - *Hot water % of total* — *37%*

The Hamilton pensioners in this study used more energy overall (including gas) per person than the non-pensioners, and slightly less energy for hot water per person. Temperatures during winter in living rooms and bedrooms were 1 to 2 °C higher in the pensioner households. Most pensioners achieved comfortable and healthy temperatures, while many non-pensioners did not, especially in bedrooms. The higher temperatures in the pensioner housing may be due to the thermal efficiency of their well-insulated units, which require only about 500 W of dedicated heating to maintain indoor temperatures 10°C above outside temperatures. In contrast, a group of pensioners living in poorly insulated units in Wellington had living room temperatures 6°C colder than the Hamilton pensioners, with average June temperatures of only 14.5°C. When the Wellington units were insulated the temperatures rose to around 17°C, still 3.5°C cooler than the Hamilton units. It is plausible that the cost of heating affects the living room temperatures of pensioners.

By New Zealand norms, this group of Hamilton pensioners are exceptional in that their units and hot water systems are highly thermally efficient, which makes a major contribution to both their low energy demand, and their indoor temperatures. Pensioners living in older, poorly insulated units or in houses would likely have a higher energy demand and costs, and lower indoor temperatures as heating would be less affordable and less effective.

Standby Power and Losses

Standby power is drawn by an appliance when it is not in operation but is connected to the mains. Depending on the appliance type, this can range from nil to as much as 20 W or more. These power consumptions may seem trivial, but since most households have many such appliances, the actual energy consumption may be a significant fraction of the total energy consumption of a household. A survey of international studies reported that around 10% of domestic electricity consumption is from standby power consumption. Much of this consumption is a waste of money and energy, a source of unnecessary Greenhouse Gas emissions, and can be reduced through good electrical design.

If the average national baseload is similar to that found for the randomly selected Wellington and Hamilton households, then the total baseload is around 130 MW continuous, with a yearly consumption of 1,100 GWh, which has a retail price of approximately $115 million, and CO_2 emissions of around 730,000 tonnes, if supplied by thermal generation. This is approximately 3% of New Zealand's total electricity generation, and up to 1% of New Zealand's total GHG emissions (if supplied by thermal power stations). Clearly, the potential reductions of baseload and standby consumption in NZ households are large, and has potential for Demand Side Management (DSM) and GHG reductions.

The largest five contributors to the household baseload are (from highest to lowest):

- fridge or fridge freezer
- television
- video
- washing machine
- microwave.

In rounded figures, HEEP standby and baseload estimates per house available to date may be summarised as follows:

- **Average total baseload** **103 W**
- Standby from common appliances [1] 36 W
- Standby from minor appliances 10 W
- Average consumption of heated towel rails 25 W
- **Remaining unquantified baseload** **32 W**

For some appliance classes, such as televisions and VCRs, the future standby consumption demand may decrease, as modern appliances have lower standby power than older units, and the total number is not growing quickly. However, there are a host of other rapidly increasing appliances that may increase standby consumption and a proliferation of electronic and computer controls replacing manual control. Examples include computers, cable decoders, satellite decoders and receivers, video games, faxes, answering machines, cordless phones, and various battery chargers for portable devices. For whiteware in particular, computer controls are becoming more and more common. Unless measures are taken to reduce the standby power of these appliances, then standby and baseload losses may increase dramatically.

[1] *Other studies do not include all of the power consumption during non-usage time for fridges and fridge freezers, videos and microwave. This is because the power is consumed for specific tasks (for example butter conditioner, TV channel tracking, microwave clocks). In this study we have used a more inclusive approach.*

Indoor Temperatures

The 1971/72 Household Electricity Survey [2] measured average winter (August-September 1971) temperatures in the kitchen, lounge and main bedroom. This confirmed that New Zealand houses were then only heated to low levels. Although there was no measured evidence to support it, it has been assumed that nowadays occupants are demanding more comfortable temperatures, and that average temperatures have risen in response. Monitoring of randomly selected households in Wellington and Hamilton suggests this is not so. The average measured temperatures were about 1°C less than those measured almost 30 years ago.

There were also regional differences, with the Hamilton households showing higher average indoor temperatures than those in the Wellington sample. The spread of measured temperatures was higher for the Wellington sample, with about 25% having evening temperatures below 16°C.

Survey results indicate that only about 50% of New Zealand households consistently achieve comfortable temperatures during the winter. Correlations of these responses with measured average evening living room temperatures over the winter show a clear relationship between temperatures and comfort perception. The average temperature in houses, which were reportedly always comfortable, was approximately 19°C. Comparing the average winter evening temperatures with the decade in which the house was built also showed a clear relationship, with higher temperatures in houses built since the 1980s.

Solar Gains

Winter space heating is a large component of the energy used in New Zealand households. Heating energy requirements are determined by local climate, the physical properties of the building and the comfort expectations of the occupants. Requirements can be minimised with appropriate design that makes effective use of the available solar radiation. This year a typical house was investigated to assess the impact of solar radiation on indoor temperatures.

Indoor temperatures within buildings are dynamic. The vertical temperature distribution within the living room of the house under investigation was found to depend on the nature of the heating system employed. Convective heating produced a greater vertical temperature difference than radiant heating. Solar gains produced a radiant effect on the afternoon temperatures within the living room, with temperatures comparable to the evening temperatures when the radiant heater was used.

HEEP, Appliance Standards & Energy Labelling

As part of the HEEP project, the pattern and amount of energy use of appliances of all types, sizes, and ages used by real people in real houses is monitored in great detail, and appliance usage is also surveyed. These results are important to assist in understanding how codes and standards can underpin society's efficient use of energy. Mandatory minimum energy performance standards (MEPS) for appliances do not represent a 'good' energy efficiency goal, but are critical to minimise market failures. The availability of 'Better' and 'Best' standards, not only for building design, but also for significant energy using appliances, will provide support and guidance to those wishing to 'do better' than any mandatory minimums.

The New Zealand Building Code does not require existing buildings to meet the current standards for hot water systems when changes are made, and it is legal to replace an old hot water cylinder with one of any grade or age. The HEEP results will provide information on possible benefits of requiring that all replacement hot water systems meet current requirements, and the second hand market for non-complying hot water systems be stopped.

The HEEP results would support the inclusion of standby power consumption of appliances should be included in MEPS and energy labelling, as this can account for as much as 10% of domestic energy use but can be easily reduced. Any labelling programme should be accompanied by advertising and public education, training of retail staff, and the provision of readily available information, so that consumers know what the energy label is, how to interpret it, and how to use it. Monitoring and evaluation of consumers, retailers, manufacturers, and importers is also needed to gauge the effectiveness and success of the programme, otherwise opportunities for improvement will be lost.

Occupants' Perceptions
As each household is surveyed prior to monitoring actual energy use, results are now becoming available that provide insights into attitudes towards energy services. Based on analysis of households surveyed to date, some preliminary results are available.

It appears that, when asked to rank energy-consuming appliances in priority order, people are least willing to sacrifice heating and hot water heating. The easiest sacrifice appears to be electric blankets and lighting. This may suggest that efforts to improve the efficiency of lighting may be easier to achieve than changes in the use of heating and hot water.

Almost half of those surveyed did not always achieve what they perceive as comfortable temperatures in their houses. When assessed against recorded winter temperatures, a clear relationship was shown between perceived comfort and actual temperatures. Temperatures were also assessed against ages of houses. This showed a clear increase in temperatures over the decades, particularly in those houses built after the introduction of insulation standards in 1978. This suggests the level of takeback effects (in the form of warmer rooms) that might be expected when increasing the thermal performance of new houses.

Methodology

House Construction Types
HEEP plans over time include the evaluation of energy and comfort characteristics of a number of low volume wall construction styles. The objective is to understand the potential impact of emerging new wall construction types on the national energy consumption, and the consequences for the indoor environment. The selection criterion are based on the potential of the new construction method to become widespread as well as the extent to which it differs in thermal performance from timber frame construction. On this basis, the following construction types have been selected for monitoring:

- **Concrete masonry**
- **Tilt up slab wall**
- **Polystyrene block**
- **Solid timber**
- **Light steel frame**
- **Wood based panels**

Due to budget constraints, the monitoring sample of each of these low volume construction types is expected to be very small. Also, as well as the basic wall type, the design of all other construction elements and the occupants' behaviour influence the thermal performance of the buildings. In this context, the result of this sub-study is expected to provide a snapshot of some individual cases, rather than a general understanding of the performance differences of the different construction types.

New sample selection
Initially it was planned to base the order of regional data collection on practical and logistic circumstances, as well as on the willingness of the energy or lines companies to participate. The household proportion in the major electricity company areas was accordingly taken from power company customer record numbers based on 1996 data, including all those power companies with a residential customer base of more than 40,000 residential customers.

Since then it has become apparent that power company participation cannot be relied on to ultimately cover the whole country. Company areas are changing too frequently to use them as the basic regional selection unit. In addition, energy retailers are no longer geographically defined, making them unsuitable.

A new regional selection strategy has now been set in place. This is based on household population records from Statistics New Zealand, and uses their regional and district stratifications. This means that the current planned sampling is:

	Total households	***HEEP sample***
Auckland	306,000	**97**
Christchurch	116,000	**37**
Dunedin	43,000	**14**
Hamilton	50,000	**16**
Invercargill	20,000	**6**
Tauranga	29,000	**9**
Wellington	120,000	**38**
Rest of New Zealand	583,000	**190**
NZ Totals	**1,267,000**	**407**

Year 6 monitoring will involve the completion of the Auckland sample, and moving into in Christchurch and the 'Rest of New Zealand'.

Proposed Remote Logging Strategy
In order to allow HEEP to encompass a wide range of rural as well as urban households within reasonable costs, a remote logging strategy is required. Suitable systems will be investigated in Year 6 to allow this. The basic idea is to send loggers to the households monthly, along with details of where to connect the loggers. The occupants are then responsible for exchanging "full" loggers with "empty" logger and forwarding the former back to BRANZ for downloading and analysis of data.

Copies of the full Year 5 report are available from: BRANZ

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1. INTRODUCTION

The last major New Zealand investigation of energy use in houses was conducted in 1971/72 by the (then) New Zealand Electricity Department and the Department of Statistics [1]. Since then new technologies have found widespread acceptance, and the living patterns and socio-demographic composition of the population have drastically changed. However, no updated information on household energy use has been available.

The Household Energy End-use Project (HEEP) was established in late 1995 by a group of funding and research organizations as a long-term research activity to create a scientifically and technically rigorous, up-to-date public knowledge base of energy use and end-uses, energy services provision and key occupant, building and appliance determinants of energy use in residential buildings. Energy consumption is analysed both in terms of time-of-use across the day and over the year in order to examine daily and seasonal patterns. Focus is not solely on the technical aspects[2] of energy use, but also on the physical and social characteristics of the house and occupants.

HEEP represents a major commitment by a number of funding and research organizations to develop, and make available, improved knowledge about the actual energy use of real New Zealand houses occupied by real families. This report covers the activities of the fifth full year of HEEP.

1.1 Objective

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

- **Energy consumption:** *how much energy is used by households*
- **Energy types:** *which types[3] of energy are used by households*
- **Appliances:** *which household appliances[4] use this energy*
- **Time periods:** *during which seasons and times of day energy is consumed*
- **Household types:** *how do different[5] types of households use energy*
- **Occupant behaviour:** *what behaviours affect household energy use*
- **Energy service:** *what service[6] is provided by the energy use.*

Data collected during the project will enable HEEP participants to extract specific information to suit their particular needs. The range of possible 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*

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[2] *Such as efficiency of appliances, building envelope, heating devices etc.*
[3] *Electricity, natural gas, LPG, solid fuel etc.*
[4] *Including space heating and water heating.*
[5] *In terms of socio-demographic characteristics.*
[6] *Such as room temperatures, hot water delivery etc.*

- **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.*

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

1.2 The HEEP Model

In the past, energy use in houses has been mostly described and modelled as purely a function of the building's thermal performance together with the efficiency of the space heating system, the water heating system and other energy consuming appliances. However, it has become increasingly clear that this approach ignores the critical influence of human behaviour [3]. Research results indicate that the attitudes and behaviour of an energy consumer explain a large proportion of energy use. The HEEP model aims to relate physical and technological determinants as well as socio-demographic determinants of energy use by New Zealand households. The following diagram indicates the current concept of the structure of the HEEP model.

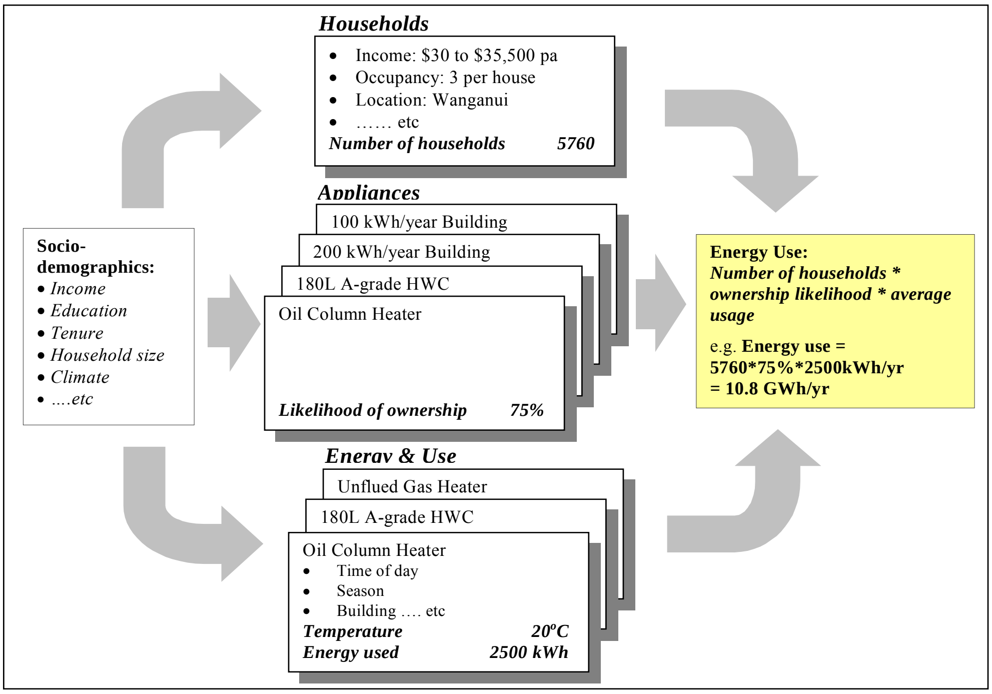

Figure 1:The HEEP Model Structure

Based on the HEEP model structure, Figure 1 shows that household energy use is determined 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 1, 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 between $30,000 and $35,000 in Wanganui who heat their houses to a comfortable 20 °C temperatures using oil column heaters?*

1.3 History

The first few years of the HEEP project focussed on the development and implementation of large-scale monitoring and data analysis methodology for the types of energy used in households, and other specific monitoring problems. This involved a series of selected households as pilot studies, as well as specific case studies that concentrated on particular areas or household types[7]. These selected households are shown in the following table:

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

Table 1: Non-randomly selected households completed to date

Table 2 summarises the areas of methodology covered over the years:

	Systems investigated or underway
1996: Year 1	Electrical end-uses only
1997: Year 2	Solid fuel burners
1998: Year 3	Reticulated gas appliances
1999: Year 4	Random house selection monitoring Total level monitoring LPG trials
2000: Year 5	Refining of solid fuel monitoring and analysis techniques LPG monitoring
2001: Year 6	Remote logging development Development of methods for solar and wetbacks

Table 2: History of HEEP monitoring activities

[7] *For example, pensioner housing.*

Random selection of households started in 1999. The following table shows 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	6	2001/02	(underway) 48
		TOTAL RANDOM HOUSEHOLDS TO DATE	**108**

Table 3: Randomly selected households monitored to date

As can be seen, the sample completed to date cannot yet be used to give reliable conclusions for the whole country. However the randomly selected households in Wellington and Hamilton now represent approximately 13% of New Zealand's households and the analyses done on the results for these houses are representative of the behaviour of that population of households.

When the current monitoring of households in the Auckland region is completed at the beginning of 2002, the HEEP sample will represent 340,000 households, or 27% of the country. Monitoring the remainder of the Auckland households will optimise the statistical validity for that area. As each new area is monitored, more New Zealand households will be represented in the HEEP sample. The progress is planned to be about 20% to 25% per year.

1.4 HEEP Participants

The number of participants involved in HEEP has steadily increased over the years since the project's inception. A more detailed description of each participant is given in Appendix 10.1. The following are currently involved, and their support is gratefully acknowledged:

Building Research Association of New Zealand (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:

Fitzgerald Applied Sociology
John Jowett, Consultant Statistician
Victoria University Wellington, School of Architecture

1.5 Further Information

If you or your organisation is interested in participating in any part of the HEEP work or further information on the research, please contact the staff at BRANZ:

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2. METHODOLOGY

This section provides an overview of the development and application of the model used for the HEEP monitoring work. It summarises work presented in earlier reports together with more detailed descriptions of new analysis completed in the past year.

2.1 Project Design

Four sets of input data are necessary to establish the model discussed in Section 1.2 The HEEP Model, and shown in Figure 1. These are as follows:

- **Households:** *socio-demographic information on house occupants*
- **Appliances:** *ownership of appliances and heating systems*
- **Energy:** *records of the energy end-use of households and appliances*
- **Indoor environment:** *records of the indoor conditions*

A model linking these allows more accuracy than models based solely on physical properties of households and appliances. As energy end-use logging is very expensive, it is not feasible to include such detailed monitoring of every household in the study; so a two[8]-level approach is used as follows:

a) **End-use metering:** detailed household energy use monitoring by time[9], end use[10] and indoor temperature patterns. Household characteristics are determined through socio-demographic surveys.
   - o *Allows breakdown of total energy use into end-use components.*

b) **Total level metering:** less detailed monitoring of a larger number of households. The total house energy consumption of all fuel types is monitored, with household characteristics identified in the same manner as for the detailed metering.
   - o *Allows analysis of physical building, socio-demographic and climatic determinants and provides main basis for statistical analysis.*

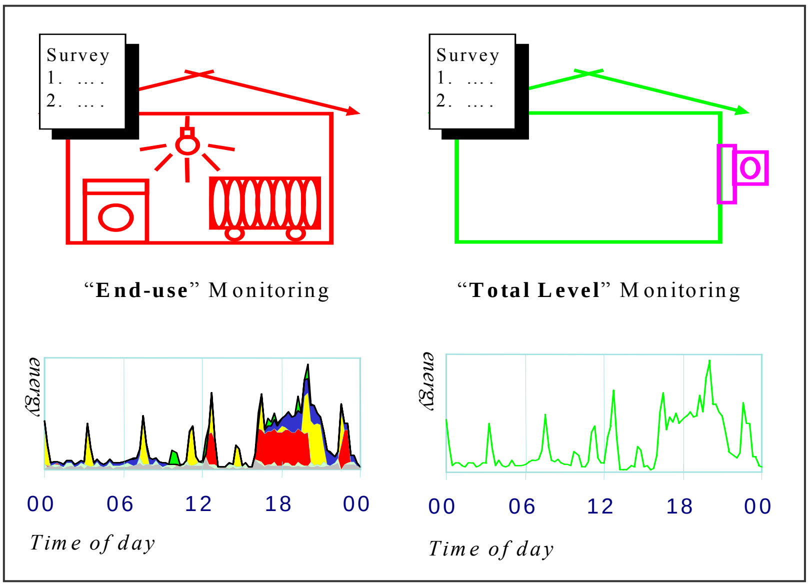

Figure 2: Levels of monitoring

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[8] *The original concept was a three-level process that included distribution level monitoring. This has not been undertaken due to lack of support from line and retail companies.*
[9] *10 minute intervals with the total duration designed to pick up seasonal variations.*
[10] *Using appliance-based dataloggers to show actual proportions and timing of energy flows.*

Figure 2 shows how the levels of monitoring are used in order to provide both micro and macro level data. This approach allows data collection at two levels of detail, which is then integrated in order to maximise the information available from the raw data.

2.2 Sampling Structure

Sample design issues were described in detail in the HEEP Year 3 report [4], and the following is a summary of some of the key points covered at that time.

It is important to have an alternative option to back up the correlation analysis and the model approach. This 'fall back' option allows collected data to be used for average annual energy use estimations of the national household population. In order to use the data for this purpose it is desirable that data is collected from:

a) a sufficiently large sample of households.

b) a representative sample of households.

2.2.1 Sample Size

Based on earlier statistical analysis, the required number of households to be monitored is approximately 400. This is mainly based on the recognition that heating and hot water energy use each contribute approximately 35% to the total energy consumption and the data quality of these two end-uses and the total load should therefore determine the sample size of the HEEP investigation. The largest requirement of these data sets is the one for heating. Even treating the night store heated households separately, it still requires a sample size of **375 households** nationwide. A target sample size of **400 households** nationwide was chosen to ensure that results would be statistically representative of the country.

2.2.2 Household Selection

Sample representativeness is easiest met by selecting a random sample of households, which are then monitored. Information from Statistics New Zealand is used to select weighted random meshblocks, and random sub-sampling of households is carried out within these meshblocks[11]. The selection approach includes the following steps:

a) Select regions where logging is planned. Define regions by matching them to existing meshblock boundaries.

b) Determine household populations in selected regions, with proportions of national total.

c) Draw proportional random sample[12] of meshblocks from selected region.

d) Select a random household in each selected meshblock and obtain consent from residents. If no consent is given, repeat procedure within the meshblock until a house is found.

Like all research projects that involve volunteer public participation, there is a certain refusal rate which represents some degree of bias. In order to estimate the amount of likely bias, a statistical analysis was carried out to compare socio-demographic characteristic of the HEEP households with those of the whole population[13]. This showed that the bias was small enough to be corrected by weighting the individual strata, so it is assumed that logging results will be representative of the whole population.

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[11] *Information from Statistics New Zealand is resolved on meshblock level. Meshblocks consist of between approximately 20 and 100 houses within close proximity of each other.*

[12] *The random sampling shall be conducted with meshblocks weighted according to their meshblock household population.*

[13] *Using NZ averages derived from the 1996 Census (Fitzgerald 1999).*

2.3 Updated Sampling Structure

2.3.1 Previous Regional Selection

Initially it was planned to base the order in which data collection would cover different regions mainly on practical and logistic circumstances, as well as on the willingness of the energy or lines companies to participate. The household proportion in the major electricity company areas was accordingly taken from power company customer record numbers based on 1996 data, including all those power companies with a residential customer base of more than 40,000 residential customers.

Since then it has become apparent that power company participation cannot be relied on to ultimately cover the whole country. Companies no longer cover clearly defined geographical regions, and their areas are changing too frequently to use them as the basic regional selection unit.

2.3.2 New Regional Selection Method

A new regional selection strategy has now been set in place. This is based entirely on household population records from Statistics New Zealand, and uses their regional and district stratifications. Since the regions already surveyed, although defined in terms of power company areas, did in fact consist of sets of whole Statistics NZ meshblocks, it is possible to include these regions as strata in the new design.

2.3.2.1 Urban Versus Rural

It is difficult to monitor remote houses. At the same time however, 31% of New Zealand's household population is located in *non-Major Urban* meshblocks. There is also no reliable historic information that would allow a complete statistical evaluation of the bias which would result if these were ignored.

Table 4 shows the **target** regional distribution of the sample, indicating the proportions of *Major Urban*, *Minor Urban*, *Secondary Urban* and *Rural* households within each region. A more detailed table, which breaks the regions into local authority areas, is given in Appendix 10.2.

Target Regional Distribution	***Urban Level***					
Region	*Major Urban*	*Minor Urban*	*Rural etc.*	*Secondary Urban*	**Sub Totals**	*% of sample*
Auckland	103	2	5	1	***112***	*28%*
Bay of Plenty	15	3	5	2	***25***	*6%*
Canterbury	38	4	7	5	***55***	*14%*
Gisborne	4		1		***5***	*1%*
Hawke's Bay	13	1	2		***16***	*4%*
Manawatu-Wanganui	13	4	5	4	***26***	*7%*
Marlborough		0	1	3	***4***	*1%*
Nelson	5		0		***5***	*1%*
Northland	5	3	7		***15***	*4%*
Otago	13	3	4	2	***22***	*6%*
Southland	6	1	3	1	***11***	*3%*
Taranaki	6	2	3	1	***12***	*3%*
Tasman	1	1	2		***4***	*1%*
Waikato	17	8	9	4	***38***	*10%*
Wellington	38	2	2	6	***47***	*12%*
West Coast		1	1	1	***4***	*1%*
Grand Totals	***276***	***36***	***56***	***31***	**400**	
%s of sample	*69%*	*9%*	*14%*	*8%*		

Table 4: Target regional distribution of sample households

2.3.2.2 Stratification and Clustering

Sampling is now based on Census 96 information[14]. The country is divided into a number of strata, some of which have already been surveyed. In all but one of the strata, it is proposed to continue sampling as before:

a) *A sample size is determined by dividing the total of 400 sample households in proportion to the number of households in the stratum.*

b) *An appropriate number of meshblocks is chosen randomly, with probability of selection proportional to the number of households it contains.*

c) *One household is then chosen at random from each selected meshblock.*

Table 5 shows the strata, the number of households and area units in each, along with the sample size allocated to each stratum. In general, the individual strata are defined by Territorial Authority (TA) boundaries. If the required sample size is 9 or over, then that TA constitutes a stratum. If the sample size is less than 9, then that area is part of the special stratum *Rest of New Zealand*[15].

Stratum	***Area Units***	***Households***	***Samples***
Auckland (Auckland, Manukau, North Shore & Waitakere Cities)	7,018	306,000	**97**
Christchurch	2,605	116,000	**37**
Dunedin	1,325	43,000	**14**
Hamilton (Waikato Electricity Region)	1,308	50,000	**16**
Invercargill	709	20,000	**6**
Tauranga	561	29,000	**9**
Wellington (former Capital Power & Hutt Valley Energy Board Regions)	3,514	120,000	**38**
Rest of New Zealand	19,768	583,000	**190**
NZ Totals	**36,808**	**1,267,000**	**407** [16]

Table 5: Summary of selected strata and sample sizes

In the *Rest of New Zealand* stratum it is proposed to take a two-stage sample based on the area units defined by Statistics New Zealand. For the first stage, 19 area units will be used as clusters and chosen at random with probability proportional to size (number of households). For the second stage, within each selected area unit, a random sample of 10 households will be selected, using the method described in b) and c) above. While the total sample size for this stratum fixed, the numbers of area units, and the sample sizes within each area unit, are provisional. These numbers are discussed further below.

2.3.2.3 Determination of Cluster Numbers & Sizes

It was decided to cluster the *Rest of New Zealand* stratum because remote logging is complex, and the logistics of using the normal method over 190 households scattered randomly throughout NZ are formidable. There is insufficient historic information available with which to conduct a statistical analysis of optimum cluster size and distribution. The optimum is determined by the cost of sampling and the relative variability between and within clusters. At one extreme, if there were no variation

[14] *Later censuses could be taken into account but as that would complicate the statistics, it is not presently planned.*
[15] *Refer Appendix 10.2. One exception is the TA Invercargill City, which requires 6 sample households. In this case, in order to ensure adequate geographic coverage, it was decided to define Invercargill as a separate stratum.*
[16] *The difference between the 400 required households and the actual sum of 407 has two reasons: 1) A rounding inaccuracy resulting in 1 additional household and 2) the "Rest of New Zealand" stratum requiring 184 households but selecting sets of 10 houses per cluster resulting in an additional 6 households.*

between clusters, a sample size of just one cluster would involve no loss of efficiency. However at the other extreme, if there were no variation within clusters, surveying more than one household per cluster would be a waste of time. All possibilities between these extremes are possible. In default of any real evidence on which to base an optimal sample size per cluster, it becomes simply a matter of taking as many clusters as possible given the resource constraints.

The cluster dimension[17] also has implications on both the representativeness of each cluster for the geographic locations it represents and the logistic simplicity of monitoring them. As stated before, the reason for clustering is the geographic spread of the sample households. However, the use of clusters which are very small could lead to very homogeneous clusters. A very homogeneous cluster has the effective status of a single observation, not only in estimating an overall mean, but also in estimating differences of means of various subsets and regression slopes. Certain subsets of interest (e.g. householders with high income) may end up appearing in very few clusters, so reducing the effective sample size to one or two. While in a non-clustered sample these households would end up scattered over New Zealand, in a clustered sample they may all end up living in the same place - increasing the risks of spurious correlations arising. The problem is reduced as clusters become more heterogeneous, so that the households with characteristics of interest are scattered among them.

Cluster No	*Area Unit*	*Territorial Authority Description*	*Region*	*North/South Island*
1	Kamo West	Whangarei District	Northland	N
2	Wairoa	Wairoa District	Hawke's Bay	N
3	Mangapapa	Gisborne District	Gisborne	N
4	Oamaru South	Waitaki District	Otago	S
5	Wai-Iti	Tasman District	Tasman	S
6	Kaikohe	Far North District	Northland	N
7	Seddon	Marlborough District	Marlborough	S
8	Tamatea North	Napier City	Hawke's Bay	N
9	Rangatira	Taupo District	Waikato	N
10	Awhitu	Franklin District	Auckland	N
11	Minden	Western Bay of Plenty District	Bay of Plenty	N
12	Waikanae Central	Kapiti Coast District	Wellington	N
13	Orewa	Rodney District	Auckland	N
14	Arapuni	South Waikato District	Waikato	N
15	Sherwood Rise	Whangarei District	Northland	N
16	Parawai	Thames-Coromandel District	Waikato	N
17	Foxton Beach	Horowhenua District	Manawatu-Wanganui	N
18	Ngakuru	Rotorua District	Waikato	N
19	Western Heights	Rotorua District	Bay of Plenty	N

Table 6: Rest of New Zealand area units

Such considerations have prompted us to use statistical area units as clusters. These area units are combinations of approximately 25 meshblocks each. Table 6 shows the randomly selected area units. It can be seen that, of the 19 clusters, 16 are in the North Island and 3 are in the South Island. A map of the country, showing the locations of the Rest of New Zealand clusters as shown above, and the larger regional strata, is given in Appendix 10.3.

[17] *How large the clusters are geographically.*

2.3.2.4 Implications of Clustering

By the use of sampling with probability proportional to size, the self-weighting nature of the design has been maintained. In forming estimates of national averages and other statistics[18] clustering may be ignored, with estimates formed in the same way as if clustering were not used.

Additional difficulties caused by clustering will arise in the estimation of standard errors and the judging of statistical significance. To take the simplest case, the standard error of a population mean over a stratum in which clustering is used is usually based on the variation between cluster means, and the 'sample size' used to scale down the variance is the number of clusters, rather than the number of households. This is normally a relatively straightforward business, but in this case the interaction with the appliance selection strategy will cause problems. It is likely that for some appliances, no observations will have been made in some clusters. Different considerations will arise in various cases[19]. To obtain valid estimations of the precision of such things as correlation and regression coefficients in clustered samples is not in any case straightforward and will be made less so by the interaction with the appliance selection strategy, and it may be that we will have to fall back on broad approximations.

2.3.2.5 Timetable of Monitoring

The order in which regions were to be monitored was originally based on the willingness of power companies to participate in the study, but this new selection system requires no such dependency. However, due to insufficient historic data, some decisions must be based on educated guesses, together with other aspects of the project such as marketing etc. On these grounds, it was therefore decided to conduct the 2001 monitoring in the Auckland urban areas.

This has the advantage that one of the main population growth centres is being monitored at present with the results available shortly. The alternative of monitoring households in the South Island was considered. This alternative would have had the advantage that an understanding of climate-related energy variations would have been available sooner, since no statistically reliable results are yet available for the South Island. In contrast, the Hamilton data could have been used as an approximation for the Auckland climate. The current capability is to monitor approximately 50 households per year. There are 97 HEEP households in the Auckland urban council areas (Auckland, Manukau, Waitakere, and North Shore cities). Logging therefore has to be spread over two years. For logistical reasons, it is desirable to conduct the second year of Auckland monitoring in the immediately following year (2002)[20].

Most clusters are so far from each other that there is little logistic advantage of monitoring them in any particular order. Almost each of the clusters will require a separate download person and installation travel arrangements. Because of these considerations, the order in which the clusters are being monitored can be random.

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[18] *Such as differences between types of household, or regression coefficients.*

[19] *For example, with infrequently monitored appliances in which a single appliance is monitored in a few clusters, the sample could reasonably be treated as not clustered.*

[20] *Another consideration is that the clustered data should possibly be monitored in the same years as the non-clustered data. Otherwise similar bias correction problems may occur as described previously, i.e. if all clustered households are monitored in one year it will be difficult to distinguish the climatic effects of the specific year from the effects from the socio-demographic characteristics of the clustered meshblocks (predominantly rural). Therefore is would be desirable to monitor some clustered houses in 2002, as well.*

2.4 Data Gathering & Monitoring

Social, economic, demographic and physical information is gathered on each house and household. During a building audit and survey, the following is collected:

- ***Socio-demographic and physical surveys****: in a face-to-face interview, information on socio/demographic characteristics of the household members as well as energy behaviour is collected. This takes from one to two hours.*
- ***House plans****: obtained from the local council - allows evaluation of the thermal performance of the building by examining orientation, materials, glazing type, envelope insulation etc.*
- ***House audit****: a walk-through audit is conducted, noting factors that affect energy consumption*[21]*. Information is also collected about major appliances, such as age, model, and power consumption. Photos are taken of all monitored appliances and the house exterior. Water temperature and shower flow rate are measured.*

Energy use: in all households the total and hot water electricity use is measured, as well as total energy use for each other fuel type (natural gas, LPG, coal, wood).

- ***Appliance monitoring****: in a subset of households, the energy consumption of individual appliances is monitored.*
- ***Electricity circuit monitoring****: in a subset of households, all fixed-wired appliances, particularly heaters and hot water heating, are monitored if on separate circuits. The metering equipment allows monitoring of up to eight power circuits, which are allocated in accordance with the ranking of the estimated consumption of this type of appliance.*
- ***Reticulated gas****: additional pulse-output gas meters are installed in the gas lines. These are connected to a small logging unit to measure gas consumption.*
- ***LPG****: thermocouples are installed in front of the LPG heater grill and the temperature readings are converted into energy terms.*
- ***Solid fuel****: thermocouples are attached to the burner. Occupants are asked to record their approximate daily fire wood use for calibration purposes.*
- ***Historical data****: monthly electricity and gas usage records for the last five years are retrieved from the local utility company.*
- ***Temperature monitoring****: temperatures are logged every 10 minutes to provide data on how the house responds to changing external conditions and the use of heating and ventilation.*
    - ***Internal****: three sensors are distributed around each house.*
    - ***External****: about 20% of houses will have an external sensor. These are geographically spread so that all houses will be in vicinity of a monitored site. Data from the NIWA climate database is also used.*

The average house monitoring cost is approximately NZ$7,000 per house, compared to similar studies overseas, that vary between NZ$10,000 and NZ$21,000 per monitored house [5].

Budgeting constraints required the development of low cost innovative monitoring approaches. In most cases, a trade-off had to be accepted between the accuracy of the results, labour intensity in data processing and the cost of the installation, data retrieval and equipment. Some methods have been tested only in the laboratory environment so far, and we have not yet been able to verify the methods in the field. Other methods have been revised following the pilot study, after discovering that the data quality was not acceptable.

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[21] *Insulation, thermal curtains, double glazing, hot water cylinder grade and settings, shower flow rates and general house conditions (dampness, mould, etc.).*

2.5 Proposed Remote Logging Strategy

Remote logging is required so that households in isolated areas can be monitored, in order to allow the HEEP study to include a wider range of rural as well as urban households within reasonable costs. The basic idea is to send loggers to the households monthly, along with details of where to connect the loggers. At this stage, remote logging can only be carried out on total load households. In the future it may be possible set up remote logging for EUM households by using a phone connection.

2.5.1 Method

Each month a package with the required loggers and a prepaid postbag will be sent to the home being monitored. The loggers will have been preset with the correct date and time. The prepaid bag is used to return the loggers from the previous month.

Each type of logger will be colour-coded for quick and easy recognition using a coloured sticker on the front of the logger:

- *BRANZ Temperature Loggers - Red*
- *BRANZ Pulse Loggers – Yellow*
- *Microvolt Loggers – Blue.*

On the back of the logger, another sticky label will be placed with the information on where the homeowner needs to place or connect the logger and the file name.

When homeowners receive the package, they will disconnect the old loggers and connect or place the new loggers in the position described on the logger stickers. They will also fill in the finish date/time and meter reading (where required) on the old logger and the start date/time and meter reading (where required) of the new logger. The old loggers will then be posted back for processing.

When loggers are initially installed at the commencement of monitoring, homeowners are given a calendar. The idea behind this is twofold; firstly to provide a list of contact names and numbers at the back of the calendar, and secondly to allow the noting of any information that may be useful for the study i.e. new appliances or major power cuts etc. They will also be provided with a list of' '*things we would like to know'*. The use of the calendar means that all information is put in one place and automatically dated. This information will be either passed on via a monthly phone call, or each month the previous calendar sheet could be torn off and sent with the return loggers.

2.5.2 Training for Homeowner

Training will be done as part of the initial installation. Once the installation has been completed the leader of the installation team needs to show the homeowner what they are required to do:

a) Show homeowners what each type of logger looks like, what their purpose is and, if required, how to connect them.

b) Go around the home and identify where loggers are.

c) Show, using dummy loggers with stickers, what will be received by mail and what they are required to do in terms of filling out the information on the sticker and returning the loggers.

2.5.3 Keeping the Homeowner Involved

Because there is a long time period from the time logging starts in a house to the time the homeowner receives any information, it is important that their interest is maintained, so that loggers are swapped correctly and promptly each month. With the process outlined above, steps have been made to ensure this will happen:

- *amount of input from the homeowners is minimal and simple*
- *follow up phone call allows for any communication*

- *calendar to record appliance details etc, with contact details on each page and possibly the day on when the loggers should be swapped already determined*
- *similar incentives to other households being monitored.*

2.6 House Construction Types

During the period covered by this report, the Foundation for Research Science and Technology contract covering the HEEP data analysis changed[22]. The contracted objectives shifted away from specific research elements of the programme to the development of outputs, including a socio-physical model of household energy use. A part of the earlier contract was specifically concerned with the obtaining of data on the energy performance of less common wall construction types in comparison to other construction types. The need for this data continues, and the following section reports on the initial investigation.

2.6.1 Method of Selecting Types

A number of low volume wall construction types were considered by BRANZ specialists on Fire, Structure, Moisture, Durability, Energy and Marketing, and ranked according to current market penetration and future market potential. Each was scored under a number of performance and practical aspects. Different wall construction types have different thermal performance characteristics. These are mainly determined by two physical properties: thermal resistance of component layers and their thermal mass. The amount and the placement of component parts, which make up a complete wall, affect its overall physical properties and lead to different dynamic behaviours, resulting in different indoor temperature patterns and heating requirements.

2.6.2 House Type Selection

The objective is to understand the potential impact of emerging new wall construction types on the national energy consumption, and its consequences for the indoor environment. Considering this aim, the selection criterion should be based on the potential of the new construction method to become widespread and on the extent to which it differs in performance from current common construction methods. On this basis, the following construction types have been identified to be monitored:

- **Concrete masonry**: *this has scope for significant marketplace expansion. Some innovative designs, using the heat storage properties of concrete and external or inbuilt insulation, are being built and the recent revisions to masonry non-specific design standard make it easier for builders and designers. Through its thermal mass properties, high mass housing may offer the potential to dramatically change the energy consumption and the comfort levels achieved in future housing.*
- **Tilt-up slab wall**: *similar to concrete masonry construction, the thermal mass properties may change energy consumption and comfort levels achieved in future housing.*
- **Polystyrene block**: *among the emerging construction methods, concrete infill polystyrene blocks have potential for market share growth. Their potential is based on the increased speed in construction.*
- **Solid timber**: *this type of construction has a small share of the NZ market. Some new product developments aim at addressing the problem of low insulation qualities. There is anecdotal evidence that solid timber houses provide a comfortable living environment. It is therefore of interest to see if this is able to be backed up by quantitative research results.*

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[22] *FRST Contract BRA 805."Energy Use and Management in Residential Buildings" was renegotiated to become Objective 1: Energy Use and Management in Buildings in FRST Contract BRAX0002 "Better Built Environments"*

- **Light steel frame**: *these show sufficient growth potential to justify closer investigation. However, with the exception of thermal bridging issues, they are expected to behave in a similar fashion to common timber framed construction.*
- **Wood based panels**: *these have sufficient market potential and unique thermal properties to warrant an investigation.*

2.6.3 Monitoring

Timber framing is likely to remain the dominant construction method in housing. Out of the other wall construction types, **concrete masonry**, **polystyrene block** and **solid timber** walls are of particular market interest. These three wall construction types also have quite different thermal properties to the common timber framed wall. It is therefore planned, where possible with the support of the industry, to collect energy and temperature data from a number of these low volume construction types, and to contrast them against timber frame construction. Light steel frame construction and wood based panels are alternative types that may be investigated.

Due to budget constraints, the monitoring sample size of each low volume construction type will probably be small. Also, as well as the basic wall type, the design of all other construction elements together with the occupants' behaviour will influence thermal performance. In this context, the result of this study is expected to provide a snapshot of some individual cases rather than a general understanding of differences in performance of various construction types.

2.7 Monitoring of Solid Fuels

HEEP aims to investigate the energy effects of all household fuel types. This is necessary in order to estimate the likely implications of changes in use of different energy sources. Fuel switching occurs for a variety of reasons, including the availability of fuels and appropriate appliances, as well as local issues. For example, between 1986 and 1996, the proportion of households using gas for heating has increased from approximately 10% to about 35% with consequent implications for the energy supply system. Given the importance of space heating, emphasis has been put on ensuring the HEEP monitoring covers solid fuel burners.

A significant number of New Zealand households currently use solid fuel for space heating. The measurement of solid fuel is particularly difficult, since a number of factors are unknown, including:

- *properties of the solid fuel – e.g. moisture of wood, firing rate of the wood etc.*
- *properties of the heater – e.g. efficiency of the appliance*
- *occupant behaviour – e.g. leaving the heater to burn down over night.*

Three approaches were investigated in respect to determining the heat output of solid fuel burners:

- **Logbook calibration**
- **Modified Short Term Energy Monitoring (STEM) calibration**
- **Artificial Neural Network (ANN) calibration.**

The first is based on occupant-recorded information, while the latter two use a calorimetric approach by modelling the thermal building parameters and determining any 'missing heat' which is then used to calibrate the measured temperature data.

2.7.1 Logbook Calibration

This approach relies on temperature readings of the solid fuel burners in conjunction with a record of burnt firewood as kept by the occupants.

Usage data is recorded by the occupants, in terms of 'logs' of firewood. This record is then converted into a weight measure (based on an initial calibration made during the survey), and multiplied by the estimated heater efficiency. This efficiency is based on literature values, as far as they are available. One difficulty is that the efficiency of the heater varies, depending on the damper setting and on the type of wood and the burn rate of the wood, so the conversions will not always be as accurate as desirable.

The corresponding temperature readings of the solid fuel burner are uncalibrated thermocouple temperatures. When the two sets of data are plotted over time, there will be instances where the logbook records will not correctly relate to monitored temperatures. In order to calibrate recorded temperatures, the cumulative logbook recorded data is plotted against cumulative temperature measurements. Any days when the logbook entries are missing are eliminated from the temperature data set in order to correlate the logbook heat and the actual measured heat.

2.7.2 Modelling Approaches

Two alternative approaches were used to model the thermal performance of the building. Both methods show limitations and the research is ongoing. The detail of the analysis approach and the results will be published once the procedures have been further explored.

2.7.3 Modified STEM Calibration

The first approach is related to the Short Term Energy Monitoring (STEM) method developed for use in the BREHOMES [6] national heating model for the UK, and was used previously to determine the thermal parameters for four households in the HEEP study. In general the STEM approach requires that the house is heated and cooled down in a controlled way for several nights. The modification used in the HEEP approach is that this requirement is dropped. Instead, a subset of times during the occupied monitoring period is used for the analysis. In this case, although the method does not provide useful results on the basis of individual days, on average the errors mostly cancel each other out over the 12 month monitoring period.

2.7.4 Artificial Neural Network (ANN) Calibration

This approach is similar to the STEM approach in that it uses a building energy performance model to estimate the required heating energy in order to achieve the measured temperatures. The STEM approach is based on a set of clearly defined building parameters, such as the building conductance, the thermal mass and the solar opening of the building. In contrast, the ANN method uses environmental and measured parameters directly in order to establish the expected heat load. On one hand this method loses a lot of the transparency of the building model, but on the other hand it allows a more flexible approach in cases where the building parameter cannot be determined, due to the complexity of the building response.

3. DATA ANALYSIS UPDATE

3.1 Broad Level Statistics

The 1971/72 electricity survey [1] generated data that has not been revised or updated over the past 30 years. Since that study, it has commonly been held that hot water uses about 33% of total electrical energy, while lighting uses about 8%.

Some broad level statistics are now available from this project. These can be compared to the figures commonly used for the past 30 years. The new results are based on random households monitored to date, and future reports will update and add to these as more households are monitored and more results are available for analysis. However the present findings can still be considered as valid for Hamilton and Wellington, and possibly indicative of New Zealand's households.

- ***Total energy***: Average overall total (excluding LPG) 9000 kWh/year /house
  - Gas only 2359 kWh/year /house
  - Electricity only 6676 kWh/year /house
- ***Hot water***: Average overall energy use for hot water heating (inc. gas) 4000 kWh/year /house
  - *% of total energy for hot water heating (gas & electricity)* *44%*
  - *% of electricity used for electrically heated hot water* *42%*

  Average hot water standing loss[23] 1000-1100 kWh/system /year
  - *% of total energy* *11-12%*
  - *% of hot water heating energy* *25-30%*
- ***Lighting***: Average lights (circuits only) 740 kWh/year/house
  - *% used for lighting* *8%*
- ***Standby & baseload power***[24] 920 kWh/year/house
  - *% of electricity used for standby & baseload* *10%*

The interesting points arising from the limited findings are in relation to the relative importance of hot water and lighting energy to the total energy used by households, as illustrated in Figure 3.

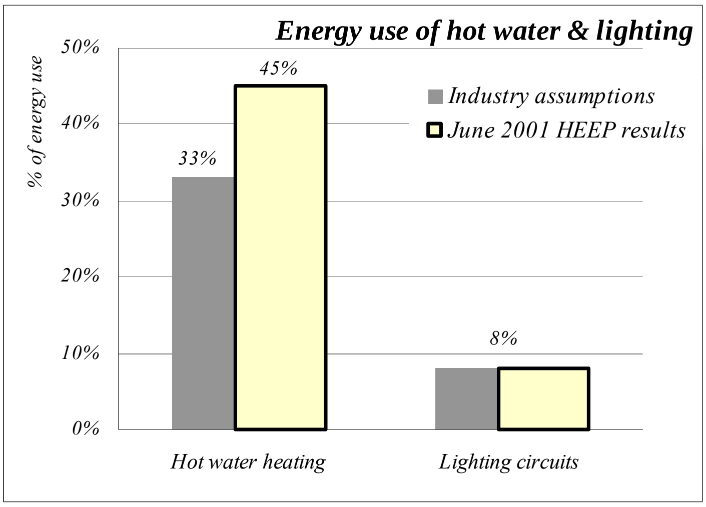


Figure 3: Importance of hot water and lighting energy consumption

While these figures will undoubtedly change as the number of monitored households increases, it is considered to be unlikely that they will decrease markedly. In fact, the water-heating component may

[23] *Corrected for annual average temperatures.*
[24] *Including off-cycles of refrigeration appliances and continuously operated heated towel rails.*

well increase as more households in the milder areas of the country are completed[25], although this may be balanced by those in colder areas such as Christchurch.

Hot water heating thus appears to play a significantly greater part in domestic energy consumption than has been assumed, which is an important factor to take into account when considering future emphasis in regard to both energy efficiency and conservation initiatives.

3.1.1 Statistical Validity

The project has passed an important milestone with the completion of HEEP monitoring of randomly selected households in Wellington and Hamilton. This means that the sample now represents 170,000 households, or approximately 13% of New Zealand households, and that the analyses done on these results can be said to be indicative of the behaviour of that population of households.

In previous years, analysis has in part used non-randomly selected households from the pilot studies. It was therefore not possible to generalise the results of those analyses to the population. When the current monitoring of households in the Auckland region is completed at the beginning of 2002, the HEEP sample will represent 340,000 households, or 27% of the country. Monitoring the remainder of the Auckland households will optimise the statistical validity for that area. As each new area is monitored, more New Zealand households will be represented in the HEEP sample. The progress is expected to be about 20% to 25% per year, leading to a rapid increase in data and knowledge about energy end-uses in New Zealand houses.

3.2 Extrapolation from Part-Year Monitoring

During the pilot study of 28 households, the monitoring period was limited to about six months per house. This allowed us to double the sample size. Data was recorded over half a summer and half a winter period together with the included transition season, with the intention to extrapolate the recorded time series to full average climate years.

Variation in energy end-use depends on many factors, including time of year, temperature, sunshine, and occupant behaviour. Investigation of monitored energy data indicates that only a small number of appliance types show strong climate-related fluctuations. These include:

- *heating energy*
- *lighting*
- *hot water energy*
- *refrigeration.*

Annual extrapolation has been attempted for lighting, hot water, heating and refrigeration end-uses so far, based on external environment variables such as the day length and the external temperature.

3.2.1 Lighting

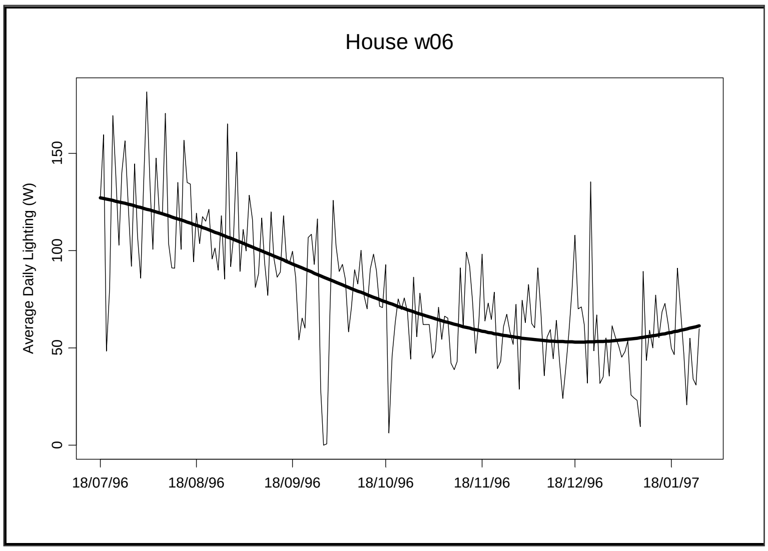
Lighting circuits were monitored for 25 of the 28 households from the pilot study. Plug-in lamps were not included and may be a significant but presently unknown fraction of the actual lighting used.

As expected, daily lighting demands show a trend for most households of increased demand during the winter months, as illustrated in Figure 4. There is no obvious change observable in lighting energy demand for any house when daylight saving was applied or removed[26], and a detailed statistical analysis found no effect. This may be due to an increase in evening lighting being offset by a decrease in morning lighting at daylight saving start and vice versa at daylight saving removal.

---

[25] *Auckland may well show a higher % for water heating, as less space heating is expected in that milder climate. Early results should be available by April 2002.*

[26] *In this example, first Sunday in October and last Sunday in March.*



A cosine function with a one-year period centred on June 20th (the shortest day) is used to fit the average daily lighting demand.

This function gives reasonable representation of the seasonal trend for most of the households.

The standard error is calculated over the daily lighting energy use during the monitoring period.

The application of this extrapolation method makes it possible to predict the expected average lighting use for any day of the year.

Figure 4: Lighting energy over 5 months

3.2.2 Hot Water Cylinders

Hot water cylinders heat water from the temperature of the main water supply to a pre-set thermostat temperature (within the accuracy of the thermostat). As the temperature of the intake water drops, more energy is required to heat it to the required temperature. Monitoring to date has found a strong trend of higher hot water energy use during winter months compared to the summer months. The impacts of possible changes in water temperature and any occupant related factors have yet to be investigated in detail.

The external daily mean air temperature is used to predict the daily average hot water energy consumption, using a linear regression model. The objective of this part of the analysis is the long term predictions, extrapolation of medium term measurements and the normalisation of energy consumption to climatological norms. Analysing average data improves the model fit, eliminating some of the short-term effects of occupant behaviour. The analysis is therefore performed using 13-day[27] moving averages for the external temperatures and hot water consumption. Investigation shows that the correlation for these linear models is generally quite poor (average r^2 =39%, average temperature dependency 0.66kWh/day°C, with a median value of 0.27kWh/day°C), which may reflect the large impact of varying user behaviours.

3.2.3 Heating

New Zealand houses are generally heated by stand-alone heaters, which have no or only very simple thermostat controls and are generally not timer controlled. Some households use 'night store heaters' but these are largely decoupled from the external temperature conditions, i.e. they are generally completely discharged at the end of the day, independent of the climate conditions. Their recharge energy is affected by the temperature of the intake water, which is lower in winter. Thus heating energy consumption is largely dependent on occupant behaviour. Other difficulties include the use of non-electric heating such as reticulated gas, LPG or solid fuel, which are more difficult to measure.

One of the crucial requirements for a successful extrapolation is that the heating energy is monitored for a sufficiently long period, and that it covers both the months of maximum usage and the months during which heating commences. This is often impractical using the half year monitoring schedule because of the technically unavoidable delays between removal of the equipment and the subsequent installation in the next set. Also, hysteresis effects cannot be easily identified on the basis of the short

[27] *13 days is approximately the time constant for air to ground temperature coupling to a depth at which supply water pipes are buried.*

monitoring period. For all these reasons it has proved difficult to establish correlation models of heating energy use, which would allow extrapolation of the measured 6-month data to full years.

3.2.4 Feasibility of Extrapolation

Based on the above findings from the pilot study it was decided to abandon the half-year monitoring schedule in favour of monitoring each set of households for a full year. Nevertheless, estimations of energy usage have to be made for 'average' climate years. This will require similar types of analysis as used for the annual extrapolation. The following section describes further work on the problems of heating extrapolation.

3.3 Heating Extrapolation

The patterns of heater use and user behaviour appear to be very complex. Many HEEP households heat intermittently, with poor temperature control and variable heating schedules, which makes modelling the heating energy difficult. In addition, extrapolation of heating must be done using only environmental variables such as meteorological data (temperatures, solar radiation etc) and the physical characteristics of the house.

3.3.1 Correlations with Temperatures

As part of the process, correlations of heating energy and external temperatures were examined. The correlation between heating energy and daily mean temperatures was quite poor. This is not unexpected, as people heat mainly in the evenings, so that the functional relationship between heating energy and external temperature is expected to be non-linear. Correlations using evening temperatures were better, and those using temperatures when heating was used were even better. Correlations also improved when daily degree hours were substituted for temperatures, although there was no obvious 'best fit' in terms of maximal correlation. The intermittent nature of heating in many HEEP households does not allow simple correlations between heating energy and daily temperatures or heating degree days. Thus only the heating period must be examined for correlation purposes.

3.3.2 Correlation with Heating Degree Hours

As correlations of heating load with external temperatures were poor, another approach was tried. The heating degree hours were compared with the heat load during heating hours only.

This is necessary, as zoned, intermittent heating does not allow comparisons with average temperatures or daily parameters.

For each house, a weekday and weekend heating schedule was defined and heating and temperature data gathered for those periods.

The heating degree hours were then calculated for a variety of base temperatures, and averaged on a weekly basis.

Figure 5 shows a weekly time series for this data.

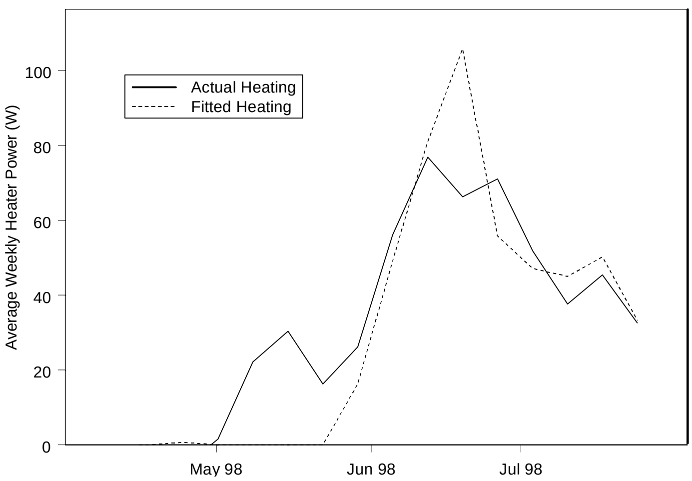


Figure 5:Time series plot - average weekly heating power vs heating degree hours

The base temperature that gave the best overall fit to the time series was then chosen for the model. The parameters of the model fit for this base temperature were then used as the basis for prediction of heating loads from external temperatures. A base temperature 13°C was selected as provide the best fit – implying that this is the threshold temperature at which HEEP households start up heating.

3.3.3 House/Room Heat Loss Calculation

A method is described here for estimating the heat loss of a room as a function of temperature difference between inside and outside. This was done as a preliminary to the full STEM modelling. Data is selected from periods when heating is in general use, so that the user behaviour is minimised. Data is selected by:

- *subsetting by time of day to a period of high heater use*
- *subsetting only those days on which heating is used.*

From this subset, data is grouped according to temperature, in 1°C groups, on external temperature and internal/external temperature. For each group the average heating energy is calculated. The results are plotted, and a robust line fitted to each. The slope of the line is expected to be the whole room heat loss (units: W/°C) if the heater is the main heat source for the room, and the room is adequately heated.

Fitted coefficients were calculated for a number of Wellington households. The method appeared to work best for lounge or main heaters, especially for those with central heating systems.

3.3.4 STEM Thermal Model

A simple (single mass node) thermal model has been applied to the HEEP households. This treats the house as a thermal circuit with one heat loss element and one heat storage element. The STEM methodology was applied under contract to a set of four HEEP houses by Robert Bishop in 1998 [7] in order to test its applicability to the whole HEEP samplings strategy. The tested model can be written as:

$$q_{heat} = UA \cdot (T_{in} - T_{Out}) + mC_p \left(\frac{\partial T_{in}}{\partial t} \right)$$

Equation 1:Heat model equation

where:
- q_{heat} = instantaneous delivered heat to house interior by internal gains and heating (W)
- UA = whole house heat coefficient (W/°C)
- T_{in} = interior air temperature (°C)
- T_{out} = external air temperature (°C)
- mC_p = thermal mass of the house (Wh/°C)
- $\frac{\partial T_{in}}{\partial t}$ = rate of change of interior air temperature (°C/hr)

The model is based on night time measurements, so solar gains may be ignored, providing that the storage capacity of the building is not too large. Sources of internal gains include:

- *elctric, gas, and solid fuel use in the house*
- *solar gains*
- *gains from occupants.*

Only the first of these, the total energy load, is monitored in the HEEP houses. To use Equation 1 to estimate UA and mC_p for a house, the other loads must be accounted for in some way.

Solar gains are particularly difficult to deal with, as they vary with the weather, time of day, season, and occupant behaviour (such as the use of curtains). Avoiding daytime periods eliminates solar gains as a factor. Gains from occupants can either be ignored, or estimated by the number of occupants at home during the period of interest, which was surveyed for the HEEP houses.

The time lag in the heat transfer between the thermal mass and internal air, or between the interior and exterior, is not accounted for in this model. To minimise potential problems with these time lags, the model is fitted in two stages:

a) *During periods of evening heating, when there are no solar gains, and the temperature in the house is maintained at a steady temperature – refer Equation 2.*

b) *Between about midnight and 6am, when no heating is supplied, and the house is cooling down – refer Equation 3.*

As the rate of change of internal temperature is approximately zero during evening heating, the equation being fitted for period a) becomes:

$$q_{heat\ Evening} = UA \cdot (T_{in} - T_{Out}) + C_1$$

Equation 2: Evening heating period

where: C_1 = small error term

Data is selected from evenings when heating is applied, and the rate of change of temperature is low. Once the data is selected it is averaged by grouping according to the temperature difference. This step is required as the heating is often intermittent. The data is then plotted, for example as in the top graph of Figure 6. The fitted line is the model in Equation 1, with an extra term to account for thermal mass effects.

Even a small change in internal temperature represents a significant amount of heat absorbed or released by the thermal mass. At the point T_{in}-T_{out}<0 the internal temperature is lower than the external temperature, and if T_{in} is well below the desired temperature then a large amount of energy must be used to warm up the thermal mass. This is heating energy applied by the occupants without having any appreciable effect on raising the indoor temperature above the outside temperature. This often occurs when people come home in the evening to a cold house. The amount of this warm-up power is probably closer related to the heating equipment used and the occupants' heating behaviour than to the thermal properties of the building. It is called the warm-up load, and is ignored by the robust line fitting technique. The slope of the line is UA.

For the unheated night time period, q_{heat} is assumed to be either much smaller than the other terms or constant, and the equation being fitted for period b) becomes:

$$q_{heat\ Night} = UA \cdot (T_{in} - T_{Out}) + mC_p \left(\frac{\partial T_{in}}{\partial t} \right) + C_2$$

Equation 3: Night time unheated period

where: C_2 = constant heat from internal gains

In this case, data is selected from the early morning period on days when no dedicated heating is applied, and the house cooled down steadily during each morning. Data are averaged by grouping according to the rate of change of temperature. The data are then plotted as shown in the bottom plot of Figure 6 and a line fitted. The slope of the line is mCp/UA. By using the slopes of two independent line fits, the intercept terms are not important. The intercept term represents unknown constant internal gains. Provided these unaccounted gains are constant over the period of interest, they can be ignored.

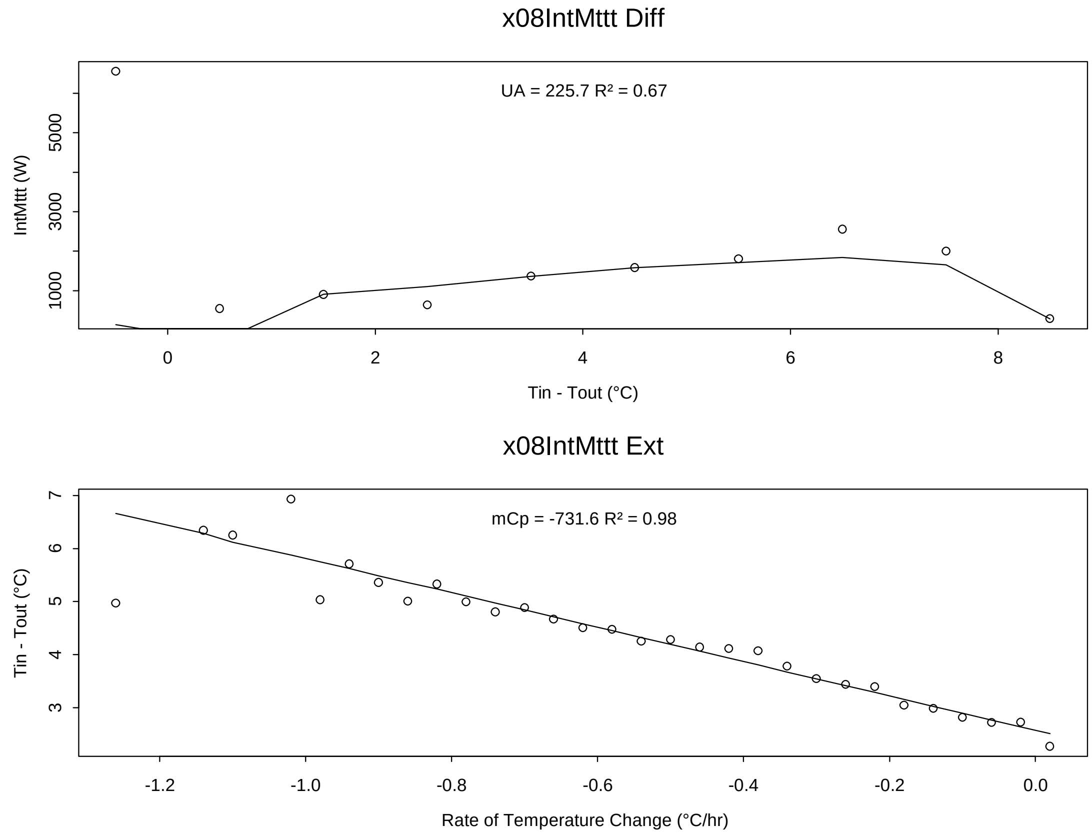


Figure 6: Fitted model plots

3.3.5 The STEM Model for a Discrete Time-series

The STEM model can be run to predict the internal temperature, or internal load in the house. To do this on the discrete time-series data the STEM equation:

$$q_{heat} = UA\ (T_{in} - T_{out}) + mC_p(\partial T_{in}/\partial t)$$

was converted to a difference equation as follows:

$$(\partial T_{in}/\partial t) = (UA\ (T_{in} - T_{out}))/\ mC_p - q_{heat}/\ mC_p$$

The time-series of data samples the continuous data at times $t_0, t_1, t_2 \ldots t_n \ldots$ To convert to a difference equation the differential term $(\partial T_{in}/\partial t)$ is approximated by:

$$T_{in,n+1} - T_{in,n} = [(UA \cdot (T_{in} - T_{out}))/\ mC_p - q_{heat}/\ mC_p\ ]\ \Delta\ t$$

where $T_{in,n}$ is the internal temperature at time t_n, and similar notation for the other variables, and Δt is the time between timestep n and n+1. So the internal temperature in the next time step is approximated as:

$$T_{in,n+1} = T_{in,n} + \left(\frac{UA \cdot (T_{in,n} - T_{out,n})}{mC_p} - \frac{q_{heat\ n}}{mC_p} \right) \cdot \Delta t$$

Equation 4: Internal temperature

This equation uses Eulers method to do the approximation. There are other methods available that are more accurate, but at the expense of greater complexity. They have not been tried and compared with this method yet [8 - techniques of difference equations are explained in Chapter 6, pg 314].

3.3.6 Estimation of Energy Loads

The difference equation can be used to estimate the energy loads within the house, if the internal and external temperatures are measured. Rearranging the equation as:

$$q_{heat\ n} = -mC_p\left(\frac{T_{in,n+1} + T_{in.n}}{\Delta t}\right) + UA \cdot (T_{in,n} - T_{out,n})$$

Equation 5: The difference equation

shows how this is implemented. A simple calculation on the temperature time series gives an estimate of the energy load time series. By subtracting the measured internal load (i.e. the sum of electricity, gas, and other loads in the house) time-series, a measure of the so-called 'missing load' is found. This missing load could include:

- *solar gains*
- *metabolic gains from people*
- *unmeasured loads*
- *hot water standing loss.*

3.3.7 Calibration by Prediction of Internal Temperatures

To successfully predict internal temperatures and applied heating, the internal load of the house must be known or estimated accurately. With whole house heat coefficients of around 300 W/°C, an error of only 100 W (about the metabolic rate of a single person) gives an error of 1/3°C in temperature. Solar gains may be much higher than this, even several kiloWatt, and so are a very important energy source. It was found that failing to account explicitly for solar gains leads to gross errors in temperature predictions. Using the equation for missing loads enables the identification and allocation of these loads, as well as providing a check on their magnitude.

Solar gains for a HEEP house are modelled by calculation of the solar insolation through windows. SUNCODE-PC routines were adapted and implemented in S-Plus to do this. Information required is:

- *solar radiation, direct and total*
- *window width, height, orientation, shade size*
- *horizon angle.*

To make predictions of applied heated based solely on meteorological data, a profile of internal loads excluding heating must be used, along with an assumed heating set point and schedule.

3.3.8 STEM Prediction

The STEM model can be run as a predictive model to predict the heating requirements for a house based on meteorological data. So far the results have not been as good as desired. Particular problems are the applicability and accuracy of the assumed heating set point and heating schedules. The extrapolated heating energies are extremely sensitive to these parameters. A summary of STEM parameters for a HEEP house is given in Appendix 10.6.

3.3.9 STEM Results

The STEM model was applied to selected HEEP houses to attempt to determine whole house U-values and thermal mass levels.

For each data subset described below, the 10-15 minute time resolution data was grouped according to temperature, and averaged. Internal temperatures were calculated as a simple average of all internal temperature sensors.

The whole house U-value was estimated using selected periods of data during the evening hours after sunset. The heating was for the entire internal gain, including applied heating, electrical and gas load, and occupant load. Data was selected from periods when the rate of change of temperature was low, to minimise the effects of thermal mass, and to avoid warm-up loads. Parameters were estimated from a two parameter robust regression (top plot in Figure 7).

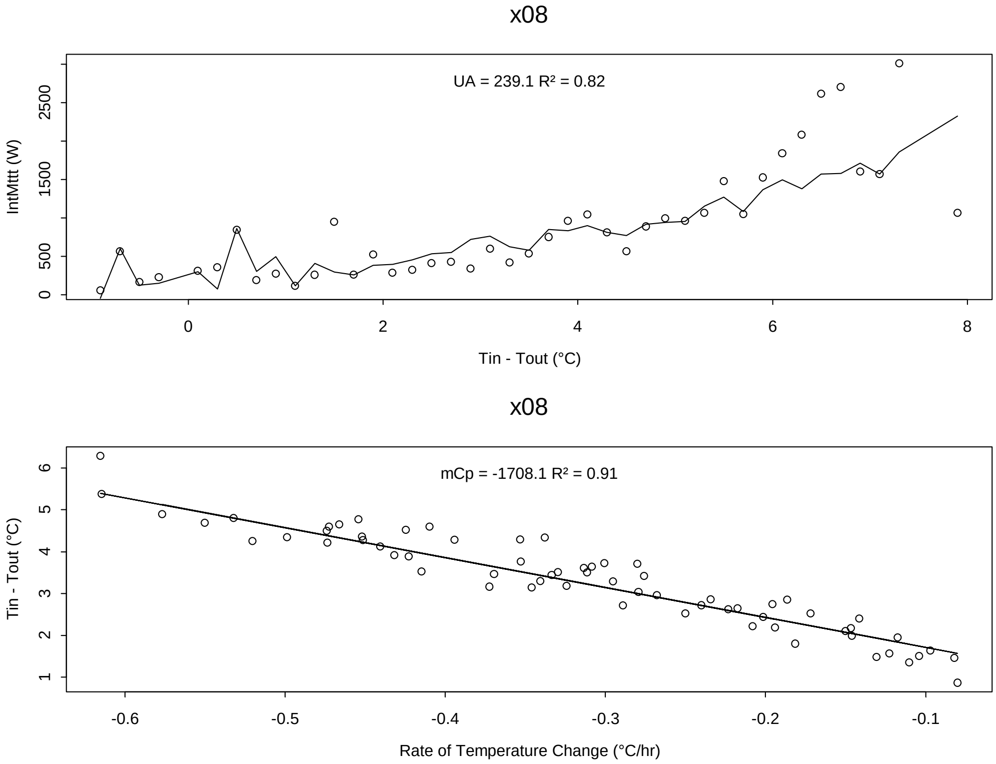


Figure 7: STEM model results

The whole house thermal mass was estimated using selected periods of data during the early morning, from around midnight to 6am (depending on the house). Data was selected only for periods when the temperature was NOT increasing, and the applied heating energy was low. This was to minimise the effects of applied heating, avoid recharge of the thermal mass, and minimise the difference between the thermal mass temperature and the internal temperature. The thermal mass was estimated from a one parameter robust regression (bottom plot in Figure 7).

The underlying data for the selected HEEP houses is given in Appendix 10.7.

3.4 Energy Profiles

Determining the load profile of a particular house, based upon the socio-demographic characteristics of its occupants allows the targeting of specific households groups for the purpose of demand-side management of peak energy deliveries with strategies such as load shifting.

The detection of such profile classes using artificial neural networks (ANN) is discussed in detail in the Year 2 HEEP report [7]. It is based on an automatic process minimising the differences within each of the different profile classes. The analysis was repeated in the HEEP Year 4 [9] analyses, including the new set of monitored households and with a number of different socio-demographic variables.

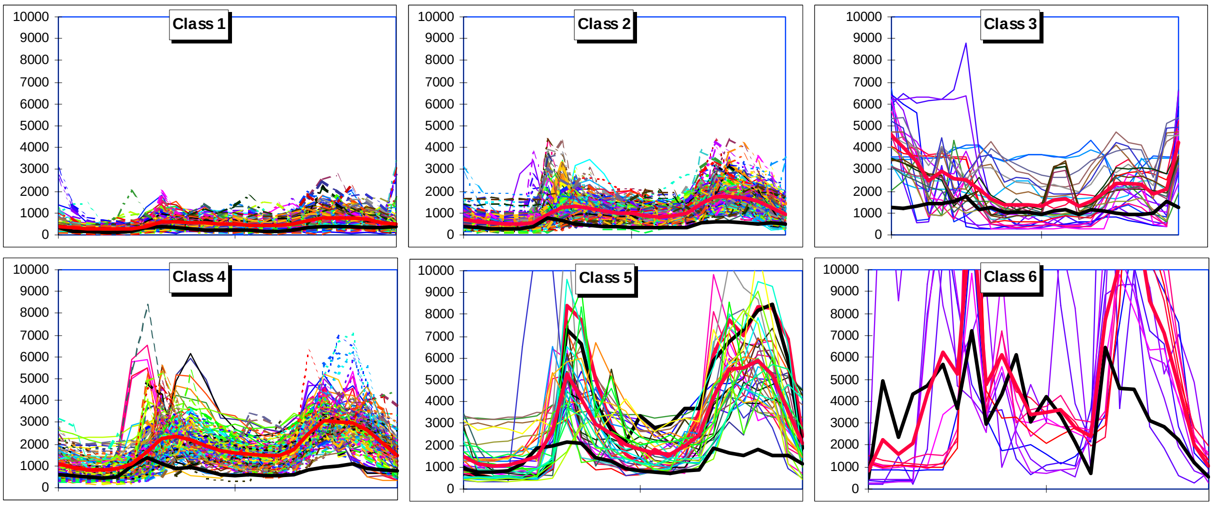


Figure 8: Energy profile classes (electricity and reticulated gas)
(Watts on the y-scale and a 24-hour time base on the x-axis)

Figure 8 shows the distinct 6 classes identified by the neural network. It distinguished primarily based on average energy consumptions with Class 1 the lowest and Class 6 the highest consumption. However the network also distinguishes between rather flat against spiky profiles (Class 4 against Class 5).

In order to try to identify possible patterns of occupancy during the day, the profile classes were further investigated. Figure 9 shows the frequency of occurrence of households with 'any occupants at home' ('*home*') and 'nobody at home' ('*away*') during the daytime for each of the profile classes.

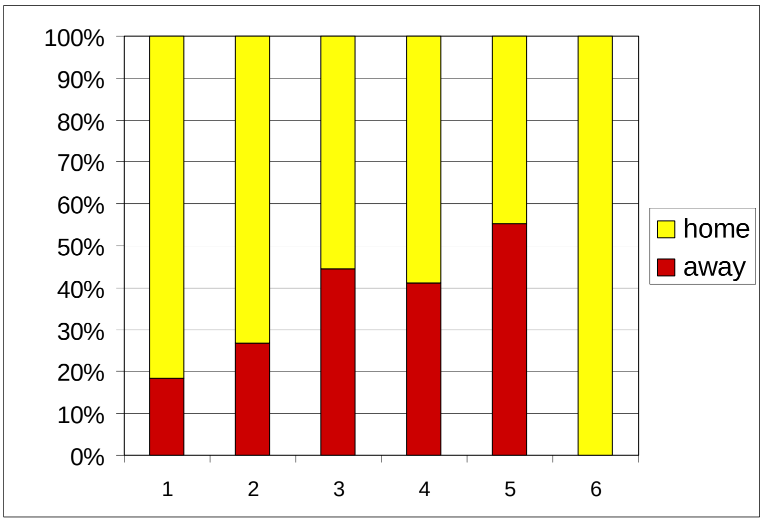


Figure 9: Frequency of people at home vs. away during the daytimes for each of the classes

Interestingly, Figure 9 shows a clear linkage between energy usage class and daytime building occupancy. With the exception of Class 6, the higher classes indicate that houses are more frequently unoccupied during the daytime. This is somewhat unexpected, because anecdotal evidence would suggest that people use more energy when they are at home. This analysis would instead suggest that when people are at home during the day they use less energy.

These results are very preliminary at this stage and the current set of data includes both randomly selected and targeted subgroups of households[28]. This may explain the surprising linkage of low

[28] *For example a set of 12 flats in Hamilton, which mainly is occupied by retired people.*

energy consumption and occupancy during daytimes. Another important factor is that the use of LPG has not yet been considered in this analysis, and this will have an impact on the results.

A more detailed investigation of the contributing profiles indicated that households tend to either have a non-changing profile class for the whole year, or they belong to two classes with the change generally occurring between September and October, and between March and April. This is a strong indication of the occurrence of an abrupt profile change caused by the use of room heating devices.

Socio-demographic characteristics of the occupants can be linked to profile classes in order to plan energy supply, transmission, and distribution networks, as well as giving the ability to target particular energy user groups with specifically targeted energy efficiency measures, or in developing tariffs appropriate to particular user groups.

3.4.1 Load Factors

Load factors are a commonly used way to describe how balanced load profiles are. A load factor is defined as the mean power during the monitoring period – generally one year – divided by the maximum power during this period. Load factors are generally calculated for the average load of large groups of electricity users. Because of this averaging effect, the group profiles are naturally smoothened. This approach is not quite suitable when analysing individual households, because load profiles in individual households have much larger fluctuations than the load profiles of consumer groups. Using the maximum load of an individual household for determining its load factor would distort the result because this maximum load may be a one-off occurrence of extraordinary circumstance and therefore very untypical for the rest of the monitoring period. Therefore a slightly modified calculation method had to be used: Instead of determining the peak load for the whole monitoring period, the time-series was first converted into twelve 24-hour average load profiles, one profile for each month. Then the maximum load of these profiles was determined and used in the load factor calculation.

Figure 10 shows the load factors for all monitored houses in Hamilton, Wanganui and Wellington. The graph shows that there is no significant difference between the mean load factors for the pensioner households and the other Hamilton households, which were randomly selected (p-value = 0.5). This result suggests that the load patterns between households occupied by pensioner and by non-pensioners are not significantly different in their peak load to base load demands.

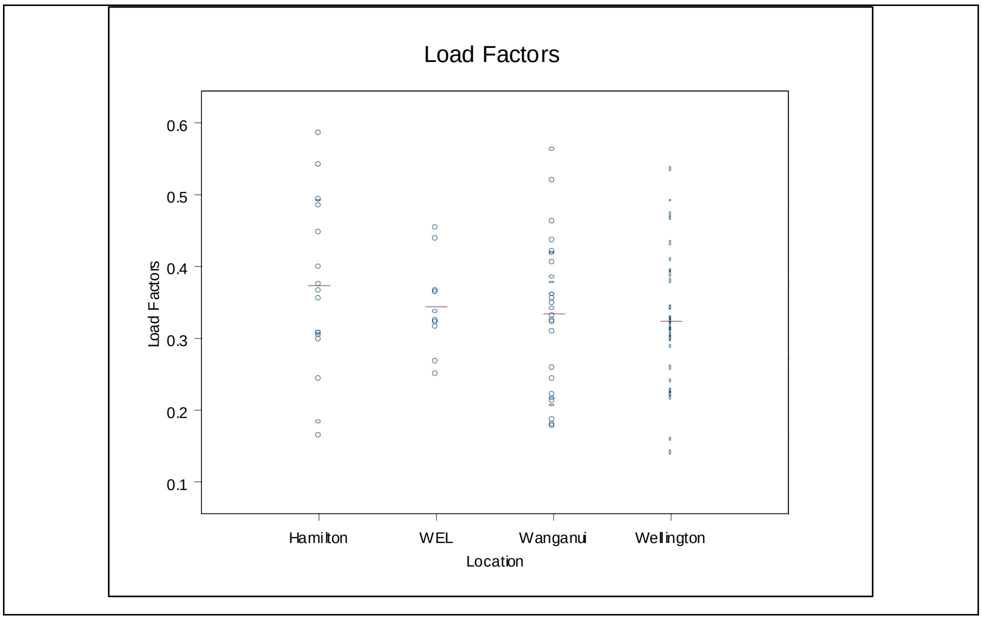


Figure 10: Power factors for monitored houses- Hamilton, Wanganui & Wellington

Note to Figure 10: "WEL" houses are a subset of townhouses in Hamilton, which are mostly occupied by super annuitants. Horizontal lines indicate the means.

To gain a more detailed understanding of the peak to average load relationship the load curves for the monitored houses were calculated using the time-series of total electricity consumption with a 1-hour resolution. The calculated load curves were then averaged across all households in the same population centre. Figure 11 indicates that the load curves for households in Hamilton have a steeper drop than the ones for other centres. In particular the households, which consist mainly of superannuitants ('WEL' households) show load curves, which suggest that their electricity consumption patterns contain fewer spikes than the patterns in other households.

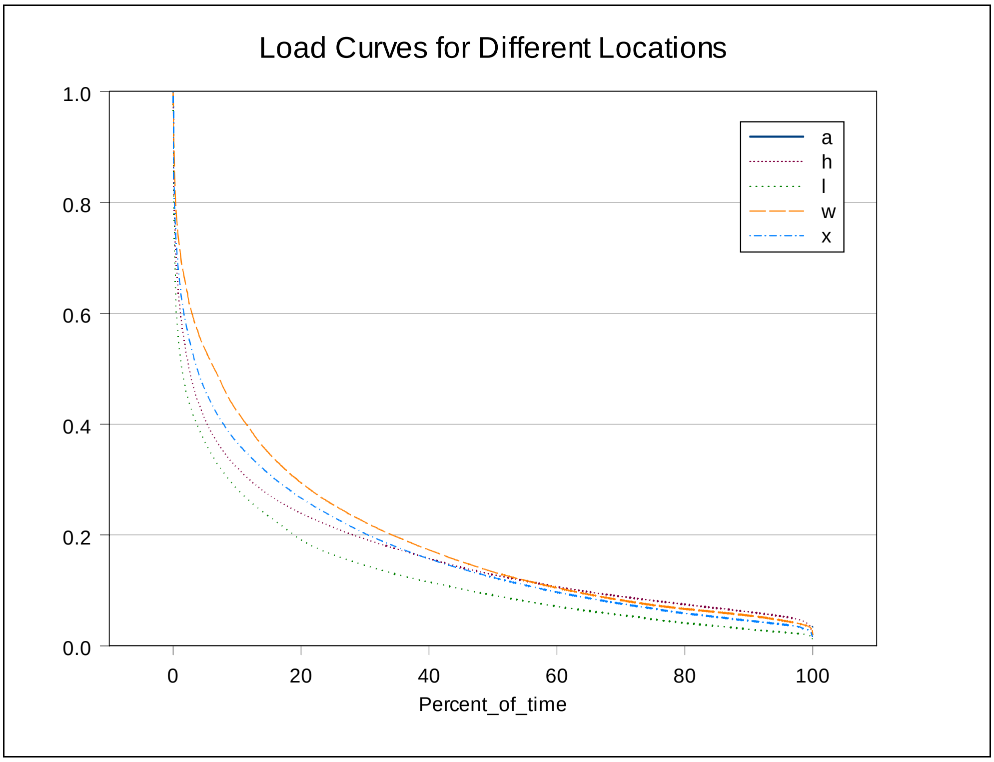


Figure 11: Load curves for the monitored houses

Note to Figure 11: Auckland (a), Hamilton (non-'WEL') (h), 'WEL' houses in Hamilton (l), Wanganui (w) and Wellington (x). (The Wanganui load curve masks the Auckland one, because they are virtually identical.)

3.5 Standby Power and Losses

Standby power is drawn by an appliance when it is not in operation but is connected to the mains. Depending on the appliance type, this can range from nil (for example, a non-electronic dryer) to 20 W or more (for example, a television). These power consumptions may seem trivial (1W continuous power is approximately 9 kWh per year and costs about $1), but since most households have many such appliances, the actual energy consumption may be a significant fraction of the total energy consumption of a household.

A survey of international studies [10] reported that around 10% of domestic electricity consumption is from standby power consumption. Much of this consumption is a waste of money and energy, a source of unnecessary Greenhouse Gas (GHG) emissions, and can be reduced through good electrical design. Among the outcomes of an international workshop [11] on standby power waste was the statement:

> *'As much as 10% of domestic electricity use is consumed as standby power. The consumption is notably consistent across OECD member countries. If the other sectors are included, standby power is responsible for as much as 1% of these countries' CO_2 emissions. – More analysis is required to validate these figures'.*

and

> *'Very large reductions in standby power consumption are technically feasible, cost-effective and can be achieved without sacrificing any features or amenities expected by consumers'.*

With appliance standby power being a sizeable consumption of electricity it is a good target for energy conservation programmes that would require appliances to meet energy performance targets specified in national test standards where such exist. These requirements have generally been based on the running costs of the appliance and have neglected standby power. However, targets based on the standby performance of appliances are now being proposed.

Before standby power targets are established, or energy efficiency programmes are put in place, it is essential to know how much power is being used by appliances on standby, how much power could potentially be saved, and at what cost, and what are the most significant appliance types.

Standby power also appears to be growing rapidly due to standby power being a feature of many modern appliances, the proliferation of electronic and computer controllers in appliances, and the increasing household ownership of electrical goods. For example, many appliances that were uncommon 10 to 20 years ago (such as microwave ovens) are now common.

The 1-Watt Plan has been proposed by Dr Alan Meier [12] of Lawrence Berkeley National Laboratory and calls for an international effort to overcome obstacles, and collaborate on definitions and test procedures[29].

3.5.1 Definition of Standby Power and Baseload

A definition of standby power has recently been made by a consensus panel for the IEA (International Energy Agency), to aid in the development and harmonisation of appliance standards internationally [11].

> *'Standby power use depends on the product being analysed. At a minimum, standby power includes power used while the product is performing no function. For many products, standby power is the lowest power used while performing at least one function'.*
>
> *'This definition covers electrical products that are typically connected to the mains all of the time'.*
>
> *'Based on this definition, certain types of products generally do not have standby power consumption. This includes, for example, products that have only two distinct conditions: 'on' and 'off', where the product does not consume power when it is off'.*

The basic concept is that standby power is the power used when the appliance is not performing its' primary function.

The baseload of a house is defined as the typical lowest power consumption when there is no occupant demand. It includes the standby power of appliances (e.g. microwave ovens, VCRs, multiple TVs, video games, dishwashers, etc), plus any appliances that operate continuously (e.g. heated towel rails, clocks, security systems etc), and is important for two major reasons:

a) It defines the lowest continuous power demand that must be met by a network (or generation system), so having a large part to play in the network load factor.

b) It includes a group of appliances that has the potential for demand reductions.

[29] *for further information, see www.standby.lbl.gov*

3.5.2 Standby Estimation

The standby power of an appliance is defined as the power used when the appliance is not performing its primary function; and could include the following:

- ***Video***: *power used when it is not playing or recording.*
- ***Range***: *energy used by the clock (and other electronics) when no cooking is being done.*
- ***Washing machine***: *power used by LED indicator light or electronics when not washing.*
- ***Fridge***: *energy used when the fridge compressor is off, and it is not defrosting, which could be the butter conditioner, or transformer and electronics.*

Note that other studies do not necessarily include all of the power consumption during non-usage time for fridges and fridge freezers, videos and microwaves - since the power is consumed for specific tasks such as the butter conditioner, TV channel tracking, microwave clocks. In this study we have used a more inclusive approach

Many modern appliances require a transformer to supply DC power for electronic and computer controls, and this may consume power continuously, even when there is no power drawn. For example, a washing machine may be used a few times each day, for about 60 minutes for each cycle. In between cycles, the electronic control system is waiting and hence the power demand does not drop to zero, but to about 9 W. This off-duty power consumption of 9 W is the standby power of this appliance. As it is used only a small fraction of the day, almost half of the consumed energy is for the 9 W standby power, and not for washing clothes, so is 'wasted energy' in the sense that it is not used to perform useful work.

The analysis method for calculating the standby power and losses is based on the frequency distribution of the appliance power consumption. For example, a fridge compressor is on for most of the time and, when the compressor switches off, the fridge has a standby power of about 17 W. The frequency distribution for such a fridge is given in Figure 12.

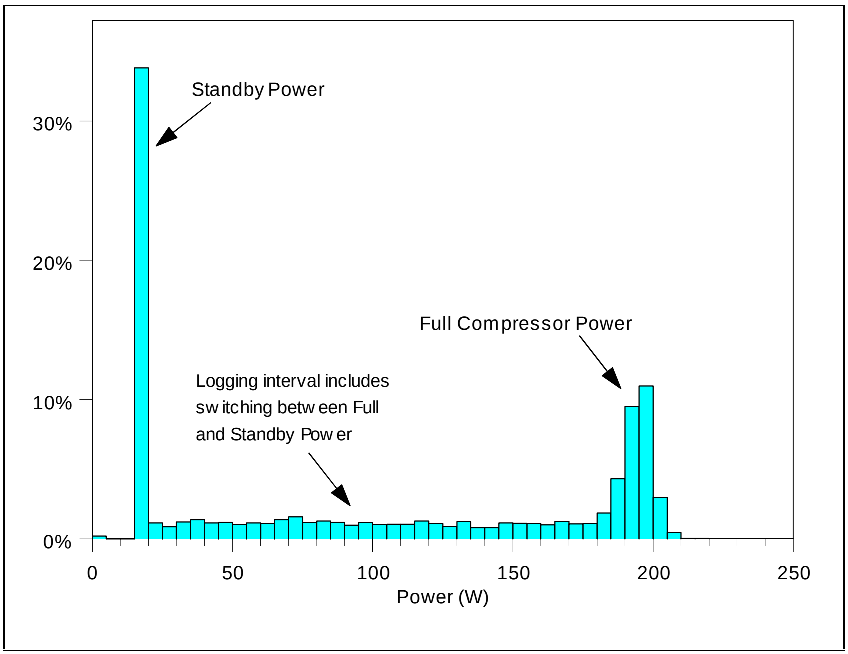


Figure 12: Fridge Histogram

The histogram in Figure 12 has two strong peaks: one at about 190 W corresponding to full compressor power, and another at about 17 W corresponding to the standby power. Power uses in-between these peaks are the fridge switching on or off some time during the 15 min sampling interval, so an intermediate power use is recorded.

The method for calculating the standby power is to find the standby power peak. Mathematically, the standby power is the **mode** of the distribution, which is defined as the value that occurs most often.

As the data is measured in steps of 1 W (i.e. 1,2,3,4… W), finding the mode is easily done by finding the most common value in the data.

For some appliances, the most common value is larger than the standby power, as they rarely switch to standby. In these cases the modal value of the data values less than the mean power is taken.

Once the standby power is known, the standby loss can be calculated. This is defined as the energy consumed when the appliance is in standby mode, rather than being 'on' or disconnected from the mains. This distinction is important as some appliances, such as televisions, are not always left in standby mode.

3.5.3 Baseload Estimation

The estimation of baseload is analogous to the estimation of standby load, as the baseload can be thought of as the standby power load of the entire house. Estimation is more complex, because there are a large number of appliances switching on and off during the course of a day, so that the total power may only be rarely at baseload level. It may perhaps occur in the middle of the night, when everyone is asleep and all appliances are switched to off or standby.

To find the baseload, the minimum monitored power for each day is taken, and a histogram created. The baseload is expected to be the most commonly occurring daily minima, which should be at the low end of the histogram. Calculating the mode generally gives a good estimate of the baseload. In households with many refrigeration appliances (or other fast switching, automated appliances) the histogram of daily minima may not be so easy to interpret, as it is rare for all of the fast switching appliances to be off concurrently. In such cases, a good estimate of the baseload cannot be made. For the HEEP sample households, this rarely occurred.

3.5.4 Appliances

The following outlines work done on appliances that contribute towards the baseload of a house.

3.5.4.1 Common Appliances

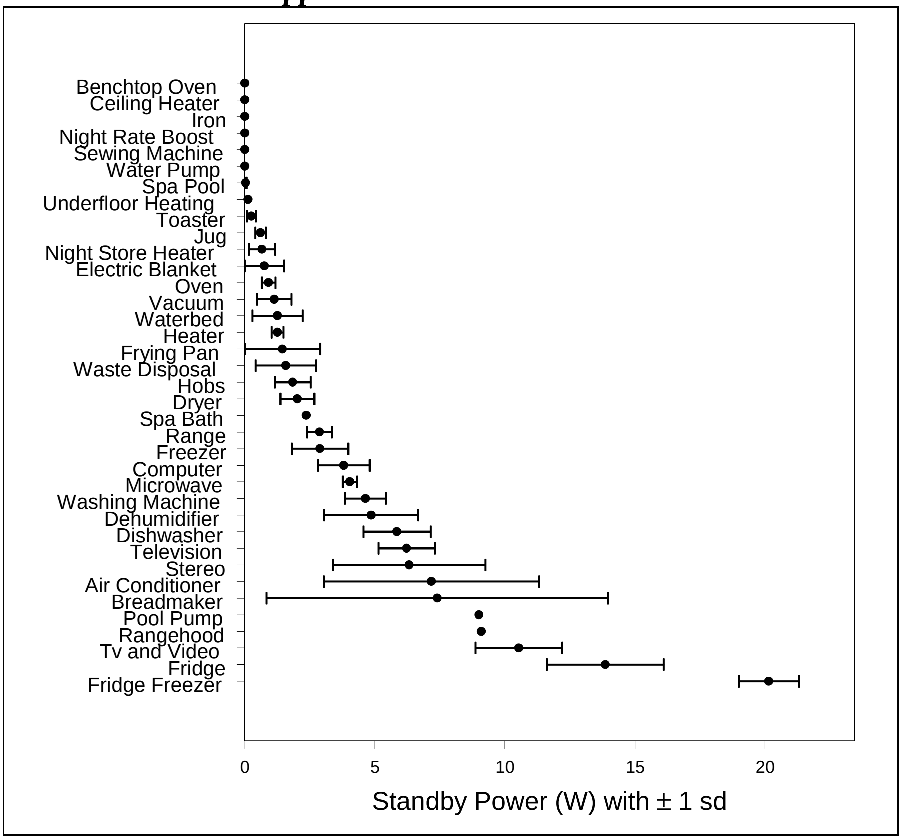


Figure 13: Average standby power of various appliance types.

The measured average standby powers of various common appliance types are presented in Figure 13.

It is important to note that the data is from households in Wanganui, Wellington, and Hamilton. Not all were randomly selected, so figures are not nationally representative. The average standby power for most appliance types is in excess of the 1 Watt value, indicating that there is a lot of scope for reductions. About 50% of all the appliances monitored were found to have a standby greater than 2 W

3.5.4.2 Other Appliances

Appliance power measurements of Auckland HEEP households were undertaken in more detail than in previous years. This means that the ownership and standby power rating of 137 appliance types can now be estimated. Appliance power measurements included a walk-through audit, so allowing almost all appliances in the household to be covered.

The standby power consumption and ownership details for some significant standby appliances is given in Table 7. For many of these appliances it is reasonable to assume that they are almost always in standby mode. However, for others such as audio equipment and home PCs, end-use monitoring is needed to establish their duty cycles, as their likely high standby usage warrants further investigation.

It is interesting to note ownership figures differ somewhat from the EERA [13] ownership figures, with more televisions (191 vs. 106) and home PCs (91 vs. 23) found in the HEEP Auckland sample.

Together, these appliances might have a total standby power consumption of around 10 W on top of the already quantified standby power. Stereos and audio equipment as a group have a very high standby power, and are now very common appliances. The current generation of DVD players also have high standby power, and are set to become much more common in the future.

Appliance	*Standby (W)*	*Ownership (per 100 households)*	*Estimated standby power consumption per house (W)*
Alarm Clock[30]	1.7	91	1.6
Answer-phone	5.4	9	0.5
Fax Machine	6.0	35	2.1
Cordless phone	1.8	37	0.7
Audio Component	8.8	21	Not yet estimated
DVD Player	8.5	5	0.4
Separate Radio Cassettes	1.4	42	Not yet estimated
Burglar Alarm[30]	2.2	5[31]	Not yet estimated
Stereo	11.6	116	Not yet estimated
Charger	0.8	26	Not yet estimated
Games console – Playstation	1.2	26	Not yet estimated
Home PC	14.7	91	Not yet estimated

Table 7: Standby consumption of other appliances

There are many other appliances, most of which already have standby estimates, or are unlikely to make a significant contribution to standby power consumption as both their measured standby power and ownership rates are very low.

3.5.4.3 Heated Towel Rails

Despite the factually correct manufacturers' claims that they use less power than a 100 W light bulb, the power consumption of heated towel rails are much higher than the typical usage of a 100 W light bulb, as they are often run continuously. For example, a 80 W heated towel rail uses 700 kWh/year if run continuously (at a cost of around $70) compared to 182 kWh for a 100 W bulb used 5 hours a day.

Power consumption cannot be measured directly, as heated towel rails cannot be monitored as end-use appliances in HEEP. This is because most of them are hard-wired into shared circuits. However, their presence and usage is surveyed in HEEP, and some information on their power rating is gathered in the power measurements.

The ownership of heated towel rails in Wellington, Hamilton, and Greater Auckland was 57 per 100 households, and 43% of households had one or more heated towel rails. Based on the Auckland power measurements, the average measured power rating was 67 W, and from the HEEP survey 70 W.

[30] *Not strictly 'standby', as the appliance is performing its main purpose of monitoring time or lack of movement etc.*
[31] *Excluding hard-wired systems.*

The usage behaviour was estimated from the HEEP survey for Wellington, Hamilton, and Greater Auckland. 61% of the towel rails were reported as being used continuously. The reported usage on the remainder was generally much lower, with most being used for less than two hours per day, and a few percent never used. Each towel rail was switched on an average of (15 ± 1.5) hours per day. The average power consumption of heated towel rails was (25 ± 6) W per household.

To summarise, the households covered to date give the following statistics for heated towel rails:

- *ownership* — *57 per 100 households*
- *average label rating* — *67 W*
- *rating from the HEEP survey* — *70 W*
- *percentage reported as being used continuously.* — *61%*
- *average time used per day* — *15 ± 1.5 hours*
- *average power consumption per household* — *25 ± 6W*

Heated towel rails are an interesting energy end-use, as they seem to be perceived by householders as using little energy, despite the fact that a constantly used heated towel rail uses more energy than a typical clothes dryer. In fact, an 80 W towel rail in constant use consumes the same amount of energy in one year as would be required to do 400, 90 minute drying cycles. When questioned on ways to conserve energy, no household in the HEEP survey to date has suggested turning off the heated towel rail, although many householders actively minimise their use of clothes dryers in order to reduce power bills.

3.5.5 Summary Results to Date

The average baseload of the randomly selected Wellington and Hamilton households is (103 ± 10) Watts with 90% of households in the range of 15 to 205 Watts. If the average national baseload is similar, then the total baseload is around 130 MW continuous, with a yearly consumption of 1,100 GWh, which has a retail price of approximately $115 million dollars, and CO_2 emissions of around 730,000 tonnes, if supplied by thermal generation.

This is approximately 3% of New Zealand's total electricity generation, and up to 1% of New Zealand's total GHG emissions (if supplied by thermal power stations). Clearly, the potential reductions of baseload and standby consumption in NZ households are large, and has potential for Demand Side Management and GHG reductions.

The contribution of standby to the baseload can be estimated by combining the standby power measurements with the surveyed appliance stock levels in New Zealand. Appliance stock levels have been estimated by EERA [13]. Stock levels and standby estimates are available for the following appliance types: air conditioner, computer, dehumidifier, dishwasher, dryer, electric blanket, freezer, fridge, fridge freezer, heater, jug, microwave, night store heater, range, television, toaster, video, washing machine, and waterbed

By combining these two sets of numbers with the estimated standby loss for each appliance class, two estimates of the average total standby per house are made. Using the EERA appliance stock levels gives (27 ± 2) W, and using the HEEP stock levels (36 ± 4) W.

The largest five contributors to the household baseload are (from highest to lowest):

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

Each of these appliances is responsible for around 3 W to 6 W of household baseload energy use.

The standby consumption and ownership factors of other minor appliances were discussed in Section 3.5.4.2. Together, these appliances might have a standby power consumption of around 10W on top of the already quantified standby power of 36 W per household, bringing the estimate to about 50W.

Stereos and audio equipment as a group have a very high standby power, and are very common appliances. The current generation of DVDs also have high standby power, and are set to become much more common in the future. There are many other appliances, most of which have already have standby estimates, or are unlikely to make a significant contribution to standby power consumption as both their measured standby power and ownership rates are very low.

As discussed in Section 3.5.4.3, heated towel rails have an average consumption of about 25 W. When this is included, it leaves a difference of just over 30 W between the standby estimate and the total measured baseload that has not yet been quantified. This remaining portion is likely to be from appliances that have not yet had standby estimated, and also from appliances that are on all the time.

This project aims to refine these estimates in future work, add other appliance types, and try to determine the most significant non-standby appliances in the baseload.

HEEP standby and baseload estimates per house available to date may be summarised as follows:

- Average baseload (random Wellington & Hamilton houses) 103 ± 10 W
- Standby from common appliances 36 ± 4 W
- Standby from minor appliances (see Table 7) 10 ± 5 W
- Average consumption of heated towel rails 25 ± 6 W
- Remaining unquantified baseload 32 ± 13 W

3.5.6 International Comparisons

Lebot, Meier and Anglade (2000) [10] reported estimates of household standby power from eight countries (including New Zealand), as listed in the following table. The estimates are not directly comparable, as the range of appliances measured varied from country to country. The New Zealand estimate is actually of the baseload, so the total standby power is somewhat lower.

Despite this, the percentage of the total electricity use is similar for most countries at around 10%, as shown in Table 8:

Country	*Average Residential Standby Power(W)*	*Annual Electricity Use (kWh/yr)*	*Percentage of total Electricity Use*
Australia	60	527	***13%***
France	38	235	***7%***
Germany	44	389	***10%***
Japan	60	530	***12%***
The Netherlands	37	330	***10%***
New Zealand	103	920	***10%***
Switzerland	19	170	***3%***
USA	50	440	***5%***

Table 8: International standby estimates

There are a number of appliance energy efficiency label programmes around the world such as the ‘Top Runner’ programme in Japan and the GEA-label from the Group for Efficient Appliances (an umbrella organisation for a number of national and manufacturers organisations throughout Europe). The most recognised is probably the *Energy Star* programme developed in the US by the Environmental Protection Agency (EPA) in 1992. A number of countries including Australia and New Zealand have adopted the *Energy Star* programme.

Energy Star labelling was initially applied to office equipment but is now expanding to a range of household appliances. One of the requirements of certification that allows use of the *Energy Star* logo is that standby power consumption of the appliance must be below a certain threshold.

3.5.7 The Future

It is difficult to assess the future direction of standby and baseload energy consumption. For some appliance classes, such as televisions and VCRs, the future standby consumption may **decrease**, as modern appliances have lower standby power than older units, and the total number is not growing quickly. However, there are a host of other appliances, rapidly increasing in number that may **increase** standby consumption, together with a proliferation of electronic and computer controls replacing manual control. Examples include computers, TV cables, satellite decoders and receivers, video games, faxes, answering machines, cordless phones, and various battery chargers for portable devices. For whiteware in particular, computer-based controls (e.g. 'soft-touch') are becoming more and more common. Unless measures are taken to reduce the standby power of such appliances, then standby and baseload losses may increase dramatically.

The emergence of digital television is likely to lead to a big jump in standby consumption. For Britain, the extra demand may peak at 500 MW for digital televisions and the satellite receivers, and cost an extra much as £15 per household per year. For the United States, it has been estimated that this could result in an extra demand of up to 18 TWh per year [14]! The recent announcement that TVNZ plans to start a digital satellite service implies that around one million households may eventually have a digital receiver, and perhaps digital television, meaning that a new demand of 10-20 MW or more could result unless low standby receivers are adopted.

Rainer, Greenberg and Meier (1996) [15] noted that changes in the United States building regulations now requiring protected electrical outlets in kitchens and other special rooms, and mains-wired smoke alarms in bedrooms, hall, and garage were increasingly common, creating new standby loads. In New Zealand, Residual Current Devices are required in wet areas, and security systems are also becoming more common.

There are many drivers leading to increased standby consumption, and the 1 W programme seems to be a sound step towards containing or reversing this growth. In addition to the potential savings in direct energy costs, standby power reduction may help to postpone investment in new generation, and perhaps also transmission capacity. One barrier to achieving this is the inability of investors in generation and transmission to invest in standby reduction. Investors can reap returns for new generations to supply inefficient appliances, but cannot easily reap the returns for standby reductions.

Standby consumption also has a significant role to play in containing the growth of GHG emissions. Lebot, Meier, and Anglade (2000) [10] reported that achieving the 1W standby power for all home appliances would reduce CO_2 emissions by an amount equal to about 3% of the reductions required of OECD countries by the Kyoto protocol. They noted that, although it is a minor contribution, it is technically feasible at costs likely to be much lower than costs of new renewable generation and that, unless such measures are taken, standby power is likely to increase rapidly.

For New Zealand, which under the Kyoto Protocol is required to return GHG emission to 1990 levels (a 23% reduction on 1997 emissions), reductions in standby could give reductions in nationwide GHG emissions of around 0.3%. This is around **1.5%** of the required Kyoto reductions, or about **7%** of the non-forest sink credits that the policy package of July 1994 indicated (80% of reductions were expected to come from credits for new forest growth). It appears that in terms of the Kyoto Protocol, standby reductions are far from trivial, with a significant chunk of emissions reductions possible from the reduction of standby power.

3.5.8 Conclusions

The baseload of a house is defined as the typical lowest power consumption when there is no occupant demand, and may be thought of as the 'standby' of the entire house. It includes the standby power of appliances, plus any appliances that operate continuously. It is important for two major reasons: firstly, it defines the lowest continuous power demand that must be met and secondly, it includes a group of appliances that has the potential for demand reductions.

Results to date are based on the randomly selected houses monitored in Wellington and Hamilton, and will be updated as further areas are completed. Using these preliminary findings, Figure 14 gives an indication of how the components of baseload appear to contribute towards the average electricity consumption of a house.

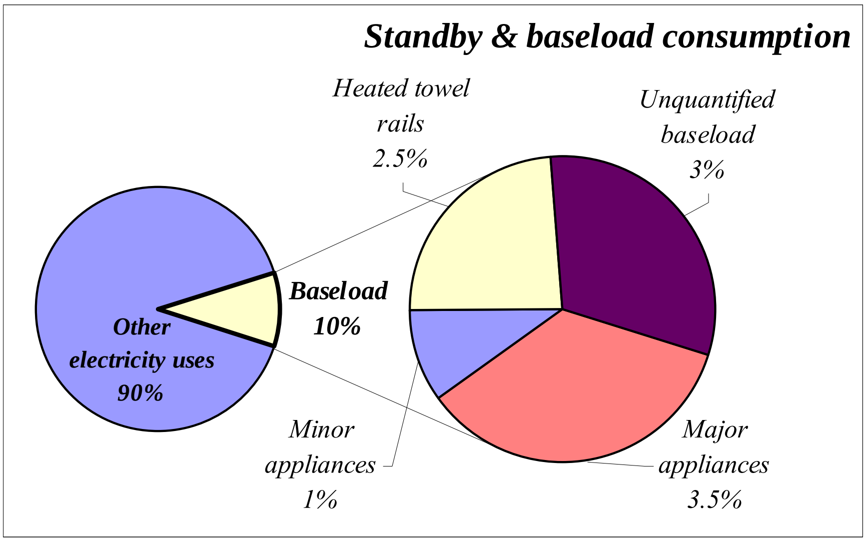


Figure 14: Baseload electricity consumption

4. HOT WATER

Water heating is a major component of New Zealand's residential energy use. Hot water systems are believed to consume about 20 PJ or 30% of New Zealand's residential energy [16]. More than 90% of hot water systems use electricity and about 8% use gas. About 16% use solid fuel, commonly as 'wet-backs' contributing to the heating in an electric water cylinder. 4% use other energy sources such as solar energy [17].

Hot water systems heat cold water to produce hot water that is then used for a variety of purposes, at a variety of temperatures. A number of energy types, such as, electricity, natural gas, LPG gas, solid fuel (wet backs) and solar energy can be used to heat the water. For most systems storage of preheated water is required, which is the case for the common hot water cylinder.

Hot water systems in New Zealand are generally not very efficient with only about 5% meeting the "A" Grade according to NZS 4602:1988 and NZS 4606:1989 [18]. Consequently the potential for national energy savings, and Greenhouse Gas emission reductions, from improvements in hot water systems is likely to be large.

4.1 Social & Demographic Aspects

Buildings do not use energy; rather it is the people inside them who use energy. However people do not choose to use energy, rather they choose to use 'services' that have an energy consumption associated with them. Hot water is delivered via a hot water system, but the energy consumption of the system is not simply related to the amount of delivered hot water. This is because physical properties of the hot water system[32] affect the energy consumption of the hot water system.

Accurate modelling of residential hot water energy usage requires consideration of both hot water demand and the physical properties of the hot water systems. Different disciplines approach these considerations in different ways. Lutzenhiser [19] suggests four classes of models:

- *physics/engineering*
- *economic*
- *psychological*
- *social/anthropological*

for general energy consumption modelling. In modelling national residential hot water energy consumption, it may be advantageous to emphasise a *physics/engineering* approach to describe the energy consumption of the hot water system, while emphasising a *sociology/anthropology* approach to determine the amount and timing of the hot water demand.

Any type of energy model requires extensive data in order to construct, validate and implement the model. Good sources of data are therefore critical to the production of accurate models. National surveys, specifically focusing on energy, are frequently employed overseas as a primary data source[33]. While these surveys have a good sample size, energy consumption information is based on monthly billing records and only collects total energy usage, rather than component energy end-uses.

4.1.1 Existing Local Information

In New Zealand, a large electricity energy end-use study was carried out in 1971/1972 [1], and included sub-metering of up to four energy end-uses (water heating, portable appliances and lights, range and fixed wired heating). The results of this study have been used frequently for New Zealand energy modelling, but the data is old and new logging methods are now able to collect far more detailed information than was possible 30 years ago.

[32] *Such as the design of the pipe distribution, volume of the stored water, amount of insulation, thermostat temperatures, presence of tempering valves etc.*

[33] *Examples of these energy surveys would be the Residential Energy Consumption Survey (RECS) (EIA, 1995) for the USA and the Survey of Household Energy Use (SHEU) (NRCan, 1994) for Canada.*

4.2 Standing Losses

A hot water cylinder uses energy to keep the water in the cylinder at the storage temperature so that hot water is always available. The heat lost through the outside of the cylinder (the cylinder standing losses) needs to be balanced by occasional heating of water in the cylinder. Additional energy is also required for heating water which replaces that actually used by the occupants.

A simplistic example of the difference between the two components is seen by householders, when they leave the house unoccupied for the holiday period. Hot water in the cylinder is still maintained at the temperature set by the thermostat and, depending on the insulation level of the cylinder, the energy needed just to replace heat losses can be significant, and may be seen as *lost energy*. Whatever surplus energy for water heating is required, once the occupants are actually occupying the building, is deemed to be *used energy*.

It is plausible that the *lost* component of the hot water energy is mainly correlated with the physical properties of the hot water system, including the location of the cylinder in the building. In contrast, the *used* component is more closely linked to the occupants' behaviour.

In order to develop a more generalised model of overall hot water energy consumption, it is desirable to link the energy with socio-demographic characteristics of the household rather than the behaviour of the individual household occupants. In summary three paths of analysis seem appropriate:

- ***Lost energy** as a function of physical parameters of the cylinder and house.*
- ***Used energy** as a function of the reported behaviour of the household occupants.*
- ***Used energy** as a function of the socio-demographic characteristics of the household.*

The first step in the analysis must be the separation of *lost energy* and *used energy* components of the total energy consumption. The method used to do this was first described in detail the HEEP Year 2 Report. To separate *lost energy* and *used energy*, total hot water energy use was averaged over the logging periods of each house as shown in Figure 15.

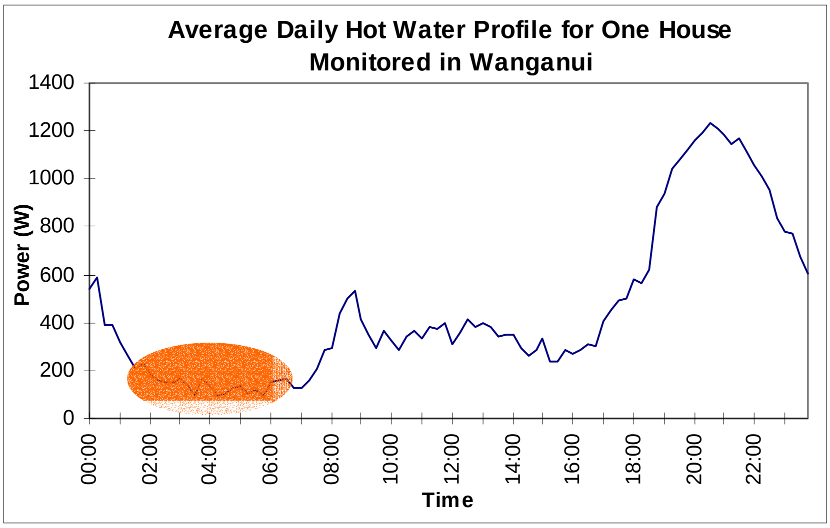


Figure 15: Average daily hot water energy use

Periods of standing loss were assumed to be the flatter areas of the graph, found typically in the early morning when no water is drawn from the cylinder, the shaded zone of Figure 15. The average standing loss was calculated for this period, extrapolated to cover the full 24-hour day, and then subtracted from the total energy use to give the average *used energy.* In some cases, such as for water cylinders on electricity night rate, more sophisticated methods were necessary. These are loosely based on the End-use Load and Conservation Assessment Program (ELCAP) method [20].

The results of the separation of the hot water energy into *lost energy* (Standing Losses) and *used energy* (Consumed Energy) for a number of randomly selected HEEP houses are shown in Table 9 and in Figure 16.

Type	***Lost Energy (kWh/day)***		***Used Energy (kWh/day)***		***Percent (%)***		**Count (*n*)**
	Lower limit	*Upper limit*	*Lower limit*	*Upper limit*	*Lower limit*	*Upper limit*	
Electricity Hot Water	2.5 ±0.3	2.7 ±0.4	5.7 ±0.5	6.5+0.6	(28 ±4)%	(32 ±5)%	32
Natural Gas Hot Water	3.2 ±0.5	3.8 ±0.5	14.4 ±2.4	14.9 +2.4	(18 ±5)%	(21 ±5)%	8
Natural Gas Instant Hot Water	n/a	n/a	n/a	13.3+2.5	n/a	n/a	4

Table 9: Average standing losses and consumed energy

From Table 9, it is seen that the electric hot water cylinders are losing about 30% of their energy in standing losses. This appears to support a similar figure reported by Carrington in 1985 [21] for a sample of five cylinders. About 18.3 PJ of New Zealand's electricity is consumed by water heaters [16]. Assuming that 25-30% of this energy is lost in standing losses then the total energy lost in New Zealand for standing losses from electric hot water cylinders is approximately 5 PJ .

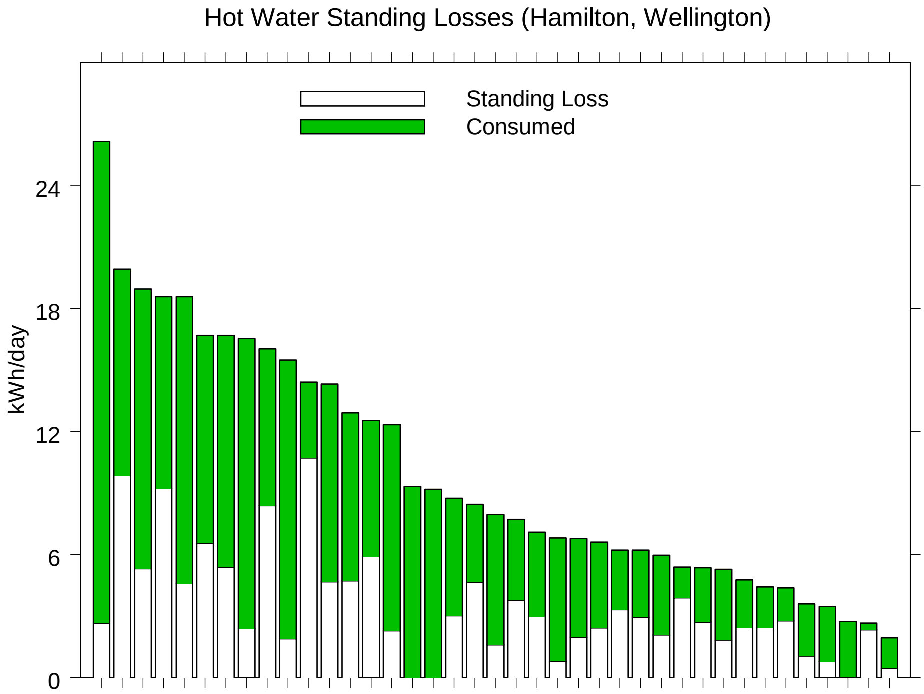


Figure 16: Standing losses for randomly selected HEEP houses

4.2.1 HEEP Calculation and Correction Methods

The method of calculating standing losses for HEEP houses is described in Appendix 10.5.1.

The standing losses of a hot water system depend on the ambient temperatures surrounding the cylinder. Since standing losses are calculated from a few hours of data, often in the early morning hours, the ambient temperature is lower than the average ambient temperature over 24 hours. So in general, the standing losses will be over-estimated.

The correction of these standing losses to the actual ambient conditions (or to a normalised climate year) is described in Appendix 10.5.2.

4.2.2 Standing Losses by Cylinder Grade and Size

To date, the HEEP survey has only limited information on cylinder grades, as most cylinders have no label on them. This has, unfortunately, limited the size of the dataset that can be used for this analysis. The standing losses were examined by cylinder grade and cylinder volume, and compared to the standing losses specified by '*Water Mark'* standards and various New Zealand standards.

For the cylinders that were analysed, all but one group showed higher normalised standing losses than the standards would suggest. This would appear to indicate that their thermal performance is worse than the standards. However, the standards use a temperature difference between the hot water storage and air temperatures of 55.6°C, while the temperature difference for monitored cylinders averaged 48°C (see Table 15).

The standing losses within a group of identical cylinder grades and volumes varied widely, typically from about 1 to 4 kWh per day, but with some as high as 7 kWh/day. We cannot explain such a wide range of variation with the cylinder parameters that we have collected. Some possible causes of the abnormally high standing losses could be:

- *large pipe and valve standing losses*
- *small leaks or dripping taps*
- *cylinders not meeting claimed grade*
- *long term failure or deterioration of insulation*
- *estimation errors related to water temperatures*[34].

At this stage, we have no way of knowing which, if any, of these possible causes are contributing to the high standing losses.

Grade	***Volume*** *(litres)*	***Number monitored***	***Standing Loss*** *(kWh/day)*	***'Water Mark' Standard*** *(including 0.7 kWh/day for pipework) (kWh/day)*	***Difference*** *(kWh/day)*	***Ratio***
A	140	3	2.6	2.1	0.5	1.24
A	180	5	3.3	2.3	1.0	1.44
A	110	9	1.6	1.9	-0.3	0.84
D	110	1	3.7	3.5	0.2	1.05
D	140	3	5.3	3.9	1.4	1.35
D	180	2	4.9	4.3	0.6	1.14
			Losses have been normalised to the 55.6°C temperature difference used in the standard testing.			

Table 10: Standing losses by cylinder grade and size

4.2.2.1 Average Cylinder Temperatures

One other factor in understanding the standing losses is that, as cold water is drawn in and heated to replace used water, the average cylinder temperature will be somewhat lower than the thermostat setting. The average cylinder temperature has been calculated for all the available hot water systems, and averages 3.1°C lower than the thermostat temperature, ranging from about 0°C to 12°C, depending on the cylinder characteristics and hot water usage. Systems with small elements will recharge more slowly, and systems with high hot water demand will spend a lot of time recharging.

This drop in temperature of 3.1°C, if accounted for in the normalisation and if correct, should increase the normalised standing losses in Table 10 by 6%.

[34] *Resulting from such factors as degradation of heating elements and old inaccurate thermostats.*

4.2.3 Reducing Standing Losses

Clearly the energy lost in standing losses is large so the immediate question is how these standing losses can be reduced. Heat losses from the cylinder can be reduced by:

- *increasing the insulation levels of the insulation surrounding the hot water cylinder*
- *reducing the temperature of the water inside the cylinder*
- *increasing the pipe insulation and installing heat traps.*

4.2.3.1 Insulation

Progress has been made to improve the insulation levels of hot water cylinders. The New Zealand Building Code (NZBC) Clause H1 has been recently revised, and now includes a requirement that new hot water cylinders installed should perform better than or equal to "B" grade [22]. Gas cylinders also have a maximum gas consumption rate while recovering from standing losses.

Unfortunately with the demise of the Electrical Development Association (EDA), the *Water Mark* labelling scheme which the EDA promoted for electric hot water cylinders, is no longer being conducted. Under the *Water Mark* scheme, hot water cylinders were given a label indicating the grading of the cylinder, which encouraged consumers to purchase cylinders with a high level of insulation.

Standing losses can also be significantly reduced for existing electric hot water cylinders by the addition of a cylinder wrap [23]. The simple payback period for these cylinder wraps is frequently less than three years.

4.2.3.2 Water Temperature

Another way of reducing standing losses is to reduce the temperature of the water stored within the hot water cylinder. However it is not simply a case of turning down the thermostats of all hot water cylinders.

People don't like to run out of hot water and HEEP has found that about 20% of households report that they sometimes run out of hot water. A simple method to reduce the chances of running out of hot water is to turn the thermostat on the cylinder up so that the water within the cylinder is heated to a higher temperature. More warm water is available for showering, as less hot water is needed from the cylinder to be mixed with the cold water to get water at a suitable temperature for showering.

Tustin (1991) [24] reports on a project in Whakatane concerned with safe water temperatures, where twelve households were provided with consumer adjustable thermostats on their hot water systems. At the time of installation these were set to 55°C and the residents were told about safe water temperatures. On returning to the houses after one year it was found that 25% of households had adjusted the thermostat upwards (greater than 60°C) to avoid running out of hot water.

Another way to reduce the chance of running out of hot water is to appropriately match the size of the hot water cylinder to the expected demand for hot water. An indication of whether this matching has not been successful (assuming that people have turned down their cylinders as much as they feel reasonable) is to examine the thermostat settings for the cylinders to see if there are a sizable number greater than 60°C.

Figure 17 shows the thermostat settings and resulting nearest tap water temperatures for a number of the HEEP houses recorded at the time of installation of the HEEP monitoring equipment for each house[35].

[35] *See Carrington et. al. (1984) [21] for comments on adjusting spot readings of water temperature.*

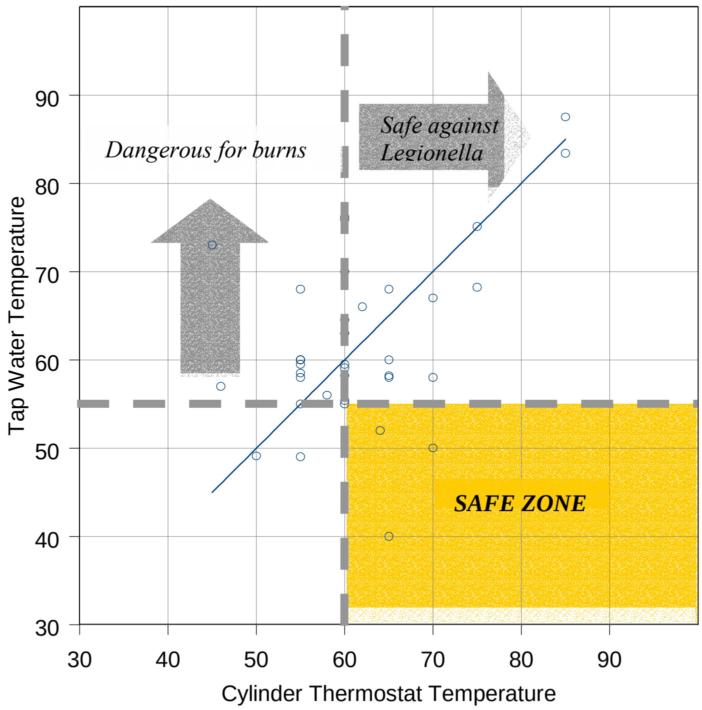


Figure 17: Cylinder thermostat setting and the resulting nearest tap water temperature

The angled line in Figure 17 shows a one-to-one correspondence. In other words, if no tempering valve is installed, the thermostat is accurate and the pipe losses are negligible, then all data points should lie on this line. The number of data points above this line are cause for concern. The reasons for this could be due to broken thermostats (for example one cylinder set to 45°C produced water at 75°C) or simply due to inaccuracies in the thermostat – although the error is meant to be only ±5°C. The nearest tap temperatures could be expected to be lower than the thermostat setting on the cylinder when a tempering valve is present on the cylinder or that the cylinder is on a controlled *night rate* tariff and the thermostat hasn't been operational for some time. The shaded area in Figure 17 is the area for safe storage and delivery of hot water. The water in the cylinder should be kept at greater than 60°C to kill legionella, but the tap temperature should be less than 55°C (or less than 45°C where the use is by the elderly or young). The target area therefore for energy efficiency and safety is the left hand side of the grey area shown with a dotted line. As shown, only 3 of the HEEP cylinders delivered water in this zone.

4.3 Hot Water Demand

The energy consumption of a hot water system is a physical process and can be accurately modelled using sophisticated models such as WHATSIM [25], for electric cylinders and TANK [26] for gas cylinders. However if consumption information only is required, then a model such as WHAM [27] could be used. All of these models require assumptions of the amount of hot water demand in order to predict the energy consumption of the water heater.

4.3.1 Influences on Demand

Hot water demand, like energy consumption, is made up of a number of distinct end-uses such as showers, baths, sink use, dish washing and clothes washing. In examining this demand, it is the delivered volume and temperature of water that is of interest. The estimate of *used energy* of the hot water system is related to total demand for hot water. Both the total hot water energy consumption and the *used energy* (where it is available) are used subsequently in this section to explore the relationship of hot water demand to other socio-demographic factors.

Houses vary greatly in the time of use of hot water. This is illustrated by the profiles of 44 HEEP houses shown in Figure 35 in Appendix 10.4. Classification of such profiles in a similar manner to that discussed in Section 3.4 Energy Profiles may highlight relationships between time of demand and socio-demographic factors. Earlier HEEP research found that 36% of the peak demand from households is due to hot water energy consumption which suggests that load shifting *ripple control* of hot water cylinders may be an effective load control strategy.

While the profiles of individual houses show the variation in the timing of hot water use, nothing has yet been said about the overall total demand for hot water. Fitzgerald and Ryan (1996) [28] examined a small sample of ten Christchurch households measured for electrical end-use consumption, and compared the total electric water heating use for each house with the following factors:

- Proportion of household members usually at home in the day ***[people at home in day]***
- Number of children in the household ***[no. of children]***
- Number of teenagers ***[no. of teens]***
- Number of adults ***[no. of adults]***
- Number of elderly ***[no. of elderly]***
- Household income bracket ***[income]***
- Minutes of reported shower time per person per week ***[shower time/person/week]***
- Number of warm or hot loads of washing per person per week ***[wash loads/person/week]***
- Number of baths per person per week ***[baths/person/week]***
- Use of wetback or not ***[wetback]***
- Whether the household was on a concessionary water heating tariff or not ***[water tariff]***
- Whether the household used a dish washer or not ***[dishwasher]***

A stepwise linear regression model was used and preceded as shown in Table 11.

Step	Variable		R^2
1	Minutes of shower per person per week	***[shower time/person/week]***	.39
2	Number of teenagers	***[no. of teens]***	.62
3	Proportion of people home during day	***[people at home in day]***	.78
4	Household Income bracket	***[Income]***	.90
5	Household on concessionary water tariff	***[water tariff]***	.99
6	Number of warm or hot loads of washing	***[wash loads/person/week]***	.99

Table 11: Factor coefficients for hot water energy use

Finally arriving at the following linear model:

Water heating = *- 156.9 + (1.35 * [**shower time/person/week**]) + (138.2 * [**no. of teens**]) +*
*(200.1 * [**people at home in day**]) + (63.1 * [**income**]) +*
*(199.6 * [**water tariff**]) – (26.6 * [**wash loads/person/week**])*

Equation 6: Water heating model

So the total showering time, the total number of teenagers, the proportion of adults home during the day and the household income are important factors. Fitzgerald and Ryan note that the variables of whether the household had a separate hot water tariff *[**water tariff**]* and the number of warm washes *[**wash loads/person/week**]* add little improvement to the model, and that the small sample size was very much a limiting factor. Fitzgerald and Ryan also note that for a larger sample size, the number of occupants is likely to be a factor.

The 1971/72 Survey of Household Electricity Consumption [1] included measurements of total electric water heating consumption and the number of occupants for 1984 randomly selected New Zealand households. Figure 18 uses this data, and a linear regression line shows a positive, but weak correlation.

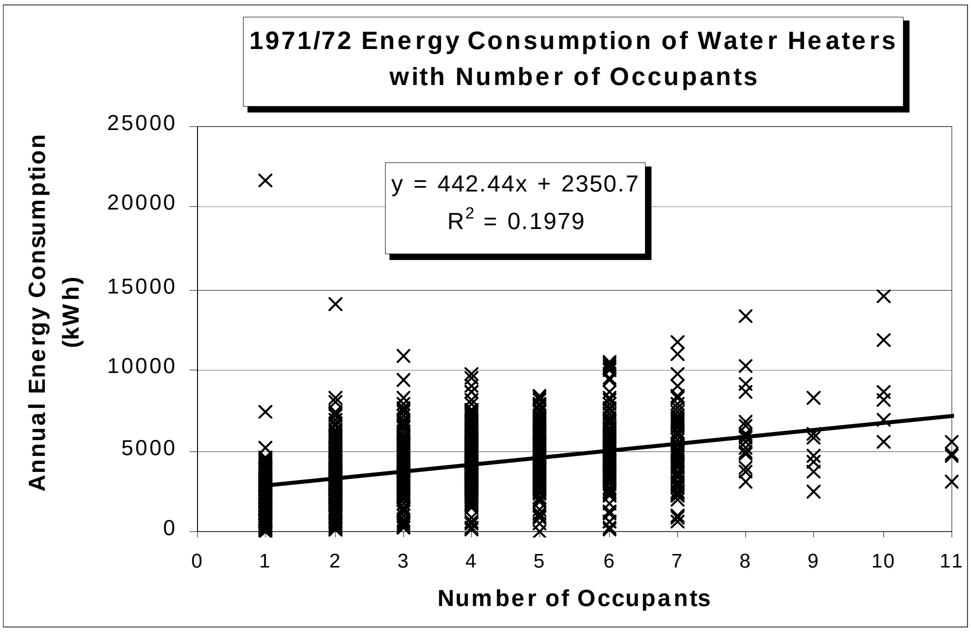


Figure 18: 1971/72 Correlation of hot water energy usage with number of occupants

The water heating information from the HEEP database was examined against a number of factors as part of a standard linear model. As suggested earlier, most success was encountered when examining the used hot water energy consumption along with the ages of the occupants, type of hot water system, and the reported shower and bath usage. Table 12 provides the output terms of a linear model against a wide range of factors.

Term	Value	Standard Error	t value	Pr(>|t|)
(Intercept)	5.707	1.029	5.547	0.000
Male.Child	0.366	0.759	0.483	0.632
Female.Child	-0.122	0.630	-0.194	0.847
Male.Teen	-0.304	1.327	-0.229	0.820
Female.Teen	**4.142**	**1.001**	**4.137**	**0.000**
Male.Adult	0.434	0.583	0.745	0.461
Female.Adult	-0.119	0.913	-0.131	0.897
Male.Aged	-0.598	0.727	-0.822	0.416
Female.Aged	-0.531	0.859	-0.618	0.540
Appliance (Nat Gas)	-0.192	0.724	-0.265	0.792
Appliance (Electric)	**2.641**	**0.399**	**6.618**	**0.000**
Appliance (Nat Gas Instant)	0.645	0.528	1.222	0.229
Showers Per Week	**0.172**	**0.071**	**2.415**	**0.021**
Baths Per Week	-0.007	0.094	-0.071	0.944
Total Shower Time	-0.003	0.004	-0.865	0.392

Table 12: Linear model terms against the used hot water consumption

Data from 53 cases within the HEEP database could be examined. Overall the multiple-R^2 for the model was 0.85.

It can be seen that the variables (Pr smaller than 5%) of significance are:

- ***number of female teenagers within the household***
- ***whether the hot water cylinder was electric***
- ***total number of showers per week.***

It is interesting to note that the total shower time is less significant than the total number of showers, which is surprising as it would be expected that the total shower time would be more closely related to the hot water used. The total shower time per week is based on the residents estimates of number of showers per week multiplied by their estimate of the average length of showers. The figure for the total showering time is comprised of two estimates whereas the number of showers per week would only have one estimate. Another reason may be that people are perhaps better at estimating the number of showers per week they have rather than the average length of their showers.

A simpler linear model was constructed from the number of female teenagers in the household, whether the household had an electric water cylinder and the number of showers per week. A total of 64 cases could be considered, as fewer cases than the previous model had to be removed due to missing values. Table 13 gives the output terms of the shortened linear model.

Overall the multiple-R^2 for the model was 0.75. Including the number of occupants as an additional term only increased the multiple-R^2 to 0.78. The database currently has a dominance of houses that have an electric hot water cylinder. The term indicating the presence of a natural gas hot water cylinder or an instantaneous natural hot water system have large standard errors so the model may not have sufficient cases of gas hot water systems to accurately model.

Term	Value	Standard Error	t value	Pr(>|t|)
(Intercept)	5.631	0.838	6.723	0.000
Female.Teen	3.838	1.006	3.815	0.000
Appliance (Nat. Gas)	-0.437	0.871	-0.502	0.618
Appliance (Electric.)	2.565	0.413	6.205	0.000
Appliance (Nat. Gas Instant)	0.840	0.625	1.344	0.184
ShowersPerWeek	0.129	0.032	4.014	0.000

Table 13: Simplified linear model against used hot water consumption

A weakness of linear models is that they work best when the variables used in the regression are not correlated. Unfortunately a considerable number of socio-demographic variables are interrelated and hence are strongly correlated. Factor Analysis is a technique that is not sensitive to the correlation between input variables and results in linear combinations (factors) that sometimes can be interpreted as the underlying categorisation of the data. This will be applied to the data in the later years of the HEEP programme.

4.3.2 Conclusions

Previous estimates of the electric hot water cylinder standing losses [21] of about 30% appear to be supported by the results from a random sample of HEEP houses, where the average standing loss was found to be similar. Standing losses for all of New Zealand's electric hot water cylinders could be as high as 5.5 PJ.

New performance requirements under NZBC Clause H1 requiring at least Grade B cylinders, which became mandatory on 29th December 2000, will improve the overall performance of electric hot water cylinders in new homes, as will retrofitting of insulation wraps to existing cylinders. The new Minimum Energy Performance Standards (MEPS) requirements which will eventually lead to a Grade A requirement for all new cylinders, will result in improvements in existing homes as old cylinders are replaced.

Hot water demand is driven by a number of factors and work is still being undertaken to examine these. At this intermediate stage, the number of female teenagers appears to be a factor as is the number of showers per week. The total number of occupants may have some influence on the hot water demand.

Sufficient data has yet to be collected on households with gas hot water cylinders in order to allow investigation of the hot water demand for these households.

4.4 Properties of HEEP Hot Water Systems

The properties of the hot water systems from the randomly selected Wellington and Hamilton houses appear in Table 14. These figures are indicative of combined Wellington and Hamilton households.

	Electric storage	*± 1 SD*	***Natural Gas storage***	*± 1 SD*	***Natural Gas Instantaneous***	*± 1 SD*
Count	32		8		4	
Age *(years)*	19.5	2.5	11.8	1.8	2.0	
Thermostat Setting *(°C)*	63.5	1.5	65.8	2.0	55.0	
Volume *(litres)*	152.9	4.6	138.6	10.2	0.0	0.0
Used hot water *(litres per day)*	113.5	11.2	304.1	66.0		
Standing loss						
lower limit (kWh/day)	2.5	0.3	3.4	0.5	0.0	0.0
upper limit (kWh/day)	2.9	0.4	4.0	0.5		
Used Hot Water Energy						
lower limit (kWh/day)	5.4	0.5	13.7	2.1		
upper limit (kWh/day)	6.2	0.6	14.3	2.2	13.3	2.5
Tap Temperature *(°C)*	63.1	2.1	57.9	3.7	58.4	1.7
Normalised Standing Loss						
lower limit (kWh/day)	2.5	0.3	3.2	0.5		
upper limit (kWh/day)	2.7	0.4	3.8	0.5		
Normalised Used hot water						
lower limit (kWh/day)	5.7	0.5	14.4	2.4		
upper limit (kWh/day)	6.5	0.6	14.9	2.4		
Normalised ambient temperature[36] *(°C)*	15.7	0.5	17.9	0.8		

Table 14:Wellington & Hamilton hot water systems

Table 15 gives the combined results of all hot water systems in Hamilton and Wellington.

[36] *The normalised ambient temperature is the estimated average estimated temperature that the hot water system loses heat to. See section 10.5.2, page 82.*

Age (years)	17.9 ± 1.6
Cylinder Thermostat Setting (°C)	63.9 ± 1.3
Volume (litres)	157.9 ± 2.2
Used hot water (litres per day)	161.2 ± 5.3
Standing loss lower limit (kWh/day)	2.5 ± 0.5
Standing loss upper limit (kWh/day)	3.1 ± 0.5
Used Hot Water Energy upper limit (kWh/day)	8.8 ± 1.1
Used Hot Water Energy lower limit (kWh/day)	7.1 ± 1
Tap Temperature (°C)	62.2 ± 1.6
Normalised Standing Loss lower limit (kWh/day)	2.8 ± 0.5
Normalised Standing Loss upper limit (kWh/day)	3 ± 0.5
Normalised Used hot water upper limit (kWh/day)	8.6 ± 1.1
Normalised Used hot water lower limit (kWh/day)	7.6 ± 1
Normalised ambient temperature (°C)	16.1 ± 0.7

Table 15: Wellington & Hamilton – all types of systems

The key points arising from Table 14 and Table 15 are:

- **Types of hot water systems**:
  - *66% electric storage systems*
  - *25% gas storage systems*
  - *8% instantaneous gas systems.*
- **Ages of hot water systems:**
  - *almost 20 years for electric storage systems*
  - *12 years for gas storage*
  - *2 years for gas instantaneous.*

  This was as expected, as the life of gas storage heaters is less than that of low pressure electric storage heaters, while instantaneous gas heaters have only recently come into the domestic market.
- **Cylinder sizes:**
  - *electric cylinders were the largest at an average of 153 litres*
    - *49% were 135 litres*
    - *43% were 180 litres*
    - *8% were other sizes.*
  - *gas cylinders were variable in size, averaging 139 litres*
  - *overall, the average water storage capacity per household was 158 litres. Note, some households have more than one cylinder.*
- **Hot water use:**
  - *households with gas storage hot water used more than double the amount of hot water as those with electric*
  - *households with instantaneous gas systems used more than double than those with electric storage, although the sample is too small to draw conclusions on this*
  - *overall, the average hot water use was 159 litres/day.*

- **Temperatures:**
  - *there was no significant difference in average tap temperatures between systems – which range from 58°C to 63°C*
  - *tap temperatures varied most for electric storage systems - from 43°C to 87.5°C. This possibly indicated a tendency to increase storage temperatures to increase available hot water*
  - *cylinder thermostat settings were generally inaccurate with differences of more than 5°C common.*
- **Standing losses**
  - *Gas storage systems showed higher standing losses than electric, although the difference is only marginally statistically significant at this stage and further measurement on more houses are needed before this can be confirmed.*
  - *Standing losses for electric storage heaters were 28-32% of hot water energy used.*
  - *Standing losses for gas storage heaters were 18-21% of hot water energy used.*

4.5 Pensioners' Hot Water Use

WEL Energy Trust sponsored the monitoring of 12 pensioner houses in Hamilton, as an additional case study to the 17 Hamilton HEEP houses. These houses were monitored from February 2000 to January 2001 to the full level of HEEP monitoring, which included a comprehensive survey and building audit, and monitoring of total and hot water energy use, LPG heating, and temperatures in the living room and bedroom. This section covers the hot water aspects of the study, while temperature and other aspects are covered in Section 5.2 Pensioner Housing.

4.5.1 Hot Water Energy Demand

Pensioner households used more than 60% less energy for hot water then non-pensioner households in the study. Very few pensioner households used more total hot water than non-pensioners households.

Table 16 shows the comparison between the two groups.

Hamilton HEEP households	*Total Hot Water Demand (kWh/day)*	*Energy Used for Delivered Hot Water (kWh/day)*	*Standing Loss (kWh/day)*
Pensioners	3.8 ± 0.4	2.2 ± 0.3	1.5 ± 0.2
Non-Pensioners	9.9 ± 1.3	5.7 ± 0.9	4.2 ± 1.2
Pensioners' difference	*62% less*	*61% less*	*64% less*

Table 16:Hot water energy comparison

As shown, average standing losses were also much lower for the pensioners, at 1.5 kWh/day compared to 4.2 kWh per day for the non-pensioners. The lower standing loss for the pensioners was due to:

- *smaller hot water systems (110 litres),*
- *the cylinders being inside the house, and*
- *all the systems being 'A' grade.*

In general, for the non-pensioner houses, the cylinders were larger, older, of lower grade, with some in un-heated spaces - all factors contributing to higher standing losses. For the pensioner houses, all cylinders were the same size, make, model, and age, and in identical locations within each house. The major differences between systems were in water storage temperatures.

Table 17 summarises key information on the properties of the hot water systems.

	Cylinder Age (years)	Cylinder Volume (litres)	Thermostat Setting (°C)	Tap Temp. (°C)	Estimated hot water use per day (litres)	% standing loss of total consumption
Pensioners	9.8	110.0	56.1	63.9	39.6	40%
Standard deviation	*0.4*	*0*	*1.7*	*1.9*	*4.5*	
Non-pensioners	15.1	147.0	64.5	62.1	101.0	35%
Standard deviation	*3.1*	*7.5*	*2.5*	*2.1*	*16*	
Pensioners difference		*25% smaller*	*13% cooler*	*Similar*	*61% less*	

Table 17: Hot water systems – comparison of properties

Tap temperatures[37] ranged from 57 to 76°C, with an average of 65°C. These temperatures are all hotter than the 45°C recommended in the building code for children or the aged, and have the potential to cause serious burns. The thermostat settings for these systems averaged 56°C, with the most common setting 55°C, which is very misleading for this batch of hot water cylinders as one cylinder thermostat setting of 45°C delivered 73°C hot water at the tap.

For the non-pensioner houses, hot water systems varied greatly in types and operation. There were four gas systems, with two of these instantaneous types. Cylinder sizes ranged from 69 to 180 litres, grades from uninsulated to ‘A’ grade, and age from nearly new to over 45 years old. Tap temperatures ranged from 51 to 79 °C, and thermostat settings from 49 to 77 °C.

4.5.2 Standing Loss Determined by Tap Temperatures

Standing losses are determined by the physical characteristics of the hot water system, which for the pensioner houses are nearly identical. This allowed a very good correlation between the standing losses and the tap temperatures for the pensioner houses as shown in Figure 19.

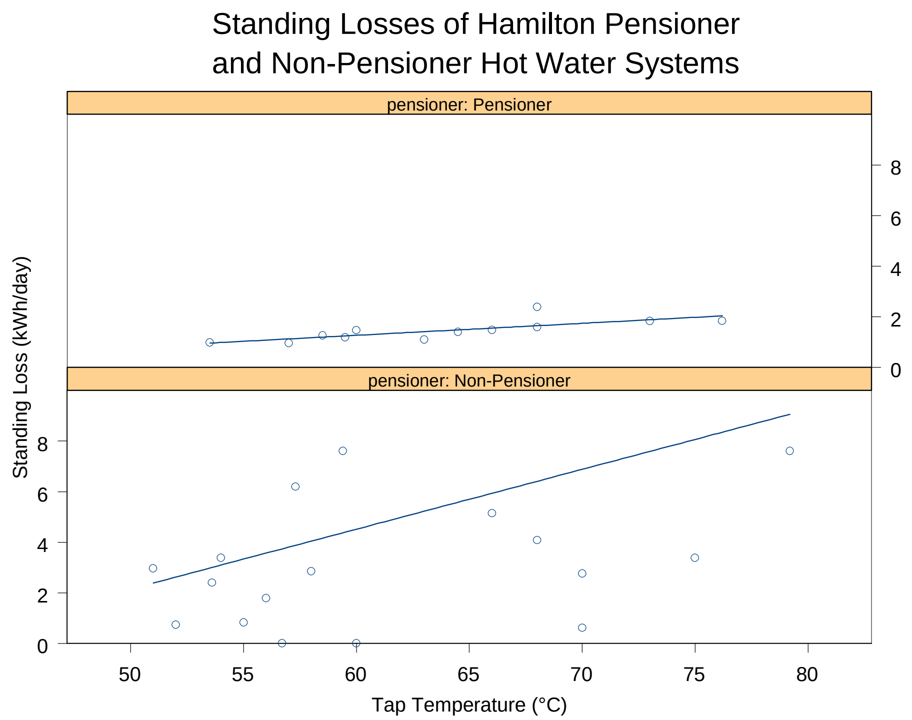


Figure 19: Standing losses as function of tap temperatures

[37] *Which will be slightly lower than the cylinder storage temperatures.*

Two anomalous houses were found, one where the hot water cylinder is turned off regularly to save energy, and the other where the occupants are awake at all hours of the day and night. In both these houses, special analysis had to be done to correctly estimate the standing losses.

From the linear model fitted to the pensioner standing loss data in Figure 19, it was possible to predict what standing losses would be if the tap temperature was set to 55°C. This should give a cylinder temperature of approx 60°C which is sufficient to control legionella bacteria in storage cylinders. The savings averaged $15 per year, simply from setting the thermostat properly. The estimated average daily hot water usage was about 39 litres per day, and no-one reported running out of hot water. It therefore appears that the cylinders are of sufficient size that reducing their temperature would not lead to inadequate hot water delivery.

If the pensioner houses had lower grade cylinders, standing losses would be much higher. With a 135 litre 'C' grade cylinder, the losses would be around $70 per year, and more than half the hot water energy consumption.

As the pensioners have a low hot water usage, careful sizing and specification of hot water systems is needed to ensure safe and efficient operation. The consequences of pensioners using large, low-grade cylinders could be a large increase in energy use from higher standing losses, and possible safety concerns if cylinder storage temperatures are manipulated to either save energy, or provide adequate shower performance from poorly designed systems.

4.5.3 Conclusions

The systems for the pensioners in this study are generally energy efficient, although the delivered hot water temperatures could be reduced in some cases in order to improve safety and efficiency.

5. TEMPERATURE ANALYSIS

This section discusses the development of a cost-effective methodology for monitoring and interpreting temperature patterns within a house covering vertical temperature stratification and temperature zoning effects. Some of the initial results on temperature patterns found in New Zealand houses are temperature stratifications of up to 4°C and comparatively low average room temperatures, indicating that New Zealand houses are often under-heated.

It also describes a methodology for extracting the main thermal building parameters (building conductance, thermal mass and solar aperture) from the measured energy and temperature time series. The method is based on a previously developed Short Term Energy Monitoring (STEM) technique. The analysis results are used to calibrate a simple heating energy calculation model (ALF), which is used for New Zealand building code compliance verification.

5.1 Temperature Patterns in New Zealand Houses

Space heating is an important end-use in New Zealand's houses. The energy used by space heating in a house is determined by the climate, the physical properties of the building, and the comfort expectations of the occupants. However, predicting future energy demand for space heating is complicated by the changing (and possibly increasing) comfort requirements of the occupants. When insulation levels of houses are increased, expected technical savings are not achieved, as occupants tend to use some of these savings ("take-back") in order to increase the temperature within the house. As temperature levels in New Zealand houses appear to be low compared to other countries, increases in temperature may have benefits other than energy savings, such as improvements to health.

In order to better understand future space heating demand changes, the HEEP work has included a detailed examination of air temperature distribution patterns in a selected number of houses. This work has investigated issues of time scale (how often to measure temperatures) and temperature spatial distribution.

The time scale is the lesser of the two issues. The air temperature needs to be measured at a rate long enough to be consistent with the time constant of the sensor, but also with a high enough frequency to detect trends in heater use, as well as the variation in the external climate and time of day, while not being confused by small fluctuations. After experimentation, a period of 10 minutes has been used in the majority of HEEP houses, although finer resolution is used for specific investigations.

5.1.1 Temperature Spatial Distribution

Temperature will vary within the house, both by the zone or room in which the logger is located, and where the logger is placed within that zone or room. One subset of the HEEP data includes nine houses where up to four temperature measurements of differing heights were made in the living room as well as measurements from other rooms within the house. Each of these houses had between eight and ten locations monitored. These houses were not heated uniformly – an initial principal component analysis of the dataset has revealed a distinction between the main bedroom and the living area as most significant.

A dominant feature of air temperature variation within a room is the systematic variation with height[38]. In order to establish a vertical temperature profile, temperatures at a number of measurements points at various heights needed to be gathered. Information on the vertical stratification of air temperature was examined by using data from temperature data-loggers placed at heights of 0.4m, 0.9m, 1.4m and 1.9m in a corner of a living room within a Palmerston North house. The results confirmed that, within a room, care must be taken with the placement of the temperature loggers in order to ensure the measured temperature is representative of the air temperature of interest.

[38] *Vertical temperature stratification.*

The loggers should be sufficiently far away from the wall, ceiling and floor, or any heat source or sinks (heaters, windows, etc.) where draughts may be present. The logger should not be in direct view of any radiation sources such as direct sunlight, household lighting and radiant heaters, or located near any direct heat source.

5.1.2 Measured Temperatures

The 1971/72 Household Electricity Survey [2] measured average winter temperatures in August-September 1971 in the kitchen, lounge and main bedroom of houses. This confirmed that New Zealand houses have traditionally been only heated to low levels. Although there was no measured evidence to support it, it has been assumed that occupants are now demanding more comfortable temperatures, and that average temperatures will have risen in response.

As part of the HEEP project, living room temperatures were monitored in randomly selected Wellington and Hamilton houses[39] during 1999 and 2000. The results were analysed for the months of August to September, which allows the two groups to be compared both to each other and to the 1971 houses. Table 18 shows 1999/2000 temperatures, and those from the 1971 study.

	Wellington 1999	*southern North Island 1971*	*Hamilton 2000*	*northern North Island 1971*
Living Room: mean temperature	**15.5°C**	**16.6°C**	**16.7°C**	**17.7°C**
Standard Deviation	1.36°C	-	1.16 °C	-
95% Confidence Interval	14.9 to 16.0°C	-	16.1 to 17.3°C	-
External Temperature	9.4°C	11.0°C	9.2°C	12.0°C
Internal/External temp. difference	*6.1°C*	*5.6°C*	*7.5°C*	*5.7°C*

Table 18:1999/2000 temperatures and 1971 temperatures

As can be seen, the 1971 figures covered broad regions, rather than the two specific cities in which the HEEP households were located. In order to assess comparability, further investigation was therefore carried out on 1971 temperatures for Wellington and Hamilton.

The external temperature for Wellington was taken as the average daily mean temperatures from Kelburn and Wallaceville in Upper Hutt. The external temperature for Hamilton was taken as the average daily mean temperature from Ruakura and Hamilton Airport. In order to put the 1971 room temperatures in context, external temperatures can be calculated for 1971 for Wellington and Hamilton as shown in Table 19.

Year	*Wellington*	*Hamilton*
1971	10.3 °C	11.1 °C
1999	9.4 °C	-
2000	-	9.2 °C

Table 19: 1999/2000 and 1971 external temperatures in Wellington & Hamilton

Table 19 shows that 1971 average daily mean temperatures in Wellington and Hamilton were cooler than those shown in Table 18 for the regions used in the 1971 study. Assuming a correlation between inside and outside temperatures, this suggests that 1971 living room temperatures in these two cities may also have been slightly lower than those shown in Table 18.

[39] *28 in Wellington in 1999, and 17 in Hamilton in 2000. It should be noted that only 28 of the 43 households finally monitored in Wellington had sufficient data available during a comparable time period.*

Figure 20 gives the detailed results of the 1999/2000 measurements.

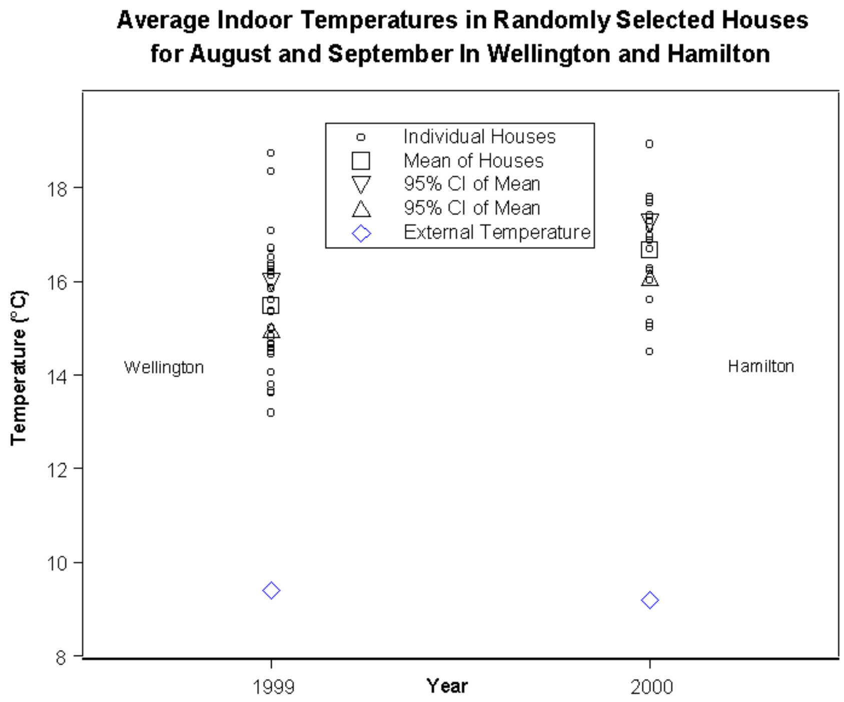


Figure 20: Wellington and Hamilton room temperatures

For each of these houses, the daily average indoor temperature can be plotted against the daily average outdoor temperatures. As an example, this is shown for one Wellington house in Figure 21.

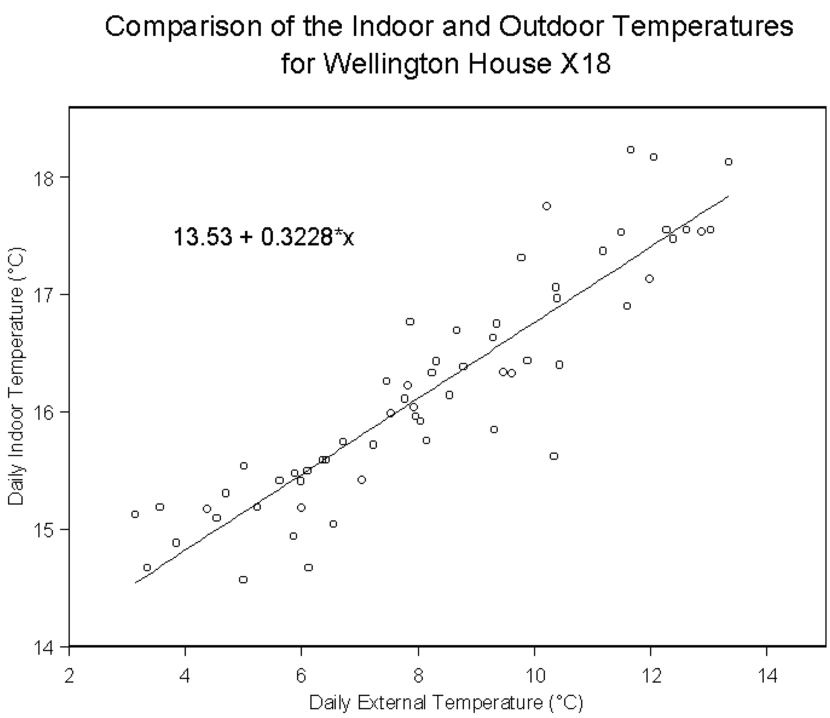


Figure 21: Indoor/outdoor temperatures for Wellington house X18

The mean slope[40] of the line for all houses has a value of 0.4 for both Wellington and Hamilton. This means that, when the outside conditions change by 1 °C, the average indoor temperatures across a number of houses increases by approximately 0.4 °C – a result that is consistent with that for earlier measurements in Wanganui.

The difference between the inside temperature and the outside temperature gives an indication of how effectively the building is performing, as well as the heating energy. As shown in Table 18, the average differences between inside and outside temperatures in 1971 for the southern North Island region and northern North Island region is similar at 5.6 °C and 5.7 °C respectively. However, it is interesting to note that the differences for Wellington and Hamilton are greater; at 6.1 °C for Wellington and 7.5 °C for Hamilton.

The greater difference between the inside temperature and the outside temperature in Hamilton as compared to Wellington may be due to Hamilton having more energy efficient houses than Wellington. As thermal insulation regulations came into effect in the mid to late 70's, newer buildings are likely to have better insulation than older buildings. The ages of houses in the two samples were therefore compared, and the results are shown in Figure 22.

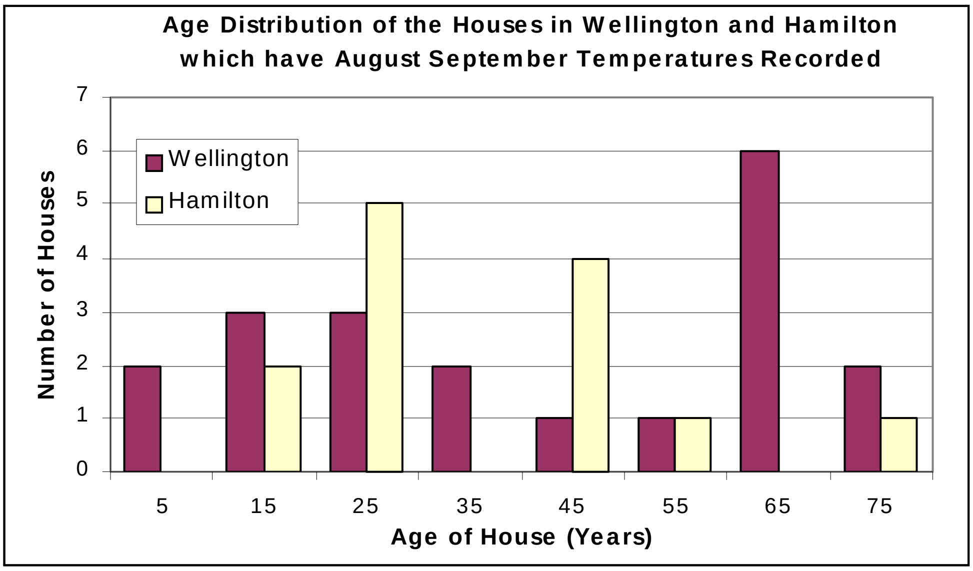


Figure 22: Age distribution of Wellington and Hamilton houses

Figure 22 shows the distribution of ages for those houses with information on the date of construction. It can be seen that the Wellington sample (20 houses) has appreciably more houses built during the 1930's as compared to Hamilton (13houses). The average age of the houses in the Hamilton sample is 36 years old whereas the Wellington sample's average age is 42 years. This may be reflected in the insulation level of the Hamilton houses in the sample being higher than that for the Wellington houses, which may help to explain the relative external/internal temperature differences for the two regions.

5.1.2.1 Evening Temperatures

Evening temperatures can be expected to be more dependent on heating than daytime temperatures, so these were examined separately. Table 20 gives the results for evening temperatures in the Wellington and Hamilton HEEP houses.

[40] *0.3228 for the example.*

Evening (6 pm – 10 pm)	Wellington 1999	Hamilton 2000
Mean living room temperature	**17.1 °C**	**18.7 °C**
Standard Deviation	*1.64 °C*	*1.25 °C*
95 % Confidence Interval	*16.5 – 17.7 °C*	*18.0 – 19.3 °C*

Table 20: Wellington/Hamilton evening temperatures

The detailed results are shown in Figure 23.

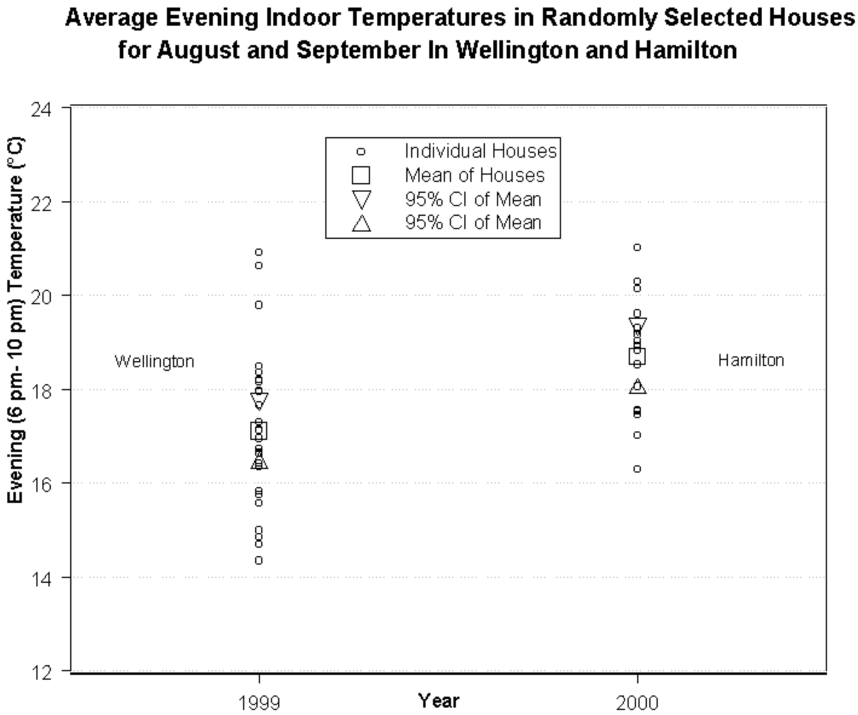


Figure 23: Wellington and Hamilton evening temperatures

The most notable points arising from Table 20 and Figure 23 are:

- *Hamilton evening living room temperatures are 1.6°C higher than those in Wellington*
- *Wellington's spread of living room temperatures is greater than that of Hamilton. This may be due to the wider spread in ages of the Wellington houses*
- *there are 7 houses (25%) in the Wellington sample that have average winter evening temperatures below 16°C.*

Further explanation of the differences will involve investigation into the relationship between space heating, indoor temperatures and the occupants. This will be examined in much greater detail as the project continues.

5.2 Pensioner Housing

From February 2000 to January 2001, sponsored by the WEL Energy Trust, a group of 12 pensioner houses in Hamilton were monitored, in addition to the 17 Hamilton HEEP houses. As well as full monitoring, a comprehensive survey and building audit were done, along with monitoring of total energy use, hot water energy use (see Section 4.5 Pensioners' Hot Water Use), LPG heating, and bedroom/living room temperatures. One of the aims was to explore suppositions about energy use by the elderly, such as:

- *superannuitants use less energy than the average household because they have smaller houses, fewer appliances and fewer occupants per household*
- *superannuitants are more frequently at home, so they use energy more evenly spread throughout the day*
- *because superannuitants use more energy during afternoons instead of morning and evening (non-peak times) the cost of power to them should be smaller than for the average household*
- *superannuitants don't heat their houses because 'that's the way they have been brought up'. However the opposite theory is also available: 'superannuitants want warmer houses because of their age and medical conditions.'*

5.2.1 Thermal Properties of Dwellings

The Short Term Energy Monitoring (STEM) modelling process was used to determine the whole house U-value (reciprocal of R-value) and whole house thermal mass. The U-value indicates how much energy is required to maintain a given temperature difference between the inside and outside. The thermal mass indicates how much energy is required to raise the temperature of the materials in the house. A house with a low U-value requires less heating than a house with a high U-value to maintain the same internal temperatures.

The U-values are much lower than values typical of New Zealand houses (200 W/°C or higher), indicating that a lot less energy is needed to maintain comfortable temperatures in these houses. The lower values are due to the smaller area and volume of the pensioner units, the common walls between units, and the fact that the units are fully insulated and air-tight.

At their rate of heat loss, only around 1000 W of energy[41] is needed to maintain the units at 18 °C when the outside temperature is 8 °C[42]. In the evening, non-dedicated heating loads can easily be 100 W per person, 50-100 W for lights, 50 W for hot water standing losses, and 50-200 W for miscellaneous appliances, giving around 5 °C 'free' heating.

5.2.2 Temperatures

The average evening temperatures (6pm-10pm) for each month of the year are given in Table 21:

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Pensioner	24.4	25.1	24.3	22.6	21.4	20.3	20.7	20.4	20.3	21.0	21.1	23.6
Standard deviation	*0.4*	*0.4*	*0.3*	*0.5*	*0.6*	*0.5*	*0.6*	*0.6*	*0.6*	*0.5*	*0.5*	*0.4*
Non-Pensioner	24.7	24.9	23.6	21.1	20.1	18.9	18.9	18.5	19.1	20.3	20.5	23.7
Standard deviation	*0.3*	*0.5*	*0.4*	*0.19*	*0.4*	*0.5*	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*	*0.2*

Table 21: Average monthly living room evening temperatures in Hamilton houses (°C)

[41] *Which includes the metabolic heat of the people, and all energy in the house, including lights, cooking etc.*
[42] *However the U-values have a very large scatter, so care must be taken not to over-emphasise the average rate of heat loss at this stage.*

For the winter months May-August, the pensioner living rooms are from 1.3 to 1.9°C warmer than the non-pensioner houses. These differences are significant. Most of the pensioner houses maintained average evening temperatures of around 20°C or more in the winter months. In the summer months, there is no significant difference in living room temperatures between the pensioner and non-pensioner houses.

For the bedrooms, Table 22 shows the average overnight (1am to 5am) monthly average temperatures. During the winter months, the pensioner bedroom temperatures are on average 1.3-1.7°C warmer than the non-pensioner houses.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Pensioner	21.4	22.5	21.1	19.4	17.8	15.8	16.4	15.3	16.1	17.7	18	21.3
Standard deviation	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.5*	*0.5*	*0.4*	*0.3*	*0.4*	*0.3*
Non-Pensioner	20.4	21.6	19.8	18.0	16.3	14.5	14.7	13.8	15.0	16.9	16.9	20.7
Standard deviation	*0.3*	*0.15*	*0.2*	*0.19*	*0.2*	*0.4*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.15*

Table 22: Bedroom overnight temperatures in Hamilton houses (°C)

The difference in temperatures is significant for all months of the year, so we can conclude that the overnight temperatures of bedrooms are on average (1.2 ± 0.1)°C higher than in non-pensioner housing, with larger differences in the winter months. In June, more than half of the pensioners achieved average bedroom temperatures over 16°C, which meets minimal WHO recommendations, in contrast to only 2 houses out of 17 in the general Hamilton population.

The Hamilton pensioners maintain higher winter temperatures in winter in the living rooms during evenings, and overnight in bedrooms, than the general Hamilton population. This is despite the fact that the income of the pensioners is low. The small size, relative thermal efficiency of the units, and desire for comfort appear to be likely factors enabling the pensioners to maintain comfortable temperatures. Figure 24 and Figure 25 show the temperature range throughout the year for the family rooms of Hamilton pensioner and non-pensioner houses.

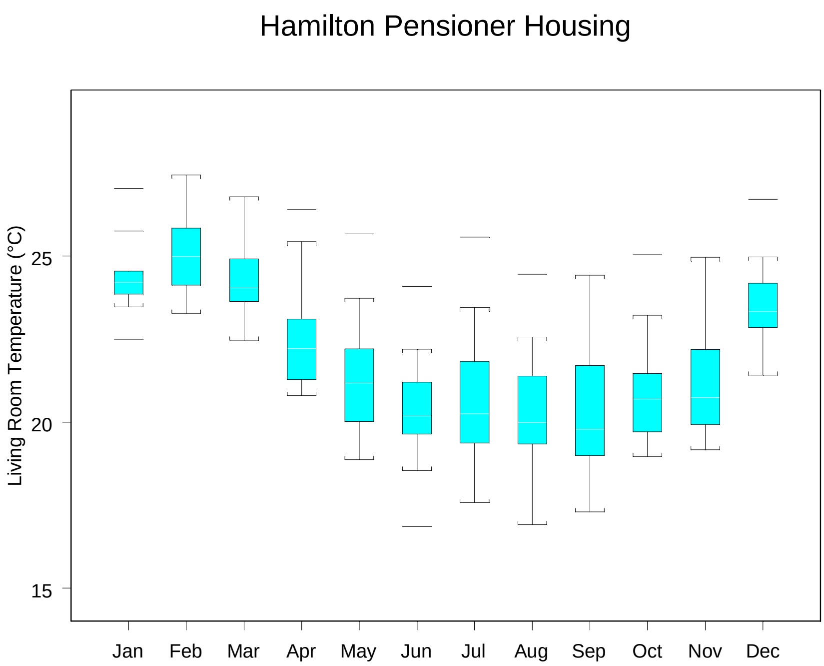


Figure 24: Hamilton pensioner family room evening temperatures

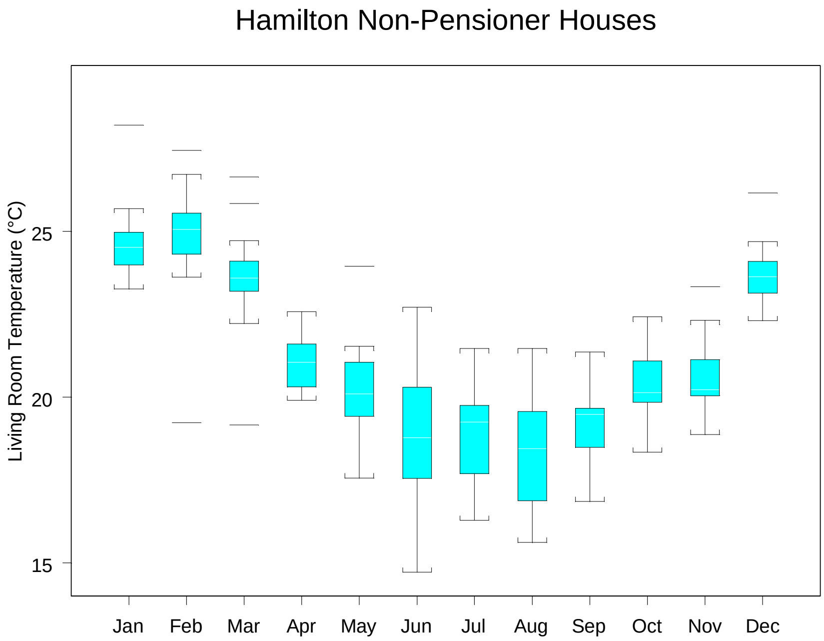


Figure 25: Hamilton non-pensioner family room evening temperatures

Eight out of the twelve pensioner units used portable LPG heaters, which have maximal heat outputs of more than 4 kW. Do these pensioners maintain higher temperatures as a result of larger heater output and lack of thermostat control?

The LPG heated pensioner houses were (1.6 ± 1.0)°C cooler than the other pensioner houses in the winter evening periods. This difference is not statistically significant, so we cannot draw any conclusion from this result.

The average income band reported for the pensioners was $15,000 to $20,000, compared to the rest of the Hamilton sample at just over $40,000. This implies that the average household income of the pensioners is about half that of the rest of Hamilton. The household sizes are also smaller, with either 1 or 2 occupants. In conclusion, the Hamilton pensioners in general appear to maintain comfortable and healthy winter temperatures, and these are 1-2°C higher than the general Hamilton population.

5.2.3 Wellington Pensioner Case Study

A BRANZ researcher has also done a case study of some Wellington pensioners, specifically to examine the effect on perceived comfort, internal temperatures and humidity, and energy usage of retrofitting to improve thermal performance.

The temperature data for 11 units was made available for this report by Malcolm Cunningham, and is shown in Table 23.

Temperatures (6 pm to 10 pm)	*Jun*	*Jul*	*Aug*
Hamilton pensioners	20.3°C	20.7°C	20.4°C
Wellington pensioners (after retrofit)	17.1°C	17.0°C	17.0°C
Difference(Hamilton – Wellington after retrofit)	*+3.2°C*	*+3.7°C*	*+3.4°C*

Table 23: Comparison of Hamilton and Wellington pensioner living room evening temperatures (°C).

As shown in Table 23, the Wellington pensioners, on average, chose to heat to lower evening temperatures than the Hamilton pensioners, both before and after the retrofits. The Hamilton units were kept about 3.5°C warmer in winter than those in Wellington after the improvements in insulation. Only two of the Wellington pensioners maintained temperatures higher than 20°C.

These two groups of pensioners were on similar income levels, but the Hamilton units had better thermal performance and a slightly warmer climate, so the cost of heating to, for example, 20°C would be lower than for the Wellington pensioner units.

After retrofitting, most of the Wellington pensioners chose to both maintain higher evening temperatures, and reduce energy consumption, which indicates that the perceived cost of heating may be a constraint on the selected heating temperature setpoint and that they might have chosen lower temperatures to control the cost of heating.

The good thermal efficiency of the Hamilton pensioner units, and their efficient hot water systems both contribute to a low power bill, and this may make the cost of heating to a higher temperature acceptable to the Hamilton pensioners.

5.2.4 Overall Energy Consumption

The total and hot water energy consumptions of the Hamilton pensioner and non-pensioner houses are given in Table 24.

	Pensioners	*Per Pensioner*	*Non-pensioners*	*Per Non-pensioner*
Yearly Total energy	3314 kWh	2209	7038 kWh	1928
Yearly Hot Water energy	1224 kWh	816	3388 kWh	928
Hot water % of total	*37%*	-	*48%*	

Table 24: Comparison of yearly total and hot water energy consumption (including gas)

On average, there were 3.65 people per house for the general Hamilton group, and 1.5 people per house for the pensioner houses and, comparing the energy consumption per person, we see that the pensioners use more energy per person than the non-pensioner households for the total energy use, and less per person for hot water.

5.2.5 Temperature Profiles

The use of profiles to classify types of occupants was discussed in Section 3.4 Energy Profiles. Profiles allow a better understanding of the occupants' behaviour.

Figure 26 shows classification of the average family room temperatures. Each line represents a 24-hour profile for one house and one month.

Because classification was conducted on absolute temperatures, the algorithm established classes mainly on the basis of their average temperature levels, i.e. decreasing average temperatures from class 1 to class 9.

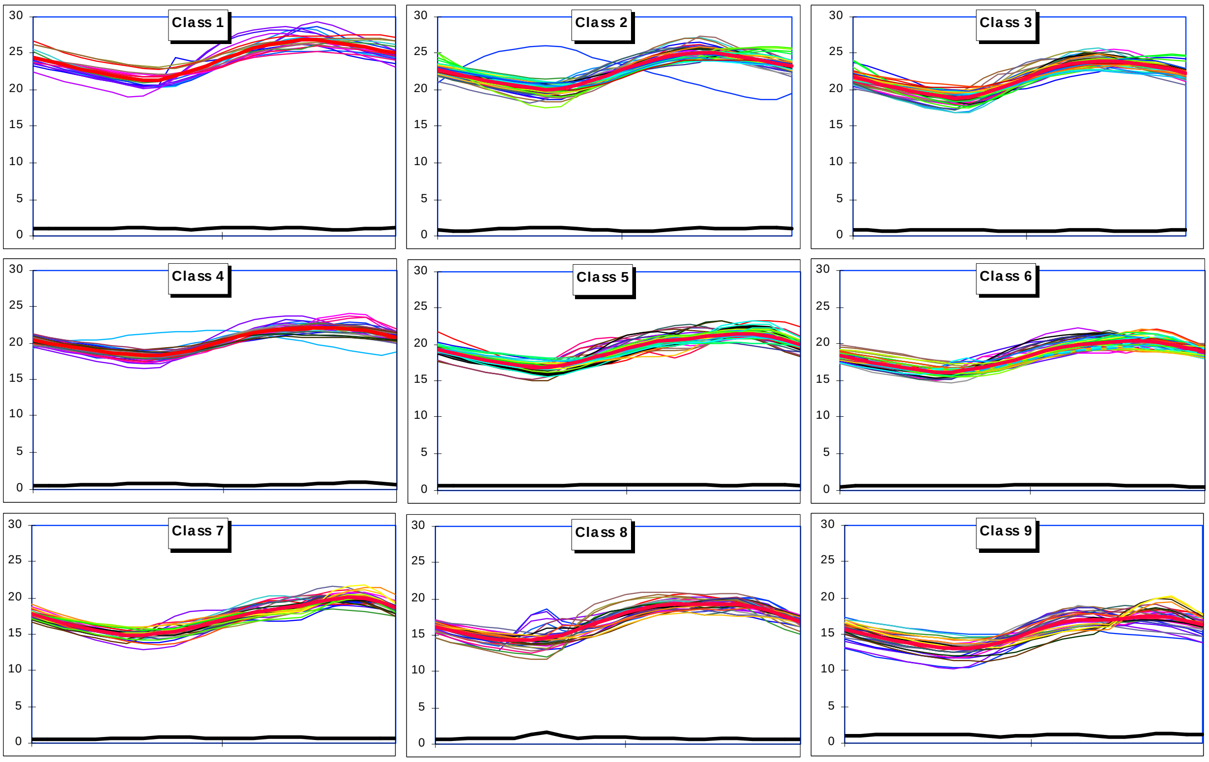


Figure 26: Temperature profiles for Hamilton houses

The profiles are then investigated to show the proportion of households within a certain income bracket having one of the family room temperature profiles as shown in Figure 27.

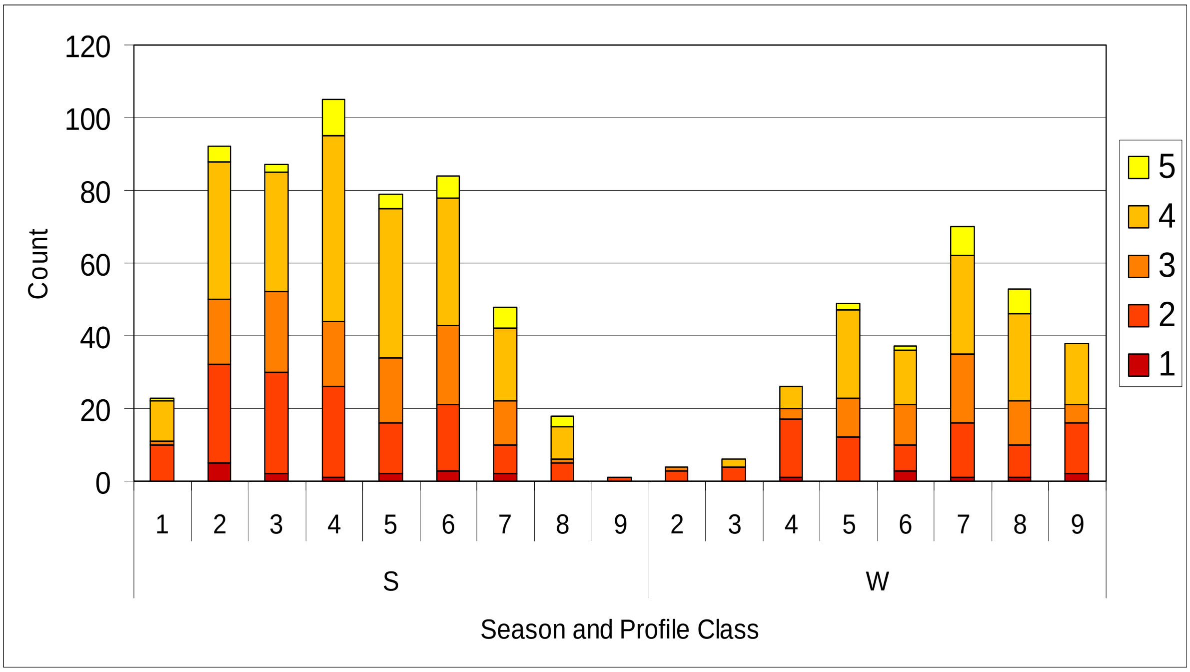


Figure 27: Temperature profiles and income levels (for summer (S) and winter (W) seasons)

The five income levels used for this analysis are as shown in Table 25:

Income Group	Gross annual income
1	$0-$10,000
2	$10,001-$25,000
3	$25,001-$50,000
4	$50,001-$100,000
5	$100,001 +

Table 25: Income levels

Figure 27 is also divided into summer and winter seasons, with the winter season for Hamilton defined as May to August. The increase of the bars for higher profile classes in the winter season (right end of the chart) indicates the dropping average temperatures during this time. However, the chart also indicates that, during the winter season, the high income family rooms tend to be cooler than the family rooms in low income households. This may be related to house designs[43] that are more difficult to heat. In particular, the selection of thermally efficient pensioner houses in the Hamilton sample may contribute to this effect. Alternatively it may indicate that the large pensioner group, which makes up the bulk of the low-income group, may require higher family room temperatures.

5.2.6 Conclusions from Hamilton Study

The Hamilton pensioners in this study use more energy overall (including gas) per person than the non-pensioners, and slightly less energy for hot water per person.

Temperatures during winter in living rooms and bedrooms are 1-2 °C higher in the pensioner houses. Most pensioners achieved comfortable and healthy temperatures, while many non-pensioners did not, especially in bedrooms. The higher temperatures in the pensioner housing may be due to the thermal efficiency of their well-insulated units, which require only about 500W of dedicated heating to maintain indoor temperatures 10°C above outside temperatures.

In contrast, a group of pensioners living in poorly insulated units in Wellington had evening living room temperatures 3.5°C colder than the Hamilton pensioners (even after insulation improvements), with average winter evening temperatures of about 17°C. It is plausible that the cost of heating affects the living room temperatures of pensioners.

The WEL Energy Trust pensioners are exceptional in that their units and hot water systems are highly thermally efficient, which makes a major contribution to both their low energy demand, and their indoor temperatures. Pensioners living in older, poorly insulated units or in houses would likely have a higher energy demand and costs, and lower indoor temperatures as heating would be less affordable and less effective. In summary:

- using M-co wholesale prices (excluding transmission and distribution charges), the average kWh electricity costs the same for the Hamilton pensioner and non-pensioner houses
- Hamilton pensioner houses use **more energy overall** (including gas) per person than Hamilton non-pensioner houses, and **slightly less energy for hot water** per person
- Winter living room and bedroom temperatures are 1 °C to 2 °C higher in the pensioner houses, compared to the non-pensioner Hamilton houses. The Hamilton pensioner houses do have higher levels of thermal insulation, requiring about 0.5 kW of heating to maintain the indoor at 10°C above outside temperatures. Following insulation improvements, Wellington pensioner units still had living room temperatures 3.5°C colder than the Hamilton units.

[43] *i.e. high income households may own larger houses.*

5.3 Solar Gains

Winter space heating is a large component of the energy used in New Zealand houses. The amount of energy required is determined by the climate, the physical properties of the building and the comfort expectations of the occupants.

Purchased heat requirements for a building can be minimised with appropriate design that generally looks to make effective use of the available solar radiation. This section describes the investigation into a typical New Zealand house in order to assess the impact of solar radiation on indoor temperatures within that house.

5.3.1 The Chosen Typical House

The chosen house was built in Palmerston North in the early 1970's with a design common at that time, as shown in the photograph.

The house is timber framed with a stud height of 2.4 metres, suspended timber floor, timber windows and a galvanised iron roof. The house is uninsulated. The northern and eastern exterior walls have brick veneer cladding. The living room is located centrally within the house, with large windows in the northern wall as shown on the left of the photo.

5.3.2 Experimental Set-up

Measurements of the indoor temperature within the living room were made for two periods of twenty-five days; one starting from the 20th May 1999 and the other from the 1st September 2000.

For the 1999 case, an extensive investigation of the living room temperatures was made. Eighteen temperature loggers placed around the living room, including two temperature loggers placed in the centre of the room (at a height of 1.9m), three and four loggers placed at differing heights in the southwest and northwest corner of the room to provide information on the vertical temperature patterns within the room and three loggers along each of the southern wall and eastern walls. The eastern wall had a flued, radiant, natural gas. A temperature logger was placed on the top of the gas heater provided an indication of when the heater was being used.

For the 2000 case, interest was restricted to examining the vertical temperature patterns so only the vertical temperature array in the southwest corner was again used. This array had temperature loggers placed at heights of 0.4 m, 0.9 m, 1.4 m and 1.9 m, however due to configuration problems no data was available from the temperature logger placed at 0.4 m.

The space heating used within the living room changed between the two periods monitored. The flued, radiant, natural gas heater used in 1999 was replaced in 2000 with a flued, flame-effect, convective, natural gas heater.

Temperature loggers were set with a five-minute interval between readings. Additional hourly measurements, covering the same time periods, of external air temperature and global horizontal solar radiation were extracted from the NIWA climate database [29] taken from Palmerston North Airport, about 4 km to the northeast of house. The global horizontal solar radiation reported in the NIWA database is the solar radiation received (in MJm^{-2}) for the previous hour.

5.3.3 Results

Hourly measurements for the first nine days of the 1999 data are shown in Figure 28.

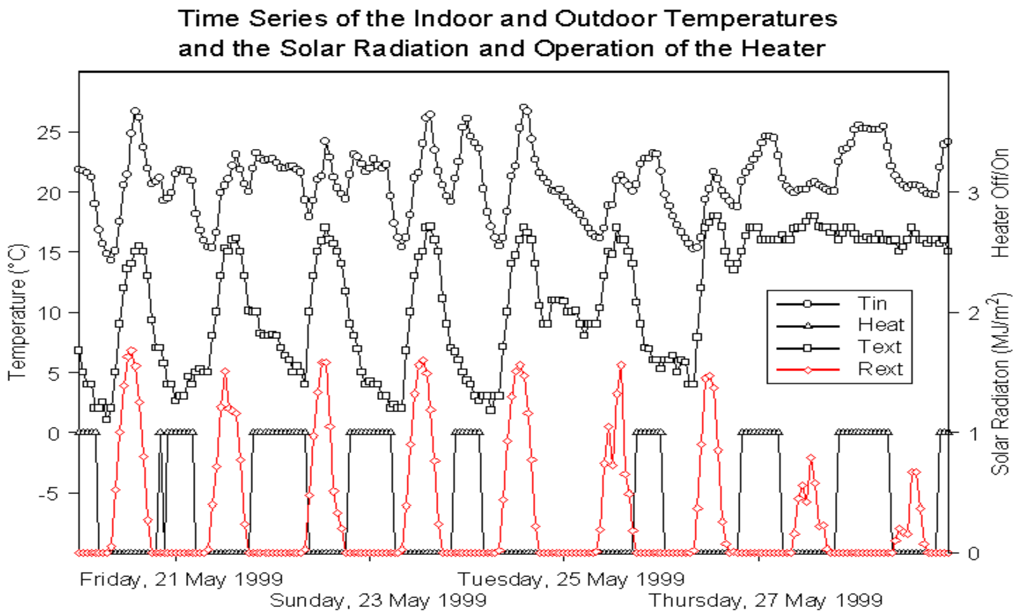


Figure 28: Measured parameters

For Figure 28:

Tin = *temperature reported by temperature logger at centre of room (°C)*
Text = *temperature recorded at Airport (°C)*
Rext = *global horizontal radiation also recorded at Airport (W/m²)*
Heat = *indicator variable as to whether heater was on or off.*

It can be seen that the occupants of the house use the radiant gas heater in the evenings and there is little overlap between the times of the solar radiation and heater operation.

In order to examine the average effect of the solar radiation, the gas heater use and the external temperature on the indoor temperature achieved within the house, an average for each of these variables was calculated for each hour of the day over the twenty-five day period. These average daily profiles are shown in Figure 29.

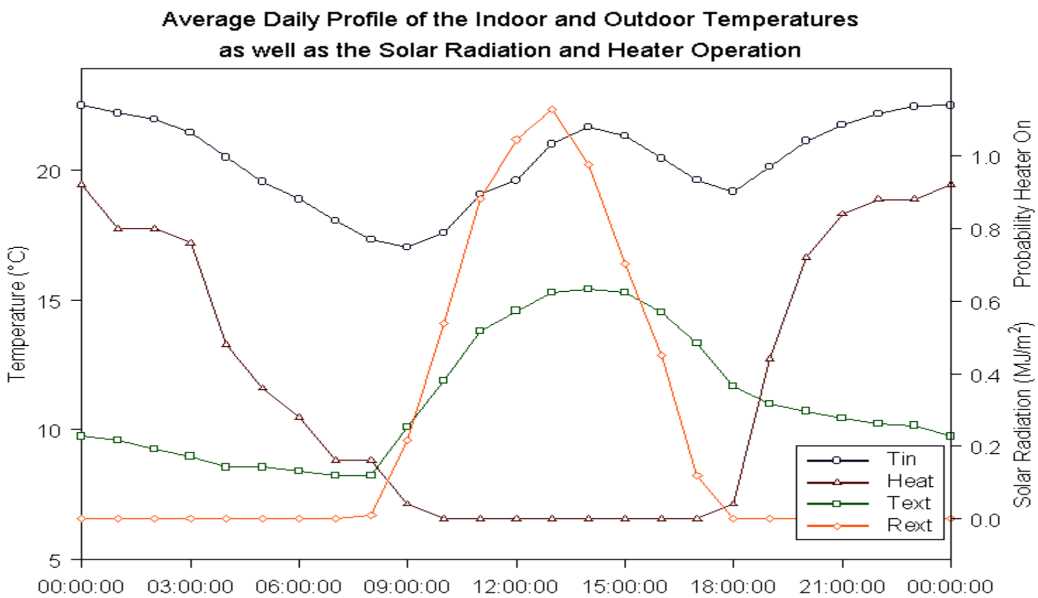


Figure 29: Average daily profile

As shown in Figure 29, the occupants frequently operate the gas heater between midnight and 6am[44]. It can also be seen that peak solar radiation occurs before peak indoor temperature, suggesting that solar radiation has a delayed effect on indoor temperature. From a cross-correlation between indoor temperature and solar radiation, it was seen that maximum correlation occurs between the variables when a lag of two hours was applied to the solar radiation.

A multiple regression of the hourly indoor temperature was examined against the operation of the heater, the external temperature and the solar radiation lagged by none, one, two or three hours. A lag of two hours provided the best fit with a multiple r^2 value of 0.68.

The fitted function was:

$$T_{in(t)} = 15.03 + 5.02 \cdot Heat_{(t)} + 0.25 \cdot T_{ext(t)} + 2.40 \cdot R_{ext(t-2)}$$

Equation 7: Hourly indoor temperature & solar radiation

The peak of the average solar radiation occurs at 13:00 and has a value of 1.13 MJ m^{-2}. The solar radiation will then have an average effect of about 2.7 °C on the indoor temperatures recorded at 15:00. The measured solar radiation at 13:00 varied from a value of 0.16 MJ m^{-2} to 1.68 MJ m^{-2} corresponding to an average solar contribution to the 15:00 indoor temperature of between 0.4 °C and 4.0 °C.

Improvements to the accuracy of Equation 7 could be made by better accounting for the deviation between the measured values of the external temperature and solar radiation and the conditions influencing the temperature within the living room. For example, restriction of solar radiation in the afternoon due to shading from the north-eastern bedroom walls has not been considered.

5.3.4 Vertical Temperature Distribution

From the measurements in 1999, it was seen that there was a systematic variation in temperature within the living room that could be related to the height of the temperature measurement. From the literature, it has also been found that the type of heating employed within the room impacts on the temperature distribution [30], [31]. However, the work described in the literature has been conducted in laboratories, and considers static situations when a particular heater is operating. Heating due to solar radiation is time dependent, and field measurements are required to account for such factors as external shading, furnishings, and occupant interactions such as closing curtains or shutters.

A large amount of data has been collected from the vertical temperature measurements taken in the Palmerston North house. Figure 30 shows four days of measurements from 1999, and Figure 31, shows six days of measurements taken during 2000. In these graphs, time is shown on the x-axis (midday is indicated by the vertical lines through the date labels) and height on the y-axis. The shading, to the scale on the right, indicates the temperature in 1°C increments. There is a horizontal line indicating a height of 1.1m.

Figure 30 and Figure 31 show that, as the living room is being heated due to either heater operation at night or solar radiation during the day, there is an increase in the vertical temperature difference (indicated by more temperature layers) between the high sensors and the low sensors.

When the living room cools, due to heat conduction through the walls and infiltration heat losses, the vertical temperature difference is reduced. The most striking contrast between the temperature measurements for 1999 and 2000 is the change in the vertical temperature differences during heating. The convective heater, in use in 2000, produces greater vertical temperature differences than the radiant heater in use in 1999.

Examining the twenty-five day periods hour by hour, gives the interval between 9pm and 1am as the time when the range of the vertical temperature differences is the smallest. This is the time when heating is most consistently applied.

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[44] *It should be noted that the occupants were in full time employment and were away from the house during most of the day.*

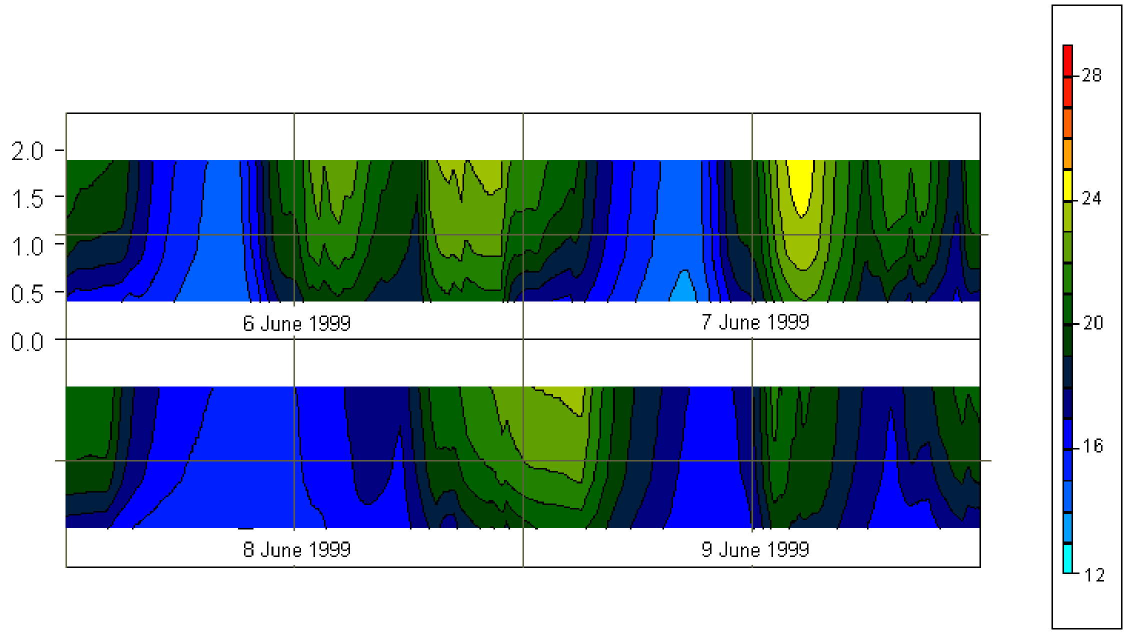

Figure 30 Vertical temperature stratification 1999 (living room southeast corner)

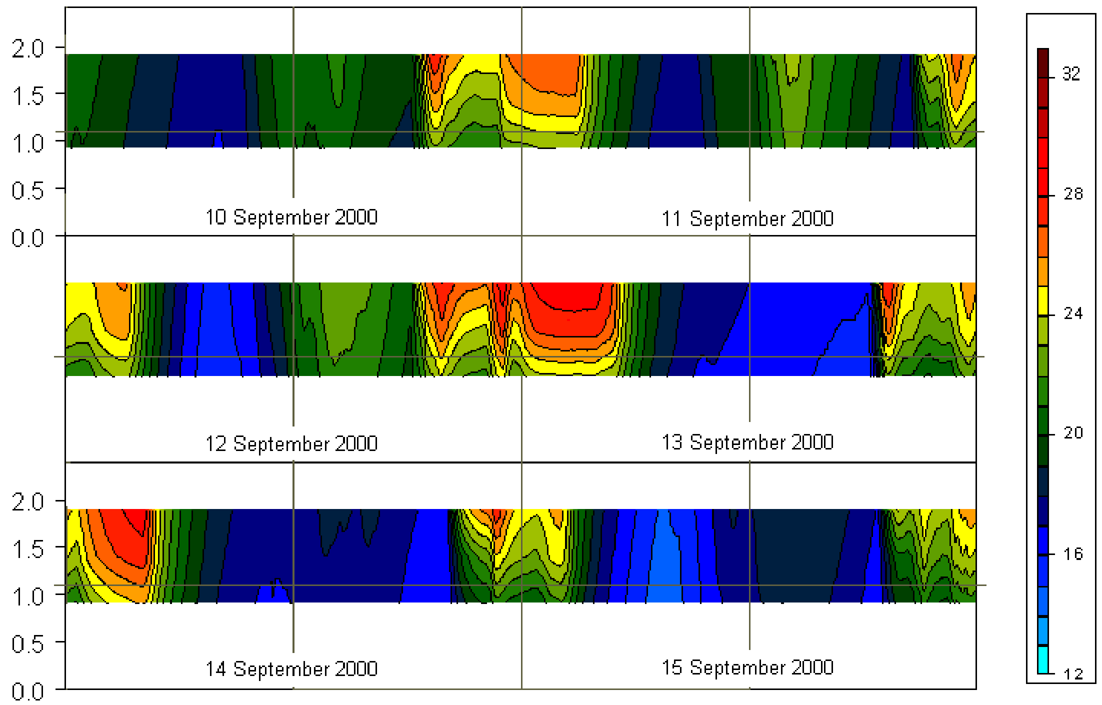

Figure 31: Vertical temperature profile, 2000 (living room southeast corner)

For 1999 (radiant heating) the temperature difference during this time between the temperature logger at 1.9 m and the temperature logger at 0.9 m was typically between 1.0 °C and 2.0 °C with an average of 1.3 °C. During 2000 (convective heating) the vertical temperature difference was typically between 3.0 °C and 7.0 °C with an average of 3.6 °C.

When the building cools, the vertical temperature difference drops to below 0.6 °C and is more sensitive to individual heating events. In the afternoon the temperature difference due to solar radiation, between 1pm and 3pm, ranges between 0.2 °C and 1.5 °C and has a consistent average of approximately 0.7 °C for both 1999 and 2000. The layering of the afternoon temperatures is similar to that of the radiant heater.

The approximate head height of a seated individual (1.1 m) is taken as a reference height. Table 26 gives the average estimated temperatures (as well as their standard deviations) at this height for the period of solar gains and the period of evening heating for 1999 and 2000. The afternoon solar gains produce similar temperatures between the two years, which are only slightly lower than the temperature measured during the evening heating for 1999 (radiant heating). Therefore the level of temperature the solar radiation provides appears to be within the preference temperature range of the occupants.

Year	*Between 13:00 and 15:00*	*Between 21:00 and 01:00*
1999 (radiant)	20.6 ± 2.2 °C	20.8 ± 1.4 °C
2000 (convective)	20.3 ± 2.4 °C	22.3 ± 1.7 °C

Table 26: Temperatures during afternoon solar gains and evening heating

The temperatures measured during the evening heating for 2000 (convective heating) are, on average, about 1.5 °C warmer than the evening heating for 1999 (radiant heating). The occupant's commentary on the change of heating was that the new flame effect convective heater was less noticeable while in operation. They reported that the difference in temperature between the living room and other rooms of the house are apparent when they move between rooms. This difference in temperature may be due to differences in comfort between radiant heating and convective heating, or may be due to the incorrect assumption that the height influencing comfort is head height (1.1 m). A lower height, closer to the centre of the body, may be a better reference height. It is interesting to note that an energy conservation programme in Ireland needed to make corrections to the temperatures recorded at high locations (0.1 m from the ceiling) depending on the nature of the heating system [32].

5.3.5 Conclusions

Indoor temperatures within buildings are dynamic. The vertical temperature distribution within the living room of the house under investigation was seen to depend on the nature of the heating system employed.

Convective heating produced a greater vertical temperature difference (3.6 °C) than radiant heating (1.3 °C). The solar gains were seen to produce a radiant effect on the afternoon temperatures within the living room, producing a vertical temperature difference approximately between 0.2 °C and 1.5 °C, with an average value of 0.7 °C. The afternoon temperatures were comparable to the evening temperatures when the radiant heater was used (1999).

6. HEEP & APPLIANCE STANDARDS

As part of the HEEP project, the actual energy use of appliances of all types, sizes, and ages by people in real houses is monitored in great detail, while the use of appliances by occupants is surveyed. In addition a large database of more than 1,500 energy measurements of appliances, including their standby power, is held.

This increasing body of information is allowing some conclusions to be drawn in regard to New Zealand's appliance stock, energy use, operating patterns and environments, together with the potential impact of appliance standards. The following text is extracted from a submission provided to EECA on the review of 'Minimum Energy Performance Standards' (MEPS) for New Zealand appliances.

6.1 Appliance Standards and Energy Labelling

Codes and standards underpin society's ability to use energy efficiently. Mandatory minimum standards for appliances, represented by MEPS and Building Code Clause H1: Energy Efficiency, do not represent a 'good' energy efficiency goal, but are critical to ensure that market failures are not permitted to continue.

'*Better'* and '*Best'* standards should not cover only the design of the building, but also significant energy using appliances in order to provide guidance to those wishing to 'do better' than the mandatory minimums. These standards should be developed in conjunction with the appropriate industry and user groups.

The Building Code does not require existing buildings to meet current standards for hot water systems when changes are made, and it is legal to replace an old hot water cylinder with one of any grade or age. It may be of benefit to require that all replacement hot water systems should meet current requirements, and the second hand market for non-complying hot water systems stopped.

A MEPS and energy labelling programme for appliances is essential, and should be implemented as soon as practicable. It should aim to achieve similar coverage to that of other programmes around the world. The standby power consumption of appliances should be included in MEPS and energy labelling, as this accounts for around 5% of domestic energy use, and can be reduced easily.

6.1.1 Current Proposals

The scope of the currently proposed MEPS programme deals with appliances that use around 40% of domestic energy, mostly coming from electric storage water heaters. This leaves other major energy uses and appliance groups untouched. A plan and timetable for further evaluation and inclusion of other appliance types and energy uses in the future should be developed.

Some high consuming appliances are conspicuously absent from the current MEPS proposal. Of particular note are televisions and domestic lighting[45]. There are also many other appliances that, although individually using little power, collectively use as much as larger appliances.

6.2 Appropriate Test Standards

It is important that MEPS and any energy-labelling programme should lead to consumers buying more energy efficient appliances. The results of the HEEP monitoring suggest that the current and draft testing standards for refrigeration, clothes washers, dishwashers, and clothes dryers do not adequately represent actual conditions in New Zealand houses. This may lead to some incorrect relative rankings, which may partially defeat the energy labels. Testing standards should be revised in the future to better reflect the actual use of appliances in households, including energy used in the standby mode.

[45] *Incandescent, halogen, compact fluorescent.*

6.2.1 Washers and Driers

A range of other factors may cause incorrect ranking (by perhaps up to 2 Stars) of some clothes washers, clothes dryers, and dishwashers. These include:

- *the test cold water temperatures are too high at 20°C as it would be expected that cold water arriving at a house would be close to the average ground temperature, which is around 14°C for much of New Zealand*
- *the test ambient air temperature of 20°C is higher than temperatures measured in New Zealand houses*
- *the relative humidity at 60% would appear too low, as between 60% and 80% could be expected for occupied spaces, with higher RH for unoccupied spaces such as laundries*
- *for washing machines, not rating the standby energy biases the cold-water wash test in favour of computer-control. Manual driers are given an arbitrary 10% penalty (nearly 1 Star) compared to auto-sensing dryers, despite the fact that many manual timed driers have no standby power (saving about 6% in actual use), whereas most auto-sensing dryers do.*

For the washing machines, the net effect of these factors would be a bias in the balance between water use (underrated) and energy use (overrated) for a given appliance.

The contribution of standby power to actual energy consumption is ignored in current and draft testing standards for dishwashers, clothes dryers, and washing machines, which measure only the on-cycle energy performance. It is possible that the energy consumption of dishwashers, clothes dryers, and washing machines may be incorrectly ranked, especially when electronic and non-electronic controlled appliances are measured using the same test.

6.2.2 Fridges & Freezers

Under the current test and labelling standards AS/NZS 4474.1:1997 and AS/NZS 4474.2:2000, it is possible that a 5 Star refrigerator will use more energy than a 3 Star refrigerator under real conditions.

This is because the refrigerator testing is carried out at 32°C ambient temperature – an ad-hoc method intended to simulate the effect of door openings by increased heat ingress. However, the performance characteristic of the refrigerator will not be the same as that at a room temperature of around 18°C. The results of the HEEP study show that refrigeration appliances at 32°C range in energy use from 1.1 to 2.0 times more energy than at 18°C, so an appliance tested and ranked at 32°C will not always have the same ranking at 18°C. An improved energy labelling test standard is needed in the future.

6.2.3 Hot Water Cylinders

Only electric storage hot water heating is proposed to have MEPS under the current proposals; gas and instantaneous water heating systems are ignored. This is a serious omission, as gas water heating appliances have a large market share in North Island areas that have reticulated natural gas. Current requirements permit gas systems to have higher standing losses than the allowable MEPS for electric systems.

6.3 MEPS and Standby Power

Standby power and losses were discussed in detail in Section 3.5. For many appliances, their standby power consumption is a significant fraction of the total energy consumption (e.g. averaging over 40% for microwave ovens) and can be practicably reduced by up to 90%.

Preliminary results show that appliances with standby may consume $30-$50 million of electricity per year in standby mode in New Zealand (based on Hamilton and Wellington measurements), and this figure is set to rise by perhaps $10 million per year with the introduction of digital TV, and to increase further with the growth in new and ‘smart’ appliance types. However, standby power does not appear to be included in current test standards (with the exception of refrigeration), nor has it been treated as a stand-alone issue.

The increasing use of electronic based controls[46] is leading to the sizable standby or 'off' energy use shown in Table 27. It is therefore possible that appliances can use more energy waiting to be used, than they use when functioning. For example under the operating conditions found in New Zealand houses, the energy used by a microwave to run the permanently displayed clock is likely to be comparable or even greater than the energy used for cooking.

Table 27 [33] is based on data from 64 Australian houses, covering more than 2500 appliances, and provides information on the standby or 'off' mode power consumption of all household electrical appliances except fridges and hot water systems.

Appliance	*Average no. per household*	*Mode*	*Consumption range of all appliances tested (W)*		*Average consumption per appliance (W)*
			Min	*Max*	
TV	1.9	Standby	<1	29	9.6
VCR	1.2	Standby	3	18	7.9
Computer	0.7	Off	0	12	2.0
Computer monitor	0.7	Off	0	5	1.2
Computer speakers	0.6	Off	0	7	2.1
Printer	0.6	Off	0	13	2.0
Washing machine	1.0	Off	0	11	2.0
Dryer	0.5	Off	0	4	0.4
Microwave oven	0.9	Standby	2	11	3.9
Cordless phone	0.5	Standby	1	9	2.7
Fax machine	0.2	Standby	3	16	8.2
Answering machine	0.4	Standby	2	5	3.3
Audio/video (A)	5.0	Standby	0	50	9.5
Audio/video (A)	5.0	Off	0	25	1.3
Battery charger	3.5	Standby	0	15	1.9

Table 27: Indicative standby power consumption of appliances

Standby power consumption is already rated for many small appliances in the Japanese '*Top Runner'* programme, and the US *Energy Star* programme. As many of the appliances covered by these programmes are imported into New Zealand, with little or no local competition, implementing a similar programme for standby power consumption should encounter few problems.

MEPS may be more appropriate than energy labelling for standby power consumption alone, as energy savings to an individual consumer are only a few dollars per year. Implementing MEPS for standby power consumption should also be much easier to achieve than a labelling regime. The test methods used in *Energy Star* are very simple and self-certified by manufacturers.

A comprehensive MEPS programme covering only the standby consumption of appliances should be implemented as soon as practicable, and standby power should be included in all energy labelling test methods.

6.4 Effectiveness of Energy Labelling

The choice of a requirement for an energy label, MEPS, or both, requires careful consideration. The mere presence of MEPS may lead the public to think they are purchasing 'good' energy efficiency, and could therefore become a barrier to better energy efficiency.

This would appear to be the case for houses, where the minimum thermal performance requirements established by the NZ Building Code Clause H1 are often used as the 'target', even though significantly better performance is practicable and in many cases desirable. Consideration should be

[46] *enabling the use of remote controls, 'instant-on', 'favourite programme' memory, etc*

given to using MEPS in order to establish minimum marketplace performance, while at the same time using energy labelling to identify better performing products.

A 1998 New Zealand research report [34] by Gerard Fitzgerald has highlighted the difficulties that consumers have in interpreting and using energy labels. The research suggests that many New Zealanders have no idea of what a kWh is, or how much it costs. Simply displaying a label on a product in store may not be sufficient, as many retailers sell only one brand, making comparison-shopping based on the energy label difficult.

Any labelling programme should be accompanied by advertising and public education, training of retail staff, and the provision of readily available information, so that consumers know what the energy label is, how to interpret it, and how to use it. Monitoring and evaluation of consumers, retailers, manufacturers, and importers is also needed to gauge the effectiveness and success of the programme, otherwise opportunities for improvement will be lost.

7. REPORTED ENERGY SERVICES

All monitored households are surveyed before monitoring commences. The survey questions relate to technical details of the buildings and appliances, as well as covering some behavioural and attitudinal characteristics of the occupants. Survey results, together with monitored information, gives interesting insights into perceptions as to the relative values of the energy services attained and desired.

7.1 Perceived Value of Energy Services

One of the survey questions seeks to establish the priority of various energy services to the household occupants. The question reads:

> *'Suppose that you had to cut down the amount of energy you used in the home. In what order would you reduce your use in the areas listed on card 13? (rank responses, with 1 being the first area you would cut down in, 2 for the second etc)'.*

Card 13 lists the following six areas of energy use in houses: *electric blankets; electric appliances; lighting; TV and entertainment; water heating; and home heating.*

Analysing the average rankings of each of the items yields the following results:

Energy Use	*Average Score*	*Approx. Proportion of Energy Use*
Electric Blankets	2.21	1-3% (estimate)
Electric Appliances	2.82	15% (estimate)
Lighting	2.88	8%
TV and Entertainment	3.09	1-3% (estimate)
Water Heating	3.13	44%
Home Heating	3.20	30% (estimate)

Table 28: Perceived value of energy service (based on random and non-random households)

Table 28 suggests that people are least willing to sacrifice heating and hot water energy, while the easiest sacrifice appears to be electric blankets and lighting.

It is interesting to note that lighting contributes significant amounts to the total energy consumption (8%), and is one of the energy end-uses where savings could technically be easiest achieved. Changes can be achieved through appeals to modified user behaviour and through technology changes. These findings suggest that energy efficient lighting usage behaviour could be easier achieved than changes in hot water heating and space heating behaviour. Also, the technology of efficient lighting is available and is becoming cost effective. No specialist knowledge is required for upgrading.

7.2 Comfort Perceptions

Occupants were also asked about the temperatures they achieve in their houses. Over past years, the HEEP study has frequently found evening living room temperatures below 16°C (also see Section 5.1.2.1). One of the critical questions has always been whether occupants do not **want** to achieve higher temperatures or whether they **cannot** achieve higher temperatures. In order to determine the reason for these low temperatures, the occupants' feedback concerning their comfort perceptions gives a valuable insight. The question we asked was:

> *Does your heating achieve comfortable conditions over winter?*
> *(Response: no, sometimes, mostly, always)*

Our survey findings to date show that only 52% of houses achieve *'always comfortable'* temperatures in the winter - based on the randomly selected houses in Wellington, Hamilton and Auckland (2001 year only). This implies that 48% of houses are sometimes or mostly not heated to comfortable temperatures, with 13 % of occupants reporting that they only sometimes achieve comfortable temperatures.

Responses	*Frequency*	*Frequency %*
no	2	2%
sometimes	11	13%
mostly	28	33%
always	45	52%
Total	**86**	

Table 29: Comfort perception

The current sample of houses is from the North Island, so it is not unlikely that the proportion of uncomfortable houses will increase further when houses in colder climates are included in the study.

These comfort perceptions were compared to the actual measured winter evening temperatures. Figure 32 shows the average winter evening temperatures achieved in the houses together with the comfort perceptions by the occupants.

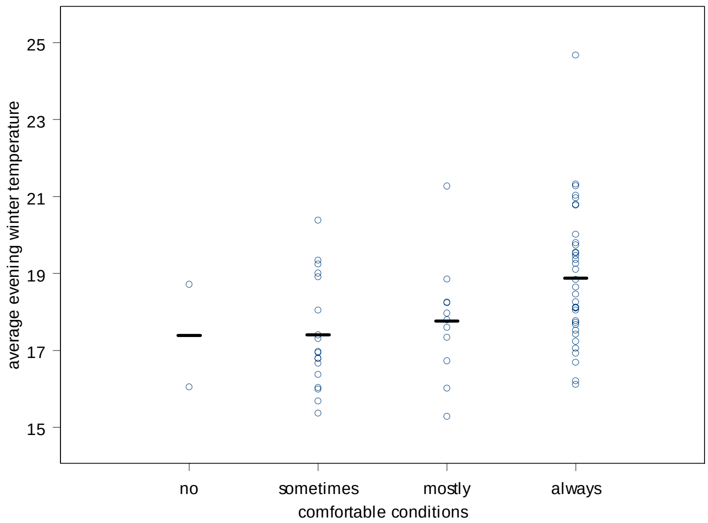

Figure 32: Average evening winter temperatures plotted against occupants' comfort perceptions (horizontal lines are mean values)

There is a clear relationship between perceived comfort and actually achieved temperatures. Figure 32 seems to indicate that, when a house can be heated to an average temperature of 19°C across the winter evenings, occupants 'always' feel comfortable.

It is also interesting to note the large standard deviations of the temperatures within each of the comfort bands. This indicates variations in comfort perception, but it may also be linked to the temperature monitoring methodology. In other words, temperatures cannot always be monitored close to locations where occupants spend most of their time - such as the couch in front of the TV. It should also be noted that three of the unsatisfied respondents reported temperatures as being too high.

These results highlight the need for better thermal design of dwellings. It was therefore considered worthwhile to investigate the insulation level of houses against average winter evening temperatures. The insulation level and thermal performance of a house is a complex parameter, determined by insulation material, thickness and location as well as other design characteristics of the building such as window sizes, orientation etc. Instead of analysing the thermal efficiency, we used the age of the building as a proxy for the energy efficiency. Over the last 40 years many educational campaigns have taken place. In addition to that building regulations have set increased energy efficiency targets, the most significant being the introduction of minimum insulation standards in 1978.

Figure 33 shows the average winter evening temperatures in the living rooms for all the monitored houses in the database plotted against the decade in which the house was built.

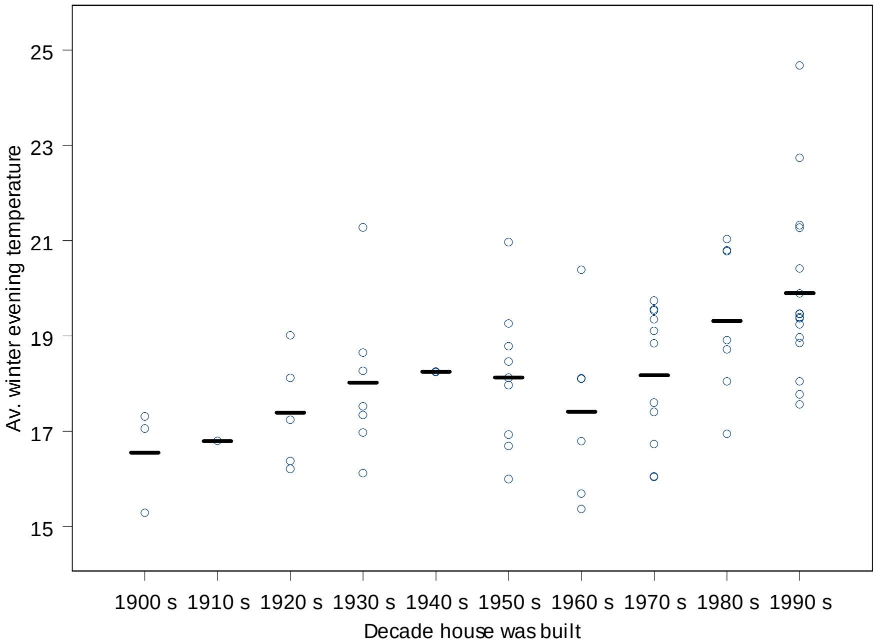

Figure 33: Average winter living room temperatures against age of the building

Figure 33 shows a clear increase in temperatures recorded in houses with later construction dates. The downward blip in the 60s may be caused by a statistical error (only 5 of the monitored houses were built in that decade), but this will be resolved as the number of monitored houses increases. Nevertheless the graph shows a steady increase in average temperatures in houses built in the 1980s and 1990s.

The average temperature in the newest houses (those built during the 1990's) is approximately 20°C. It is possible that apart from the age of the house, there may be socio-demographic aspects of the increasing temperatures – for example if the occupants in newer houses are wealthier. These issues will be further investigated in later years

7.3 Reported Insufficiencies in Hot Water Supply

Another area where New Zealand households appear to suffer, is in the availability of sufficient hot water. Households were asked the question:

> *'Do you sometimes run out of hot water? (Responses: no, yes, don't know)'*

Almost 20% of households responded to this with '*yes'.*

However, this has to be seen in context of standing losses of approximately 25% for hot water cylinders. The solution should not be to increase effective capacity by raising thermostat settings on hot water heaters. As discussed previously and shown in Figure 17, hot water thermostats are often out of calibration, so relying on them to produce water at the set temperature can be dangerous as there may be as much as 20°C difference between the thermostat setting and the actual temperature of the stored water.

A question that should be asked in this context is whether it is more cost effective to replace thermostats than to wrap cylinders. Replacing thermostats may not only provide energy savings, but may also improve the health and safety aspects of hot water systems by reducing the risks of scolding and legionella. Because of the multiple benefits, costs of retrofit programmes could be shared across agencies from different disciplines.

8. YEAR 6 ACTIVITIES

The following section outlines the activities to be carried out during HEEP year 6.

The current 47 houses in Auckland (one house has dropped out of the sample) will continue to be monitored until January 2001, when the monitoring equipment will be removed and calibrated. The remaining 50 houses in Auckland will be selected in January 2002 in order to permit the installation of loggers in February 2002.

Loggers will be installed into 10 houses in Waikanae during late October and 37 houses in Christchurch during November 2001, and these households will also be logged for a one-year period. This will involve the purchase of new loggers for 50 houses and as well as planning their installation.

The base analysis of standby and base loads, hot water consumption and standing losses will continue, including the new data gathered from the Auckland and Christchurch houses. With the new information gathered and processed, we will also be able to provide information that will allow the exploration of regional differences.

During Year 6, we also intend to further develop the models looking at which socio-demographic groups strongly affect energy use in New Zealand housing. Analyses comparing the surveyed information to the actual energy usage will be done. Further investigation of the relationship between space heating, indoor temperatures and the occupants' characteristics (using the surveyed data) will also be carried out.

The large database on appliance types, power measurements and usage will give excellent background information for the MEPS programmes. We will be able to provide support by using this information to understand what issues are most important to consider when developing a MEPS programme and energy labelling.

9. CONCLUSIONS

Year 5 of the HEEP investigation has seen an extension into Hamilton. In addition to the 17 scheduled random households, a set of 12 specifically selected flats has been monitored. Most monitoring methodologies are now well established, and data logging occurs in a very streamlined fashion. Analysis has focussed on very topical areas, such as standby consumption of appliances and indoor temperatures.

The HEEP database now includes data from 126 houses with data from the 2001 year for 48 Auckland households to be added. Because a large proportion of data is collected in randomly selected households, analysis results are now becoming statistically more representative of al New Zealand.

Important findings from this years monitoring include the finding that hot water energy consumption is much higher than previously estimated, at around 40% of the total household energy. Standing losses are in the vicinity of 25% of hot water energy. At the same time about 20% of occupants report that they sometimes run out of hot water.

The baseload makes up about 10% of household energy consumption. Baseload includes continuously running appliances such as towel rails and alarm clocks as well as standby consumption of various electronic devices. This indicates that there is significant potential to reduce baseload and standby power consumption through technological and behavioural changes.

The instantaneous power of approximately 2500 appliances has been measured, and can now be compared to the appliance label ratings that have been recorded at the same time. Such information provides valuable understanding of appliance ownership patterns, and the relationship between the standard label testing methods and that of actual power usage on site.

Analysis is now also targeting socio/demographic drivers of energy use. As an example, hot water energy usage has been successfully correlated with the type of fuel (gas versus electricity) and the number of female teenagers in the household.

Earlier HEEP findings about disturbingly low temperatures in New Zealand houses can be confirmed by the larger database. The HEEP study has also started to identify indoor temperature benefits of thermal retrofit insulation in a set of Wellington and Hamilton flats, and is providing interesting information of temperature stratification and zoning effect. HEEP survey results indicate that only about 50% of New Zealand household always achieve comfortable temperatures during winter months. The average temperature in houses that were reportedly always comfortable was approximately 19°C; several degrees warmer than temperatures in the ‘uncomfortable’ houses. Correlating the average winter evening temperatures with the decade in which the house was built also showed a clear relationship with higher temperatures in houses built since the 1980s.

The HEEP investigation is now well established and focus is now shifting from data logging issues towards analysis aspects. The amount of collected data and the sampling strategies also allows some tentative statements about findings that are representative for the whole or a particular subset of New Zealand households.

The decision to step up data logging efforts from 50 houses per year to 100 houses per year in 2002 will lead to a rapid increase of data and knowledge. This will lead straight into commercial and public energy policy planning, such as MEPS developments and the National Energy Efficiency and Conservation Strategy. This type of use is reflected in the increasing number of requests for HEEP data by commercial and public organisations.

10. APPENDIX

10.1 HEEP Participants

Building Research Association of New Zealand (BRANZ) is New Zealand's leading building research organisation. It has over 30 years experience in research of house operation, including moisture and energy issues. BRANZ has developed a number of tools to assist with the design and operation of energy efficient housing, including the ALF (Annual Loss Factor) (Stoecklein & Bassett 1999) methodology which is a recognised verification method for the New Zealand Building Code revised Clause H1:Energy Efficiency (NZ Government 2000b) which was approved by the Government in June 2000.

Ministry of Social Welfare (formerly Department of Social Welfare, Social Policy Agency), has a mission 'to provide sound and strategic policy advice to the government for the well-being of the people of New Zealand'. The Strategic Policy Group of the Social Policy Agency advises on the broad and long-term direction of policy development on welfare issues of fundamental and enduring importance. The results of the HEEP work will contribute to the development of policy and its implementation.

Energy Efficiency and Conservation Authority (EECA) was established in 1992 as an independent government agency charged with the promotion and implementation of greater energy efficiency. In May 2000 the Energy Efficiency and Conservation Act 2000 (NZ Government 2000b) established EECA as a stand-alone Crown entity with an enduring role to promote energy efficiency and renewable energy across all sectors of the economy. It also empowers regulations to implement product energy efficiency standards and labelling, as well the disclosure of energy efficiency statistics. EECA's staff includes engineers, economists, scientists, policy experts and communications professionals in Wellington, Auckland and Christchurch. EECA also provides funding and administrative support for the project.

Fisher & Paykel is New Zealand's leading whiteware manufacturer with manufacturing plants in New Zealand and Australia. Fisher & Paykel produce a wide range of innovative appliances and have growing world-wide exports.

Foundation for Research, Science and Technology, through the **Public Good Science Fund** (**PGSF**) implements a portfolio of investments to meet Government's research and technology goals. The Foundation negotiates purchase agreements with purchasers/providers of non-departmental outputs, and ensures appropriate performance/accountability arrangements are in place and met. In the 1998/9 PGSF funding round, BRANZ obtained six-year funding to support the scientific evaluation of the HEEP data and the development of household energy models.

TransPower New Zealand Ltd is the New Zealand state-owned enterprise that owns and operates the network of electrical transmission lines, substations, switchyards and control centres collectively known as the national grid. TransPower NZ Ltd is one of the main funding participants in the HEEP investigation. TransPower's main interest in HEEP relates to electric load profiling and the ability to shift that load.

TransAlta New Zealand Ltd has a wide range of interests in electricity generation, distribution and marketing. In Wellington they also supply natural gas, and it is through this energy source that they are supporting HEEP.

The WEL Energy Trust was created following legislation which resulted in the corporatisation of the New Zealand electrical supply industry. The Trust was set up following a public submission process in 1993. It is a publicly elected body, which holds a majority of the shares in WEL Energy Group, administering this on behalf of the community. As part of its functions the Trust distributes income derived from WEL Energy Group dividends and other investments.

Fitzgerald Applied Sociology is based in Christchurch and undertakes a wide range of basic and applied social research for the public and private sectors both within New Zealand and overseas. Fitzgerald Applied Sociology is undertaking ongoing research into social factors in domestic electricity consumption at household and neighbourhood levels and has analysed some of the initial survey results.

John Jowett has had 20 years' experience as a general statistical consultant, first in the Town and Country Planning Division of the Ministry of Works, then in the Applied Statistics (formerly Biometrics) Section of the Ministry of Agriculture and Fisheries. He has specialised in the design and analysis of sample surveys and field trials. At various times in his career John has been responsible for the design and analysis of several major national surveys, ranging from sample surveys on the recreation and leisure activities of New Zealanders, to the breed composition of New Zealand sheep flocks. John is conducting some of the statistical analysis necessary for an efficient data sampling strategy.

Victoria University Wellington provides extensive scientific support and feedback through the supervision of the PhD studies of Mr. Stoecklein. The draft title of the PhD thesis is 'A Model of Energy End-use in New Zealand Houses'. The regular input of Dr. George Baird and Mr. Michael Donn from the School of Architecture supports the research approach and methodology.

10.2 Sample Distribution

Table 30: House allocation across Local Authorities

DISTRIBUTION OF HEEP HOUSES		Urban Level				Grand Totals	non clustered
Region	**Territorial Authority**	Major Urban	Minor Urban	Rural etc.	Secondary Urban		
Auckland	Auckland City	37	1	0		38	*
	Franklin District	0	1	2	1	4	
	Manukau City	23		0		23	*
	North Shore City	19				19	*
	Papakura District	4				4	
	Rodney District	4	1	2		8	
	Waitakere City	16		0		16	*
	Auckland Region Totals	***103***	***2***	***5***	***1***	***112***	
Bay of Plenty	Kawerau District		1			1	
	Opotiki District		0	1		1	
	Rotorua District	6		1		7	
	Taupo District			0		0	
	Tauranga District	9				9	*
	Western Bay of Plenty District	1	1	2		4	
	Whakatane District		0	1	2	3	
	Bay of Plenty Region Totals	15	3	5	2	25	
Canterbury	Ashburton District			1	2	3	
	Banks Peninsula District	1		0		1	
	Christchurch City	37				37	*
	Hurunui District		0	1		1	
	Kaikoura District		0	0		0	
	Mackenzie District		0	0		0	
	Selwyn District	0	0	2		2	
	Timaru District		1	1	3	5	
	Waimakariri District	1	2	1		4	
	Waimate District		0	1		1	
	Waitaki District			0		0	
	Canterbury Region Totals	38	4	7	5	55	
Gisborne Region	Gisborne District	4		1		5	
Hawke's Bay	Central Hawke's Bay District		1	1		1	
	Hastings District	7		1		7	
	Napier City	6				6	
	Rangitikei District			0		0	
	Taupo District			0		0	
	Wairoa District		1	1		1	
	Hawke's Bay Region Totals	13	1	2		16	
Manawatu-Wanganui	Horowhenua District		1	0	2	3	
	Manawatu District	0		1	2	3	
	Not Applicable			0		0	
	Palmerston North City	8		0		8	

DISTRIBUTION OF HEEP HOUSES		*Urban Level*				***Grand Totals***	*non clustered*
Region	***Territorial Authority***	*Major Urban*	*Minor Urban*	*Rural etc.*	*Secondary Urban*		
Manawatu-Wanganui (*Cont..*)							
	Rangitikei District		1	1		*2*	
	Ruapehu District		1	1		*2*	
	Stratford District			0		*0*	
	Tararua District		1	1		*2*	
	Taupo District			0		*0*	
	Waitomo District			0		*0*	
	Wanganui District	5		0		*5*	
Manawatu-Wanganui Region Totals		*13*	*4*	*5*	*4*	*26*	
Marlborough	Marlborough District		*0*	*1*	*3*	*4*	
Nelson Region	Nelson City	*5*		*0*		*5*	
Northland	Far North District		2	3		*6*	
	Kaipara District		1	1		*2*	
	Whangarei District	5		2		*7*	
Northland Region Total		*5*	*3*	*7*		*15*	
Chatham Islands	Chatham Islands District			*0*		*0*	
Otago	Central Otago District		1	1		*2*	
	Clutha District		1	1		*2*	
	Dunedin City	13		1		*14*	*
	Queenstown-Lakes District		1	0		*2*	
	Waitaki District			1	2	*2*	
Otago Region Total		*13*	*3*	*4*	*2*	*22*	
Southland	Gore District			0	1	*2*	
	Invercargill City	6	0	0		*6*	*
	Southland District		1	3		*3*	
Southland Region Total		*6*	*1*	*3*	*1*	*11*	
Taranaki	New Plymouth District	6	1	1		*8*	
	South Taranaki District		1	1	1	*3*	
	Stratford District		1	0		*1*	
Taranaki Region Total		*6*	*2*	*3*	*1*	*12*	
Tasman Region	*Tasman District*	*1*	*1*	*2*		*4*	
Waikato	Franklin District		0	1	0	*1*	
	Hamilton City	12				*12*	*
	Hauraki District		1	1		*2*	
	Matamata-Piako District		2	1		*3*	
	Otorohanga District		0	1		*1*	
	Rotorua District			0		*0*	
	South Waikato District		0	1	2	*3*	
	Taupo District		1	1	2	*3*	
	Thames-Coromandel District		2	1		*3*	
	Waikato District	2	1	1		*4*	*
	Waipa District	3		1		*4*	
	Waitomo District		1	1		*1*	
Waikato Region Total		*17*	*8*	*9*	*4*	*38*	

DISTRIBUTION OF HEEP HOUSES		***Urban Level***				***Grand Totals***	*non clustered*
Region	***Territorial Authority***	*Major Urban*	*Minor Urban*	*Rural etc.*	*Secondary Urban*		
Wellington	Carterton District		1	0		*1*	
	Kapiti Coast District		1	0	4	*5*	
	Lower Hutt City	11		0		*11*	*
	Masterton District			0	2	*3*	
	Porirua City	4		0		*4*	*
	South Wairarapa District		1	0		*1*	
	Tararua District			0		*0*	
	Upper Hutt City	4		0		*4*	*
	Wellington City	19		0		*19*	*
	Wellington Region Totals	38	*2*	*2*	*6*	*47*	
West Coast	Buller District		1	1		*1*	
	Grey District			0	1	*2*	
	Westland District		0	0		*1*	
	West Coast Region Totals		*1*	1	*1*	*4*	
	GRAND TOTALS	276	*36*	56	*31*	*400*	

10.3 Location of Monitoring Areas

Figure 34 shows locations of the clustered and the non-clustered monitoring areas.

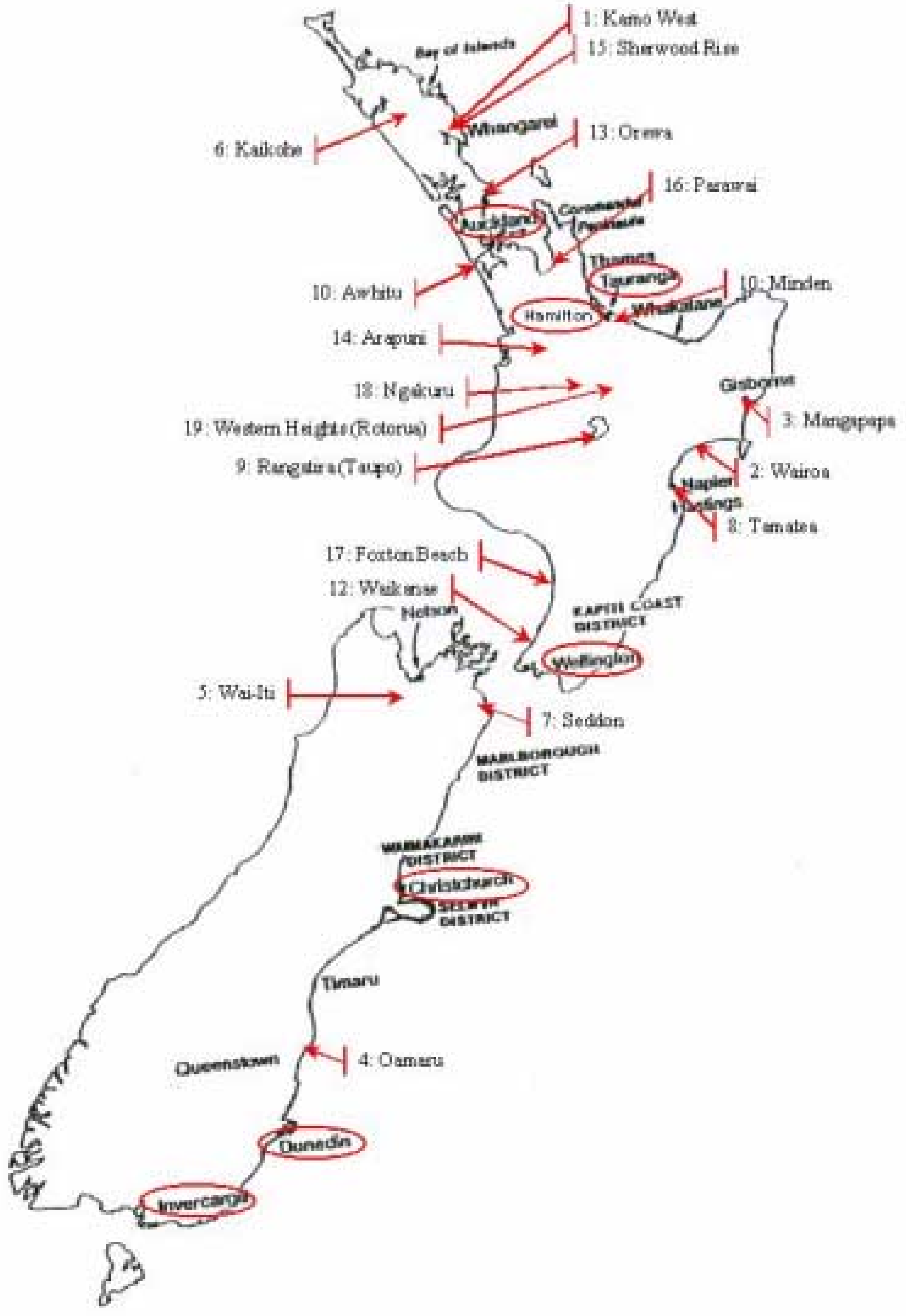

Figure 34: Location of Monitoring Areas

10.4 Average Hot Water Use Profiles

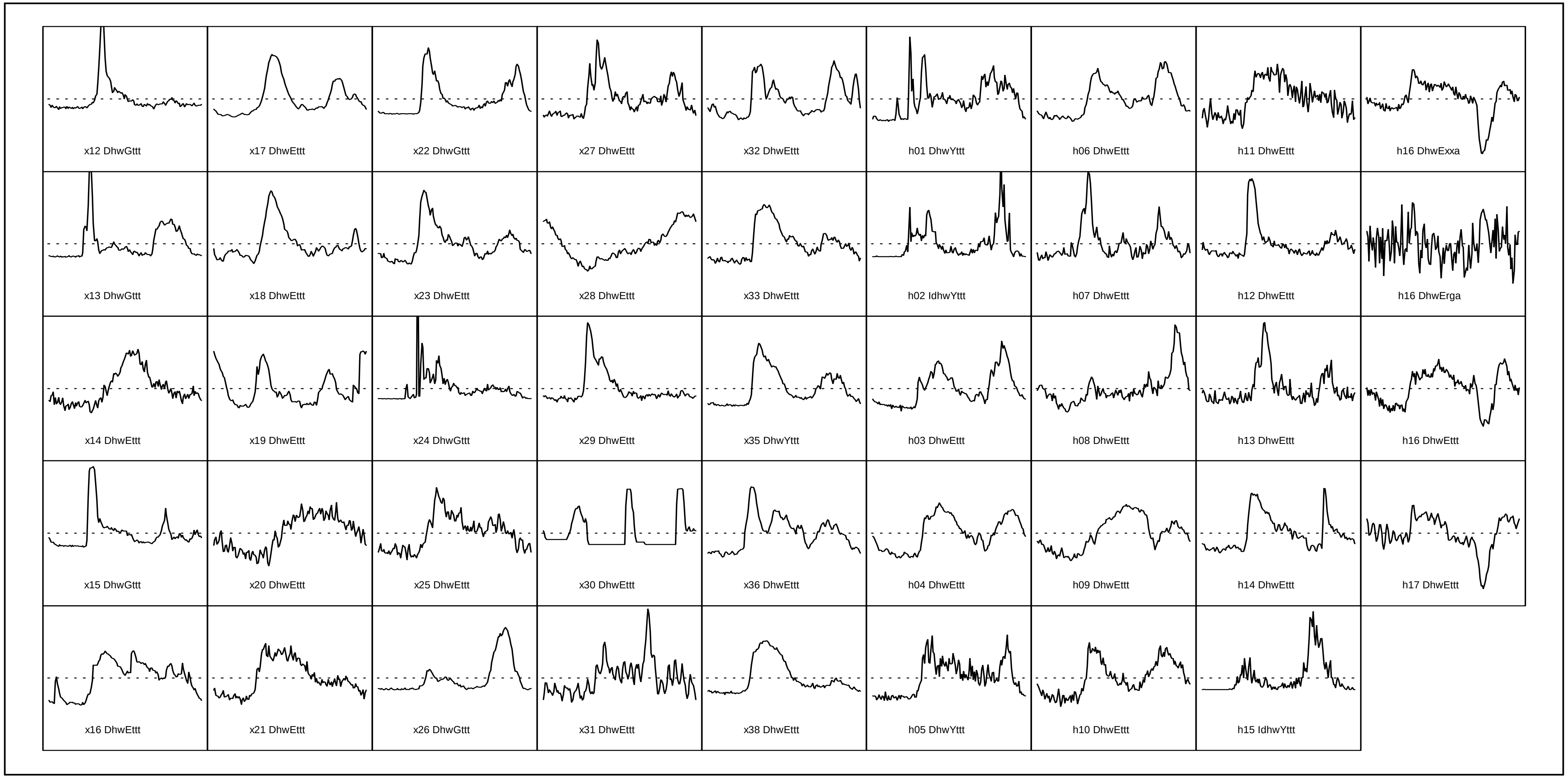

Figure 35: Average total hot water energy profiles for HEEP random houses in Wellington (X) and Hamilton (H).

The x-axis ranges from midnight to midnight in each graph. Each profile has been standardised (so that it has a mean of zero and a standard deviation of one), as the graphs are to be used to examine when hot water is being used.

10.5 HEEP Standing Losses

10.5.1 Standing Loss Calculation Method

The basic method of calculating standing losses for HEEP was to find the lowest average consumption in the daily profile over a set time window, for example 3 hours.

Originally, this time period was set the same for every house, at say from 1am to 4 am. However, this does not work for some houses, where people use a significant amount of hot water during this period. To fix this problem, the time window is allowed to vary from house to house, by choosing the lowest consecutive time period (for example 3 hours) in the daily profile. This improves the situation, and gives a fair estimate of the upper limit of standing losses, but cannot account for several factors:

- *odd or varying occupant schedules of hot water usage*
- *leaking cylinders*
- *ripple control.*

A more sophisticated technique has been developed to account for these effects. By calculating the lowest window of power consumption on each and every day, the time of standing loss is able to vary, depending on the day-to-day variation in energy use pattern. The window must be long enough to contain numerous standing loss recharge events, otherwise the window may 'dodge' events by choosing, for example, a period with only 2, rather than 3 events, which would bias the results. By examination of the data, a 3 hour period appeared to be sufficient.

This method is liable to be affected by times of ripple control, and either call them a very low standing loss, or introduce very large standing loss recharge events when the standing loss period ends. To prevent this, any sequence of more than 1 hour of consecutive zeroes is designated as ripple control, and removed from the analysis. If more than 3 hours of ripple control occurs on any one day, the entire day is removed from the analysis, as there may be insufficient data left to capture the standing loss.

To deal with leaking cylinders, the data is searched for days when the cylinder never switches off, and these days are removed from the analysis. The end result of this analysis is a daily time series of the standing losses, which are averaged to calculate the overall standing loss.

The ambient temperature correction is performed by finding the same time window in temperature as used for the hot water energy, as described in the next section.

Some houses have very odd schedules, switching off completely at some times of day. These have been labelled as Night rate systems (Ndhw*). The estimation of the standing losses of these systems is difficult, and their analysis is still under development.

10.5.2 Correction for Temperature Variations

If a hot water storage cylinder has a storage temperature T_H, and a heat loss coefficient *k*, and the average ambient temperature is T_a, then the standing loss *L* is:

$$L = k(T_H - T_a)$$

If the standing losses are determined during a period of time when T_a is not equal to the average annual temperature (for example, a few hours overnight) then the standing loss needs to be corrected. The true standing loss L_T is given by:

$$L_T = k(T_H - T_N)$$

where T_N is the true (or normalised) ambient temperature. By combining and rearranging the above equations, the correction factor is given as:

$$L_T = L\left(\frac{T_H - T_N}{T_H - T_a}\right)$$

This equation is identical to that used by the ELCAP [20] researchers. However, temperatures T_a and T_N are not measured in HEEP, so this equation cannot be used unless some assumptions are made. By rearranging again as

$$L_T = L\left(1 + \frac{T_a - T_N}{T_H - T_a}\right)$$

the necessary assumptions become implicit.

As most New Zealand houses operate by being a few degrees above the external temperature, the term $T_a - T_N$ might reasonably be approximated by the difference between the external temperature as monitored by HEEP for the time period that the standing loss is calculated (for example, 1-4 am for Feb 2000 through Jan 2001) and the annual climatological average external temperature for the region.

The term T_a in the denominator might reasonably be approximated either by the average external temperature during the standing loss calculation period for cylinders located externally, by the corresponding average indoor temperature, as measured by HEEP, or for cylinders located in an unconditioned space (e.g. garage, roof) the average of the external and average internal temperatures.

The cylinder storage temperature T_H may be approximated by the measured hot tap temperature, or if not available, the thermostat temperature.

The standing loss correction factors have been calculated for all the available HEEP hot water storage systems. The correction factors ranged from –7% to +11%, with an average of –3% with the smallest correction factors for the houses that were monitored for a whole year. These correction factors are quite small, so the absolute error in the standing loss introduced by the assumptions about the temperatures should be small.

The true, normalised ambient temperature can be derived from the data, by using equation 1 to calculate *k*, the heat loss coefficient of the cylinder, and then equation 2 to calculate the normalised temperature. The normalised ambient temperature is (17.4 ± 0.3)°C, and ranges from 12.5 to 21.6 °C.

The average tap (or thermostat temperature if not available) is (63.5 ± 1.0)°C, so the average temperature difference is (46.2 ± 1.2)°C, though an allowance must be made for the cylinder temperatures being slightly higher than the tap temperatures (expect <1°C for HEEP measurements), and the fact that the cylinder thermostat temperatures are low by (1.7 ± 1.4)°C.

10.6 A Summary of STEM Parameters for a HEEP House

(Extracted from analysis report)

```
KEY:
House:                    HEEP House ID
House R-value:            R-value of the portion of the house modelled
House Thermal Mass:       Total thermal mass of the portion of the house
Weekday Schedule:         Schedule in hours of day.eg 6 9 18 22 means 6-
                          9am
Weekend Schedule:         and 6-10pm
Setpoint:                 Estimated setpoint for heated zone
Heater Capacity:          Capacity of the heater
Pct House Heated:         Estimate of fraction of house heated
STEM Evening Period:      Used to run STEM
STEM Morning Period:      Used to run STEM
STEM Temperatures :       Temperature zones modeled
STEM Heaters:             Heating column used for model
Model Temperatures:       As above
Model Heaters:            A Above
Deg Hours Model:          Intercept and slope for the degree hours model.

Windows: Listing of the width, height, orientation, tilt, overhangs, and
                          horizon shading
RESULTS
```

House: **x02**

```
House R-value:            625 W/°C
House Thermal Mass:       -9584 Wh/°C
Weekday Schedule:         6.5 8 17 22
Weekend Schedule:         7.5 22
Setpoint:                      19 °C
Heater Capacity:          11000 W
Pct House Heated:         100
STEM Evening Period:      17 22
STEM Morning Period:      0 6
STEM Temperatures :       TempTb1a TempTb2a TempTdna TempTfra TempTsta
STEM Heaters:             IntMttt
Model Temperatures:       TempTb1a TempTb2a TempTdna TempTfra TempTsta
Model Heaters:            IntMttt
Deg Hours Model:
$TempTx16:                Intercept TempTx16
                          -158.8222 366.3277
```

Windows:

	width	height	orient	tilt	O width	O height	horizon
[1,]	2.2	4.6	0	90	1	0.2	5
[2,]	2	2.1	0	90	0	0	5
[3,]	1.7	0.3	0	90	0.15	0	5
[4,]	0.8	0.5	0	90	0.25	0	5
[5,]	0.8	0.5	0	90	0.25	0.5	5
[6,]	0.9	0.9	0	90	0	0	5
[7,]	0.7	1.2	90	90	1	0	10
[8,]	1.8	1.2	90	90	0	0	10
[9,]	0.9	0.7	180	90	0.3	0	0
[10,]	1.5	0.7	180	90	0.3	0	0
[11,]	1.8	1.4	-90	90	0	0	20
[12,]	2.8	2.1	-90	90	1.5	0	20

10.7 Data for STEM Modelling of Selected Houses

House	STEM U-Value (W/°C)	STEM Thermal Mass (Wh/°C)	Alf U-Value Inc Air Leakage (W/°C)	Alf Mass1 (Wh/°C)	Alf Mass2 (Wh/°C)
X02	625	9584	504	2155	313
X04[47]	376	3046	629	7175	398
X07	594	8144	482	4916	462
X08	239	1708	303	1732	146
X09	1305	10864	1119	5473	592
X10[48]	205	2912	249	1676	201
X11	774	5856	633	2610	295

Table 31: Comparison of STEM and ALF U-value and thermal mass estimates

[47] *This house has a fireplace that has not been included in heating.*
[48] *This is an apartment.*

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