STUDY REPORT

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Energy Use in New Zealand Households

Report on the Year 10 Analysis for the Household Energy End-use Project (HEEP)

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Energy Use in New Zealand Households – HEEP Year 10 Report

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This Executive Summary provides a selection of the results from the HEEP Year 10 report – copies of the full report can be downloaded from www.branz.co.nz or purchased from the BRANZ Bookshop on the website. **Note that all the results, monitoring and analysis methodology reported here are copyright to BRANZ Ltd**. This is the 10th and final Household Energy End-use Project (HEEP) annual report. A final report to be published in 2007 will bring together (and update) earlier annual reports, providing definitive results for the future.

The goal of HEEP is to understand how, where, when and why energy is used in New Zealand homes. This knowledge is being used to develop a model of the residential energy sector to help improve energy efficiency, reduce greenhouse gas emissions and identify new energy efficiency opportunities.

The HEEP database now holds energy, temperature, social and physical house data on some 400 randomly selected houses from Invercargill to Kaikohe. Monitoring began in 1997 and was completed in 2005, with the majority of the houses (300) being monitored in the last three years. Each house was monitored for about 11 months. All fuels (natural gas, electricity, solid fuel, solar water heaters, oil and LPG) are monitored for each house. The database holds 10 minute data for each fuel, living room and master bedroom temperatures, social data on the occupants and house physical house data (floor plan, hot water system etc).

This report gives an overview of the HEEP project including: importance of collecting data; a review of energy end-uses; social impacts on solid fuel use; temperature and energy use in Māori HEEP households; fuel poverty; analysis of summer and winter indoor temperatures; standby and baseload electricity use; analysis of energy use in pre-1978 and post-1978 houses; faulty refrigeration appliances; electricity power factors; the development of the Household Energy Efficiency Resource Assessment (HEERA) model; the HEEP appliance ownership model; and a brief international comparison of domestic hot water systems.

Energy end-uses

HEEP data can now be used to provide a national breakdown of residential energy use by fuel type and end-use. Figure i provides a breakdown of energy supply by fuel type. Figure ii shows that on average, across all fuel types, space heating is the largest single end-use (34%), followed by hot water (29%), appliances (13%), refrigeration (10%), lighting (8%) and cooking (6%). The most important fuel source is electricity, while the most important space heating fuel is solid fuel (wood and coal).

Low temperature heat is the main (63%) use of household energy, providing space heat (34%) and water heat (29%).

Electricity provides three-quarters (75%) of energy used for hot water, with gas (20%) and wetback (5%) providing almost all of the rest. Seventy-seven percent of household hot water cylinders are electric – the highest proportion for any country. Combined with the high proportion of low pressure systems (72%) this creates a unique situation. The shift towards mains pressure gas hot water systems is likely to have a significant impact, not only on energy but also on water use.

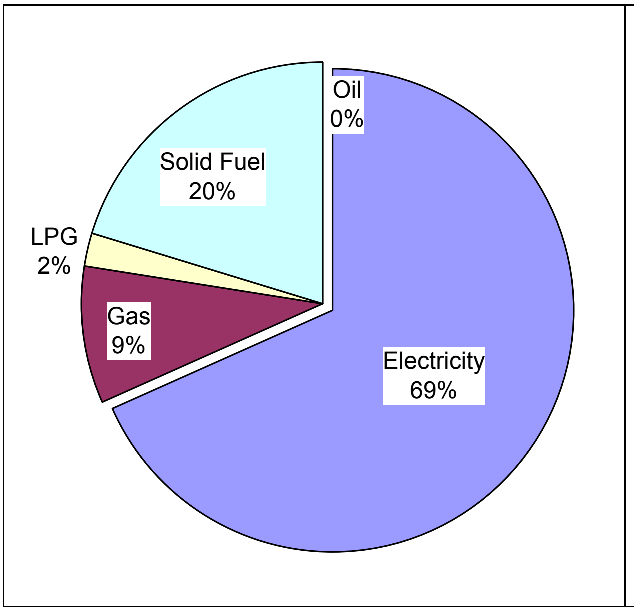

Figure i: Total energy use by fuel type

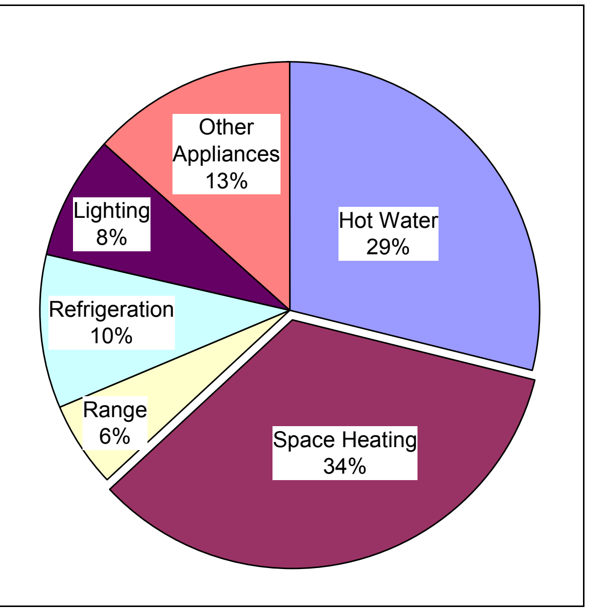

Figure ii: Total energy use by end-use

HEEP has identified solid fuel (56%) and electricity (24%) as the main space heating fuels. This has resulted in changes to the official New Zealand energy statistics (Ministry of Economic Development's (MED) Energy Data File).

Figure iii: A power station was hiding in the wood shed

The latest year report added to the national energy supply solid fuel equivalent to a 530 MW power station feeding conventional resistance heaters, or 180 MW feeding heat pumps (COP 3) (Figure iii). This increased wood from 5% to 14% of residential energy share, while reducing electricity from 82% to 69%.

The conversion of a house from one heating fuel to another is not a simple energy switch, as winter evening temperatures relate to fuel types. Houses heated by LPG or electricity tend to be the coolest, those with enclosed solid fuel heaters the warmest. The promotion of electric heating to replace solid fuel heating may have unforeseen impacts on the electricity generation, transmission and distribution system.

Other (non-low grade heat) uses are electricity dominated: appliances (13%), refrigeration (10%), range (6%) and lighting (8%) together account for 37% of total household energy use or 54% of household electricity use.

Fuel use per household	Bottom 20% Use under kWh/yr	% of energy	Top 20% Use over kWh/yr	% of energy
Electricity	4,860	10%	10,380	35%
Gas	2,580	5%	9,900	34%
Solid fuel heating	450	1%	5,740	57%
LPG heating	180	3%	1,110	50%
All fuels	**6,940**	**9%**	**14,450**	**36%**

Table i : Fuel use – top and bottom 20%

Patterns of fuel use are skewed, with large users consuming more in total than small users. Table i shows (across all fuels) the top 20% of households use over 14,450 kWh/yr or 36% of total energy use, while the bottom 20% use under 6,940 kWh/yr or 9% of energy use.

Total energy and electricity use per household appears to vary little by region, although the end-uses and the per occupant energy use differ. The report provides regional breakdowns for total, hot water and space heating energy use by fuel, and annual average energy use per house for selected end-uses. The report also provides a comparison of household electricity uses in 1971/72 with the HEEP sample.

Faulty refrigeration appliances

While installing monitoring equipment and surveying the HEEP houses, a number of old and potentially faulty refrigeration appliances were found. Visual inspection of the monitored data confirmed that a number of refrigeration appliances stayed on continuously for long periods of time. Even though insulation degrades or gets wet, coolant leaks, door seals fail, or the thermostat or controller fails, the appliance may continue to operate (i.e. make noise and keep food cool) for years. For refrigeration appliances there may be no obvious sign that the appliance is faulty and many people may not realise there is a problem.

Refrigeration appliances (refrigerators, combination fridge freezers and freezers) use, on average, (1,119±72) kWh per household per year, or approximately 15% of household electricity. About 7% of domestic refrigeration appliances are faulty, and 9% operate marginally. HEEP tested an overseas algorithm adapted to New Zealand refrigeration appliances, and it was found to reliably identify faulty refrigeration appliances.

There are also energy savings from replacement of older refrigeration appliances with modern appliances simply due to the improved energy performance. Over the past 26 years, the sales-weighted average energy use for fridge freezers has fallen by two-thirds, reflecting the impact of energy labelling and Minimum Energy Performance Standards (MEPS).

Power factors

Each year for three years electricity meters were used in three houses that reported both real and reactive power, also providing the power factor. The mean power factor varied from 0.76 to 0.97, with an overall mean of 0.86. The lower the power factor, the higher the load on the electricity system. The report provides power factor analysis for selected time periods.

Standby and baseload

Use	Load (W)
Standby	57±4
Heated towel rails	21±2
Faulty refrigeration	15±10
Minor loads	4±1
Lights left on	7±3
Remainder	8±12
Total	**112±4**

Table ii: Standby and baseload

The HEEP data has supported the first nation-wide statistically representative study of standby and baseload electricity use for any country. The baseload of a house is the typical lowest power consumption when everything that is usually switched off is off, while standby includes energy used by appliances while waiting to be used. On average these total (112±4) W continuous, with the breakdown given in Table ii. The 95% confidence interval is from 104 W to 121 W. Assuming 1.4 million houses, this is equivalent to about 160 MW of continuous load, or about 10% of the total average residential power demand, costing $150/house/year. The full report provides a detailed breakdown of standby power for common appliances.

Pre and post-1978 heating energy use

Since 1978 all new houses have been required to be insulated, yet there has been little research on the effects of this requirement. HEEP is not a longitudinal retrofit study, but it does provide the opportunity to compare the energy use and characteristics of pre-1978 and post-1978 houses. This analysis is difficult as there are many confounding factors e.g. post-1978 houses have larger floor areas, are more likely to be in warmer climates, are less likely to use solid fuel, and are occupied by households with higher average incomes. The analysis needs to account for such factors so that the effect of the post-1978 status can be evaluated on an “all other things being equal” basis. Insulation levels in pre-1978 houses vary; most houses were built without insulation, but many have had it added since or have an addition that is fully insulated.

The analysis found that in all cases mandatory insulation was associated with less energy use. However, the larger floor areas and warmer temperatures of the post-1978 houses increased energy use taking up part, or sometimes all, of the energy reductions. Most of the energy reductions have come from non-electric fuels. The total energy savings for all fuels in the 27% of post-1978 houses would be about 2-3% of total energy consumption (all fuels), while the total electricity savings in the mainly electrically heated houses (about 8% of households) would be <1% of total electricity consumption.

The results suggest that large energy savings cannot be expected from insulation retrofit of houses in New Zealand. Savings in total energy (all fuels) of perhaps 5% are feasible, with most of that saving in non-electric fuels. Potential savings in electricity are smaller still (at about 1%). New Zealand houses and people appear to be very different from other countries where residential insulation retrofits have been used successfully and we need to develop our own knowledge and solutions. The HEEP data does permit the calculation of the minimum sample size for a future retrofit study to explore the actual energy consequences of thermal insulation.

Solid fuel

Solid fuel has a long tradition of use in New Zealand homes, and the report provides an analysis of the existence and use of solid fuel heating. Some 30 years ago, solid fuel heating was used in 59% of the houses in the 1971/72 Household Electricity Survey. For the 1976 Census solid fuel was used in 49% of houses, raising to 67% for the 1986 Census solid fuel and then falling to 54% in the 2001 Census.

Fifty-nine percent of HEEP households had a solid fuel appliance available – of these 74% were enclosed (wood or coal) burner, 17% open fire and 8% either. Two housing variables have a significant association with the availability of a solid fuel appliance – the age of the house (older houses are more likely to have a solid fuel appliance) and the number of bedrooms (the more bedrooms the more likely to have a solid fuel appliance). A greater proportion of enclosed solid fuel burners are actually used than open fires.

Māori households

The number of Māori households in HEEP is small, so no general New Zealand results can be provided. Māori HEEP households are slightly over-represented among low and medium energy households compared to all HEEP households. Overall, the energy use profile for Māori is broadly similar to that for all HEEP households. There is a difference in the mean annual gross heating energy use which is 3,827 kWh/yr across all households in the HEEP sample compared to 3,001 kWh for Māori HEEP households.

Nearly half (49%) of Māori HEEP households have mean winter evening living room temperatures categorised as 'below average' or 'cold', compared with two-fifths of all HEEP households (40%). Māori HEEP households are over-represented in the 'cold' winter evening living room category.

Fuel poverty

At its simplest, fuel poverty exists when households are not able to afford comfortable domestic warmth. Warmth, and more particularly comfortable warmth, is clearly a matter of subjective perception. Internationally, there has been a consistent problem with the measurement of fuel poverty because few surveys into energy consumption and expenditure have measured temperatures. HEEP does precisely that and, in doing so, provides a unique evidential platform for grasping the nature of fuel poverty in New Zealand.

The HEEP data reveals that while low income houses appear to value increased warmth, they are unable to achieve warm indoor temperatures (despite expending a proportion of their income on energy that overseas would place the household in the fuel poverty category). Moreover, the higher proportionate expenditure of low income householders does not assure those households a warm house or even a warm living room. Households in dwellings with very cold indoor temperatures during winter (under 16ºC) appear to spend a greater proportion of their income on energy than the HEEP households overall.

Indoor temperatures – winter and summer

The heating schedule, climate, heater type and fuel, house age and thermal insulation all play important roles in winter evening temperatures. Winter (June, July and August) evening (5 pm to 11 pm) living room temperatures average 17.9°C, although the mean range is from 10°C to 23.8°C. On average, over the three winter months living rooms are below 20°C for 83% of the time – and the living room is typically the warmest room.

Winter evening temperatures show an average rise of 0.2°C per decade of house construction i.e. houses built in 2000 are 2°C warmer than those built in 1900. Newer houses (post-1978) have winter evening living room temperatures 1°C warmer (18.6°C compared to 17.6°C) and overnight (midnight to 7 am) bedroom temperatures 1.3°C warmer (14.5°C compared to 13.2°C).

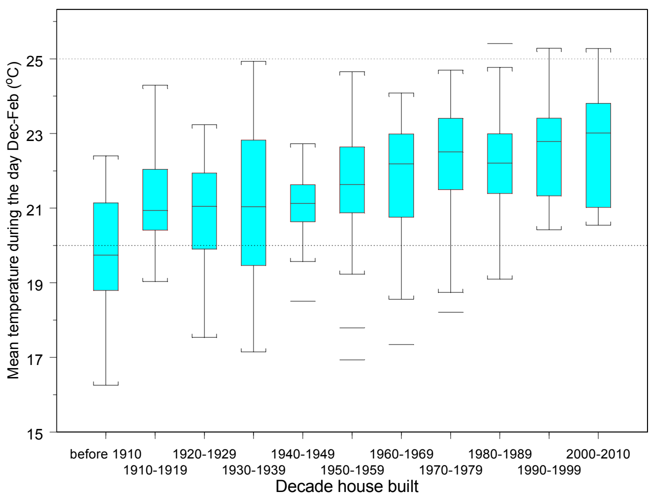

Figure iv: Summer temperatures by house age

As there is little use of air-conditioning in New Zealand houses, the house age (decade of construction) and the local climate (average external temperature) together explain 69% of the variation in mean summer living room temperatures.

Figure iv shows summer day (9 am to 5 pm) living room temperatures by decade house built. The mean summer living room day temperatures show a trend of increasing by 0.25°C per decade i.e. houses built at the end of the 20th century are 2.5°C warmer than those built at the beginning. The reasons for this increase are not obvious (e.g. areas of solar glazing, thermal insulation etc) and are being further explored.

Appliance ownership models

The HEEP appliance ownership models are an attempt to understand some of the factors that influence the type and number of appliances that households have. For example, do households with more occupants have more TVs?

A range of model algorithms have been developed from the HEEP data (including the monitored data, occupant surveys and house audit) to help understand some of the factors that influence the type and number of appliances found in households. These factors include variables based on location, income, life stage, occupant numbers, house age and tenure. Not all variables apply to all appliances and the differences can be most revealing.

Factors such as life stage, income and tenure are more important or better predictors of appliance ownership than those such as floor area and number of occupants. The number of adults and number of occupants only appear in one model each. This is perhaps surprising. Ownership of many appliances might reasonably be expected to be influenced by the number of occupants, but this does not appear to be the case – other socio-demographic characteristics appear to take precedence.

New technologies are becoming available which can have significant energy consequences. For example, the shift to digital television may see old vacuum tube technology replaced by large LCD and plasma screens. The new appliances may not use more energy per appliance, but if market penetration increases e.g. more houses having the appliance or more appliances per house, then total energy use may increase. Representing these possible futures in the HEERA model is a big challenge.

HEERA model

The HEERA model is undergoing final preparation of the database and scenario modelling software to develop a powerful analysis tool. This will support a wide range of 'what-if' type questions which, through the use of appropriate scenarios, will be able to be used for a wide range of policy analysis. Figure v illustrates the HEERA database and model structure.

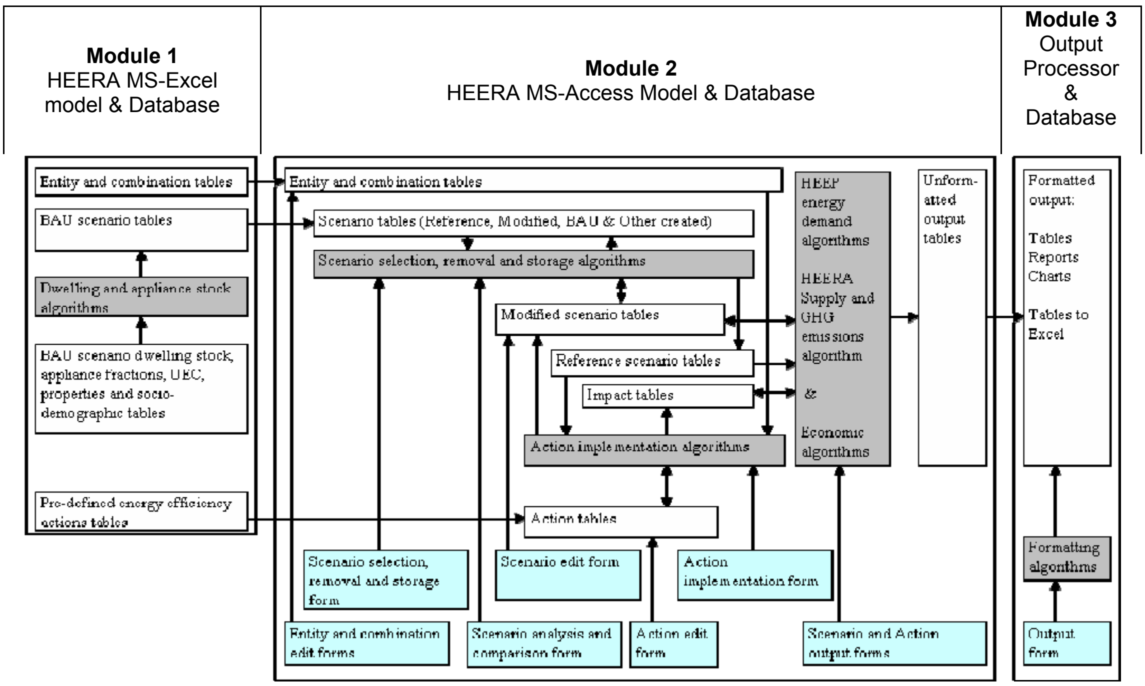

Figure v: HEERA flow diagram

Future

HEEP receives its main funding from the Foundation for Research, Science and Technology (FRST). This continues until the end of September 2007, when HEEP will terminate. The ongoing support of Building Research is also acknowledged with thanks.

HEEP now has a complete national database of some 400 houses from Invercargill in the south to Kaikohe in the north. The focus on HEEP is now on reporting analysis and developing the HEERA model. During 2007, a summary report will be prepared for publication that will provide a formal record of the research and its results.

The legacy of HEEP will be seen in the way this new knowledge of energy use in New Zealand houses which will help with energy planning for the future. The HEEP results will lead to improvements in the design, construction and utilisation of New Zealand houses to enable them to meet the year-round comfort expectations of all occupants in the most energy efficient way.

New Zealand continues to face a wide range of energy issues, not the least of which will be the problems in meeting our Kyoto targets in the first commitment period (2008 to 2012). Much of the recent debate has been electricity supply focused, but the debate needs to also consider greenhouse gas emissions, security of supply and robustness of energy options. HEEP has shown that in the residential sector energy planning is not a simple matter of selecting one fuel over another – care must be taken to ensure that policies are well based on reliable evidence, and that perverse consequences are minimised.

Obtaining HEEP reports

The HEEP team has worked hard to ensure the results of HEEP are available to the widest possible range of stakeholders – including the public, special interest groups, government agencies, universities and other researchers. References to previous HEEP reports, and other publications on the HEEP work, are given in the full report. Many of these are available for downloading at no charge from the BRANZ Bookshop on the BRANZ website, or the HEEP page on the BRANZ website.

HEEP analysis can be commissioned. Please contact us and we will work with you to define your questions and work out how HEEP analysis could best assist you. On request, your name can be included in our email list providing HEEP results several times a year.

Copies of the Executive Summary and the full Year 10 report are available through the HEEP page on the BRANZ website:

Postal address: BRANZ, Private Bag 50908, Porirua 5240, New Zealand
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ENERGY USE IN NEW ZEALAND HOUSEHOLDS: REPORT ON YEAR 10 OF THE HOUSEHOLD ENERGY END-USE PROJECT

BRANZ Study Report 155

Nigel Isaacs (ed), Michael Camilleri, Lisa French and Andrew Pollard (BRANZ Ltd), Kay Saville-Smith and Ruth Fraser (CRESA), Pieter Rossouw (CRL Ltd), John Jowett

REFERENCE

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ABSTRACT

This is the 10th annual report on the Household Energy End-Use Project (HEEP). HEEP is a multi-year, multi-discipline, New Zealand study that has monitored all fuel types (electricity, natural gas, LPG, solid fuel, oil and solar used for water heating) and the services they provide (space temperature, hot water, cooking, lights, appliances etc). Data collection was completed in 2005. This report gives an overview of the HEEP project including: importance of collecting data; a review of energy end-uses; social impacts on solid fuel use; temperature and energy use in Māori HEEP households; fuel poverty; analysis of summer and winter indoor temperatures; standby and baseload electricity use; analysis of energy use in pre-1978 and post-1978 houses; faulty refrigeration appliances; electricity power factors; the development of the HEERA model; the HEEP appliance ownership model; and a brief international comparison of DHW systems. Detailed tables provide estimates for appliance standby power and energy use, as well as for national and regional energy consumption.

KEYWORDS

Energy, temperatures, space heating, domestic hot water, appliances, fuel poverty, energy policy, fuel use, electricity, natural gas, wood, LPG, residential energy, energy end-uses, energy consumption.

Acknowledgements

The funding support of the following organisations over the life of HEEP is gratefully acknowledged:

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

The HEEP team is also grateful to all the house occupiers who over the past 10 years have responded to our questions and permitted us to monitor their homes. Without their cooperation this research would not have been possible.

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1. INTRODUCTION

The discovery of new sources of energy, the development of new conversion or generation processes and the transmission of that energy to the end user are considered to be critical to the continuation of our societies. But what uses all that energy? Without energy demand there is no reason for energy supply, but there is very little knowledge of energy demand. HEEP provides answers for the New Zealand residential sector. Perhaps the most important part of the answer is that users do not actually want energy – they want the services that energy can provide.

HEEP is a multi-year, multi-discipline research project that has involved detailed energy and temperature monitoring, occupant surveys and energy audits of some 400 randomly selected New Zealand houses. HEEP is unique in that no constraints were placed on fuel uses in the monitored houses. Whatever fuel was used in the house, it was monitored – electricity, natural gas, LPG, coal, wood, oil and solar water heating. Monitoring used electronic dataloggers recording at intervals of 10 minutes or less (Camilleri, Isaacs and French 2006). This is the 10th annual HEEP report and, unlike its predecessors, provides final analysis from the full HEEP database. Additional information, including downloads of paper reprints, is available from the BRANZ website www.branz.co.nz.

The completion of the data collection in 2005 allows us to begin to examine the facts, information and knowledge that have been gained and compare it to the previous state of knowledge.

This report brings together the analysis of the past year and provides a strong foundation for the final year of HEEP. This will be the last annual HEEP report. The final report in 2007 will provide coverage of the entire project and full results.

This section provides a brief overview of the HEEP research and its impact over the past year. The following sections report on the lessons learnt from the HEEP research and analysis – commencing with a comparison to the practical lessons from similar research in the past. Section 3 uses the HEEP data to provide the first national analysis of energy end-uses. Section 4 explores social impacts and dynamics of energy use, while Section 5 explores the summer and Section 6 the winter temperatures found in New Zealand homes. Although HEEP was not a longitudinal study (following houses over a long period of time) Section 8 provides an analysis of space heating energy use in pre-1978 and post-1978 when mandatory thermal insulation requirements were put in place, in order to provide guidance for any future longitudinal studies. Section 9 reports on energy implications of faulty refrigeration appliances and Section 10 on electric power factors. Section 11 describes the appliance ownership models developed to support the HEERA model which is described in Section 12. The HEEP Year 9 report (Isaacs et al 2005) provided a detailed analysis of hot water systems and energy, which is complemented by the material in Section 13. Section 14 discusses this report, while Section 15 lists HEEP publications and references.

1.1 HEEP monitoring overview

Figure 1 places the monitoring locations on a map of New Zealand and Table 1 summarises the locations in which HEEP has monitored the randomly selected houses. Locations circled in Figure 1 are the stratified sample selections in the urban areas, while the other locations are cluster sample selections. See the HEEP Year 9 report (Isaacs et al 2005) for a fuller discussion of house selection and monitoring.

HEEP has used a population weighted sampling framework based on major urban areas (‘strata’) and the rest of the country (‘clusters’). The strata included 221 households from Auckland, Manukau, North Shore, Waitakere, Tauranga, Hamilton, Wellington, Upper Hutt, Lower Hutt, Porirua, Christchurch, Dunedin and Invercargill. The remaining 178 households were selected from 19 area unit clusters of eight, nine or 10 houses drawn at random, with a probability proportional to the number of households from those New Zealand households not covered by the major population regions – from the far north to the deep south (see Section 3, Isaacs et al 2005 for a more detailed description).

For the purposes of analysis some of the strata have been combined into Auckland, Hamilton/Tauranga and Dunedin/Invercargill. These areas are for the metropolitan areas only. The clusters (rest of New Zealand) have been split into ‘warm’ and ‘cool’ clusters, with the warm clusters those areas where the annual heating Degree Days according to ALF are less than or equal to 620.

Regional Council	Location	No. of houses	Year(s) monitored
Northland	Kaikohe	10	2003-04
	Kamo West	10	2003-04
	Sherwood Rise	10	2003-04
Auckland	Orewa	8	2004-05
	North Shore	19	2001 & 2002
	Auckland	37	2001 & 2002
	Waitakere	16	2001 & 2002
	Manukau	24	2001 & 2002
	Awhitu	9	2004-05
Waikato	Parawai	9	2004-05
	Hamilton	17	2000
	Arapuni	10	2003-04
	Ngakuru	9	2004-05
	Rangatira	9	2004-05
Bay of Plenty	Minden	10	2003-04
	Tauranga	9	2003-04
	Western Heights	9	2004-05
Gisborne / Hawkes Bay	Mangapapa	9	2004-05
	Wairoa	9	2004-05
	Tamatea North	9	2004-05
Wanganui	Foxton Beach	10	2003-04
Wellington	Waikanae	10	2002-03
	Wellington	41	1999
Tasman	Wai-iti	9	2004-05
Marlborough	Seddon	9	2004-05
Canterbury	Christchurch	36	2002-03
Otago / Southland	Oamaru	10	2003-04
	Dunedin	14	2003-04
	Invercargill	6	2003-04
All NZ	**Total**	**397**	**1999-2005**

Table 1: Location, count and year monitored for HEEP houses

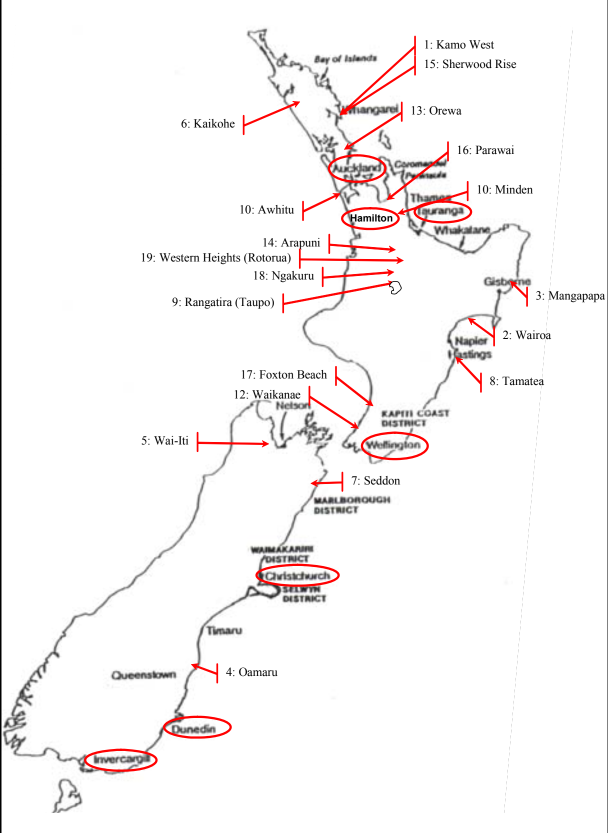

Figure 1: Map of New Zealand showing HEEP monitoring locations

HEEP monitoring was based on 10 minute records. The majority (74%) of HEEP houses have the total for each fuel and the domestic hot water (DHW) heater monitored. In the other houses, detailed end-use monitoring of all significant fuel use was undertaken e.g. gas hobs, as well as significant fixed electricity use such as electric stove. Two types of electric end-use monitoring systems were used:

- EUM – a purpose-built, commercial, power line carrier system that monitored up to eight fixed electric circuits (e.g. lighting, stove etc) and up to eight remote uses (e.g. dishwasher, television etc)
- Siemens Appliance Monitoring (SAM) – a standard Siemens revenue meter with a pulse output that fed into a BRANZ Ltd datalogger.

HEEP also made early use of the remote reading electric 'smart metering' developed by Energy Intellect Ltd (formerly Total Metering Ltd). Since 2002, three sets of meters have been placed on three houses for one year. They replace other HEEP electricity metering, and provided both real and reactive power every minute.

Apart from the early houses in Wellington, at least one bedroom and two living room temperatures were recorded.

In addition to the ongoing monitoring a detailed occupant survey, a hot water audit and an energy audit were conducted during the installation.

The data is held in a database for analysis by the appropriate statistical tool, which include S-Plus and GenStat. Where appropriate, details of the statistical tests and results are provided in this report. Further information on these is available in any standard statistical handbook.

1.2 HEEP in action

The past year has seen the results from HEEP research being applied to a wide range of activities.

Figure 2: A power station was hiding in the wood shed

Of particular importance is the impact on national energy statistics. On 28 April 2006 the latest edition of the MED Energy Data File was released, with major changes to the residential sector use of wood fuel (see Section 3.7).

HEEP data has been used by a select number of commercial clients to assist with work undertaken for submission to the Electricity Commission, Department of Building and Housing and EECA.

We are also aware that other organisations are using HEEP results e.g. the Ministry of Economic Development (MED), the Ministry for the Environment and a range of energy companies.

On 6 November 2005, Television NZ's TV 1 6 pm news featured a three minute item on HEEP research.

For the first time the full HEEP Year 9 report was made available on the BRANZ Ltd website for free downloading as a PDF file. The report was released on 16 October 2005. By 30 June 2006, 360 copies of the 139 page, 1.2 Megabyte file had been downloaded. Copies have been requested from 22 countries, from Australia to the

United Arab Emirates, although most have gone to New Zealand (65%) followed by the United Kingdom (9%) and Australia (8%). Analysis of the reasons for downloading found 56% were to be used in work or research, while only 24% were for 'personal interest'. Policy, product development and educational use were each around 5%, while students downloading the report for their studies was only 8%.

HEEP papers and Executive Summaries are also receiving considerable interest, with a 49% increase over the previous year – 4,700 downloads in the year to the end of June 2006 compared to 3,100 in the year to the end of June 2005.

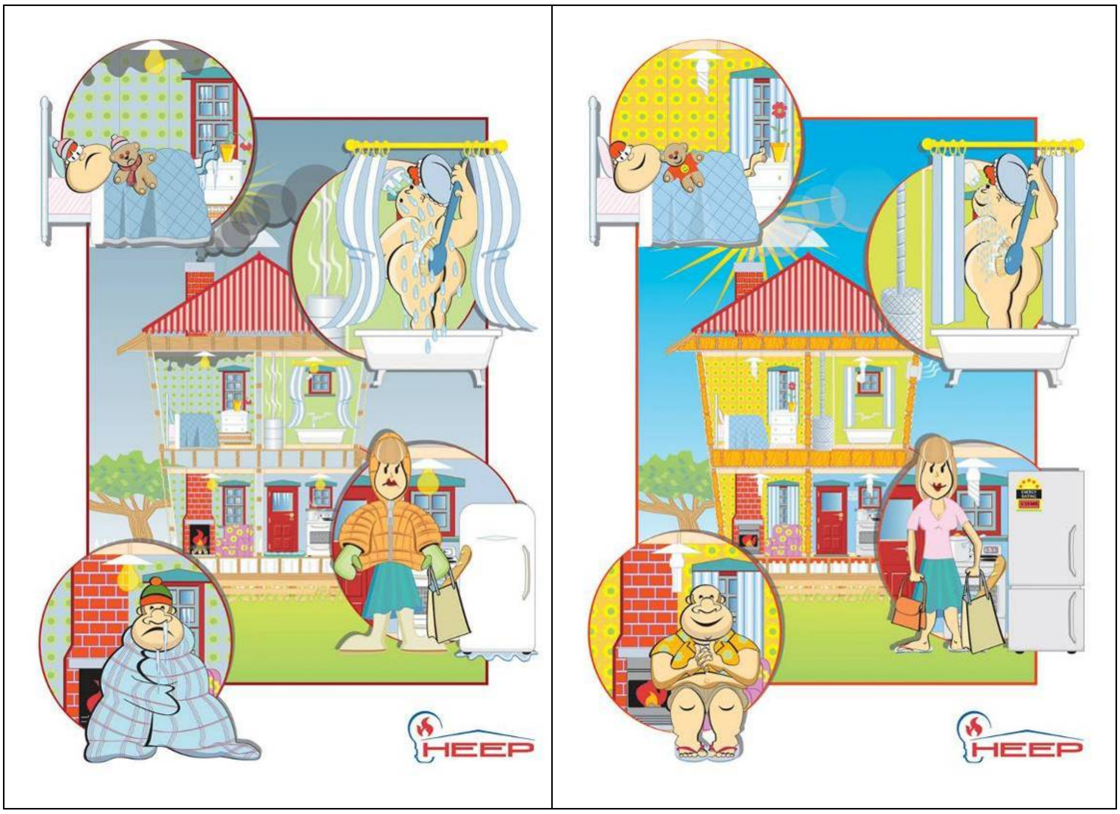

Figure 3: Theme illustrations from the HEEP Year 10 celebration

On 16 November 2005 a 10 year celebration was held for HEEP at the Wellington Museum of City and Sea. Keynote speakers were Mr Stuart Kendon (Chairman of BRANZ Ltd), Ms Jeanette Fitzsimmons (MP, Leader of the Greens and Government spokesperson on energy efficiency) and Mr Murray Bain (CEO FRST). The theme illustrations are shown in Figure 3.

1.3 Further information

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

Section 15 provides full references for a range of HEEP written material:

- HEEP reports
- HEEP *BUILD* articles
- HEEP conference papers

- Other HEEP references.

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

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

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

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2. WHY BOTHER COLLECTING DATA?

Why bother collecting energy use data? The energy supply industry knows why and have major investments in data collection, whether for managing their resources or for revenue purposes. The energy demand industry is poorly served, in part due to the benefits of data not being visible until after it has been collected and analysed.

From the USA Twin Rivers Study (Socolow 1978), through the USA End-Use Load and Consumer Assessment Program (ELCAP) (Peterson, Patton and Miller 1993), to the New Zealand HEEP project (Isaacs, Camilleri and Pollard 2004), the design and implementation of an end-use monitoring program have been documented. The results have helped form our knowledge of energy end-use, but there is still more to be learnt.

As each major monitoring program has completed its data collection and prepared its final reports, it has become clear that the new knowledge comes from more than a statistical analysis of the raw data. Many aspects of energy use may be hidden by the provision of an 'average' (or other measure of central tendency), even if statistical margins are provided.

Of the many complicating factors, the most important of these are the occupants. A complete physical model of a building is not enough to predict energy use and internal environment unless the occupant behaviour is properly described. An occupied building is a very complex system, with many interactions between the building envelope, appliances, occupants and climate. It is simply not possible to accurately predict what will happen unless there is good data on all aspects (and even then it may not be feasible).

It is easy when dealing with residential buildings to assume that knowledge of how people use them – we all live in buildings and we know what we do, so surely everyone else does similar things? Are energy use facts really necessary to build energy policy, or are market-based surveys and models enough?

Results from HEEP fall into three categories: those that were expected; those that were unexpected; and those that gave information that no one knew was missing. The latter two categories in particular are useful in guiding energy strategies and policies and helping to avoid errors. The results of the HEEP research suggest that monitoring base energy use data is essential, not only for the purposes of building energy models, but also to ensure that national, regional, local and individual household energy planning can be based on valid knowledge.

2.1 Lessons from the past for the future

HEEP has (sometimes inadvertently) tested and confirmed the validity of all the laws first described by the End-Use Load and Conservation Assessment Program (ELCAP) (Stoop 1998), which are:

<u>**1st ELCAP Law**: It is easier to recover from bad analysis than from bad data</u> e.g. the HEEP house occupant survey has now been through 19 versions.

<u>**2nd ELCAP Law**: 1,000 is much bigger than 10</u> e.g. the first four years of HEEP were taken up with a pilot study monitoring 10 houses at a time, which increased to 41 houses in the 4th year and 100 houses for the final

years. Each increase required more staff and better systems and management techniques.

3rd ELCAP Law: People are not noise. HEEP has not used automatic data screening procedures. We visually checked every data channel when it arrived, during and after initial processing, and before and during analysis. More than 10,000 channel years of data have been inspected. Some really weird usage patterns were followed up and in most cases found to be genuine.

We have postulated several Laws of HEEP as a somewhat tongue-in-cheek extension of the Laws of ELCAP:

- No matter how bizarre the behaviour, somewhere, someone is doing it.
- There is no practical maximum to the number of appliances of a particular type in a house – somewhere, someone is collecting it.
- Any imaginable (or unimaginable) electrical appliance can be found in houses.
- There is no practical maximum or minimum energy consumption – everything from negative (on-site generation and net export) to the consumption of a small commercial building is possible in any size residential dwelling.

2.1.1 Bizarre behaviour

You would expect to find the warmest indoor temperatures in the summertime, and for most houses this is true, but not all. For some HEEP houses with solid fuel burners, indoor winter temperatures of over 35°C (95°F) – warmer than the same houses in summer – were often measured. The occupants start the fire and just keep loading fuel.

Even in summer, the solid fuel burner may not be shut down. For one HEEP house the highest temperature over the year of 40°C (104°F) was recorded in the middle of the night in mid-summer. The house used the solid fuel burner for hot water as well as space heating, so we can only assume that this was the reason it was operating.

Five out of 441 (1.1%) hot water cylinders delivered water at temperatures over 90°C (194°F) – adequate to make tea or coffee from the tap! Closer investigation found the thermostats were faulty, but the occupants had noticed the water becoming hotter, and hotter, and hotter, to a stage where burns were likely if skin came in contact with either the tap or the water. This is an interesting opportunity for a direct link between public health and energy policy to be explored.

There is often nothing to indicate a faulty or even a dangerous appliance. One in six monitored refrigeration appliances were found to be faulty. Spot power measurements meant that we tested appliances as we found them (not as they might have been in the retail showroom). Examples include the:

- fridge so badly iced up that the door was held open by ice
- microwave that created lightning (probably due to a wiring fault)
- TV with its aerial connected to the mains! One roof nail in the wrong place completed the circuit, which was only discovered when plugging the aerial into the set was met by a blue flash, a puff of smoke and a shock.

2.1.2 Inveterate collectors

For every possible appliance type someone out there collects it. Televisions, sewing machines, heaters, old computers – somewhere out there is a house (or houses) with lots of them. One house had nine TVs (not all working). Another house had a large collection of new and old computers, all in use. One house had 15 plug-in fragrance dispensers – so much easier than dealing with the cause of the musty smell, and a mere 1.8 W continuous power for each one.

2.1.3 Unimaginable appliances

From the understandable hospital oxygen machine (used for the medical needs of one occupant), to the amusing emu egg incubator (the Australian large flightless bird), to the trout farm (a mere adjunct to the house), to the solid fuel powered spa pool, to the house that still used a copper[1] to heat water – any appliance that ever existed can be found in some house today.

Houses are not always just homes – sometimes they are business premises. One had a commercial freezer as they ran a catering business from home (unfortunately our monitoring equipment pulled the plug out from the socket and it thawed out a week before Christmas!). Another house had a walk-in 10 m^3 (350 ft^3) commercial fish freezer (apparently not in current commercial use), which really blew out our estimates of average refrigeration volumes. We avoided metering the energy used by the full-scale car repair workshop only by re-wiring part of the house circuit board.

The most numerous electricity end-use in New Zealand houses relates to socket lights, ranging from a minimum of seven light bulbs up to a maximum of 143 light bulbs in a house. Ignoring lights, a minimum of seven and a maximum of 82 appliances were recorded in any house, with an average of 33.

The highest occurrence of a single appliance type was the 22 sewing machines in one house. The most popular appliance is a TV (averaging just under two per house). The next most popular appliance types were also in the entertainment category – video recorders and stereo systems.

2.1.4 Unimaginable appliance energy consumption

How about a solid fuel burner that consumed over 50,000 kWh of energy per year in a relatively temperate climate? The highest all fuels household energy consumption was 16 times the lowest. The highest lighting energy consumption was more than 65 times the lowest. There are clearly rich pickings for energy efficiency in high consumption households so far left untapped. Some houses use no utility-supplied fuel for hot water in winter, as it is supplied by the solid fuel burner. About half of the open fires were either never used or used only a few times in winter.

Despite being present in nearly 40% of households, portable LPG heaters consume only 4% of residential heating energy. The reason relates to their use – 30% of the portable LPG heaters were not used during the winter, while just under half (48%) were only ever used in the low setting – equivalent to a one-and-a-half bar electric heater.

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[1] The 'copper' is an open top copper container, normally mounted in a brick frame, holding about 80 litres (21 USA gallons) of water that is heated by an open fire directly beneath.

2.2 Recommendations for the future

Why bother collecting data? Simply put, you won't know until you look. Real data can challenge conventional thinking, and even result in changes to official statistics.

The interaction between the building, energy-using appliances and occupant behaviour is so complex that it is simply not possible to predict energy use. Thermal simulation models need data of good quality and accuracy in order to give valid predictions, and that data just has to be collected – there is no other reliable way to get it. Often the most important determinants of energy use are behavioural, and no physical model can provide the details.

People behave in ways that are rational for them, and consequently their energy use is rational in their terms. What this behaviour may be is not so clear. Although the overall average may fit with preconceived expectations, the extremes are not as obvious.

Conventional application of statistical analysis raises some interesting questions – are the extreme values statistical anomalies (and should be excluded from a robust analysis) or are they realistic reflections of the huge spread of energy use? HEEP results suggest that they are not measurement outliers – they may only occur in a few houses, but they are real cases that cannot be dismissed.

These examples are just a few of the possibilities that result from examining real monitored energy data. There are many other opportunities that can come from understanding the distribution of energy use. For example, although many energy-efficiency programs focus on low income households, a quick review of the distribution of energy use reveals that there may be even more opportunities by looking at high energy-using households – and it is not only income that drives high energy use. This is further discussed in Section 3.2.

The results from HEEP paint a very different picture of energy use than the out-dated picture that has been widely used for commercial and government policy development. HEEP results have already had impacts in several areas of energy policy and will likely have even larger effects as the final results are published.

Collecting data is a difficult, time-consuming and expensive process, but the pay-offs are data, information and knowledge that cannot be gained any other way. It is also a lot more interesting (and frustrating) than sitting in front of a computer all day.

3. ENERGY END-USES

As the monitoring has been completed for each region and the data analysed, the HEEP annual reports have included appliance energy use breakdowns. With the last monitoring completed in May 2005, and the data processed and checked, this report provides the final analysis of annual appliance energy use.

The statistical analysis was carried out by John Jowett, consultant statistician to the HEEP project. Analysis of the HEEP energy data is not a straightforward process, as the selection probabilities of the various houses and appliances need to be accounted for, as well as appropriate allowances made for missing data. Analysis of the energy use by the end-use monitored plug-in appliances is particularly involved. The analysis process is documented in HEEP internal documents. The analysis was carefully designed to avoid biased estimates (those that are systematically too high or too low) – potentially a crucial issue when undertaking random monitoring of individual appliances.

In this section the annual appliance energy use is given by end-use, fuel and location. The end-uses include: the major circuit loads including total and hot water; appliance groups (e.g. refrigeration, heating); and where there is sufficient data available, individual appliances (e.g. dishwasher, TV).

Each of the individual estimates is given as a mean (average) and standard error of the mean. The standard error indicates the accuracy of the estimate, and should be considered when using these estimates. An accuracy of ±10% was the target for HEEP for the broad level estimates of quantities such as total electricity, hot water and similar large energy uses on a nation-wide basis, and the sample size of 400 houses was chosen to achieve this (see HEEP Year 3 report, Camilleri et al 1999). This level of accuracy was achieved or exceeded for the broad level national estimates, and in some cases also for the strata (city) estimates of some individual end-uses or end-use groups.

The accuracy for many of the regional estimates is not as good as the national estimates due to the smaller sample sizes, and thus care needs to be exercised when comparing estimates between regions. If the difference between two averages is comparable to their standard errors, then there is no evidence to support a conclusion that the energy consumption is different. There may well be a difference, but its existence and direction cannot be established from the data with an acceptable level of confidence – taken here as 95% confidence level.

For example, Table 6 gives the total electricity used per occupied dwelling in Auckland (7,970±520 kWh/occupied dwelling/year) and Tauranga (7,240±850) – a difference of 730, which is similar to the standard errors. As they are not statistically significantly different, we conclude there is no difference at the 95% confidence level.

It is important to note that the difference in the size of the standard errors can be due to a range of causes, including the sample size, large variations in the behaviour of the different occupants, variation in the house heating fuel type etc.

For ease of comparison, data for all fuel types is reported in units of kilowatt-hours (kWh), where 1 kWh = 3.6 MJ. All values are gross energy unless otherwise stated.

3.1 Changes in electricity use since 1971/72

Has energy use in New Zealand households changed over time? In 1971/72 a major investigation was undertaken into the use of electricity in New Zealand homes. Electro-mechanical dial-type kWh meters were used to monitor the total load and the main appliances (NZ Department of Statistics 1973). A sub-set of the houses were also investigated to learn more about the importance of thermal insulation in the New Zealand climate. Temperature monitoring was limited to 'temperature-time integrators' – small coulombic cells that provided average temperatures over a two month period (NZ Department of Statistics 1976).

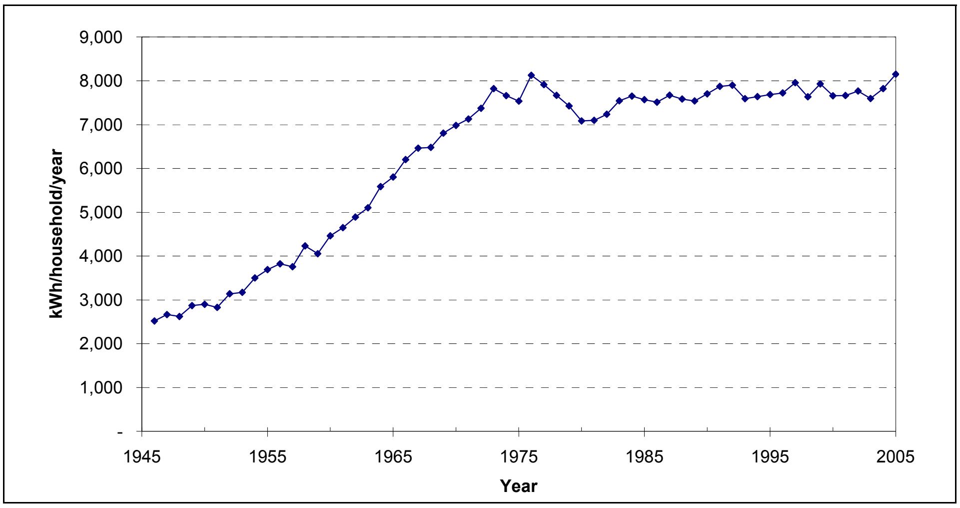


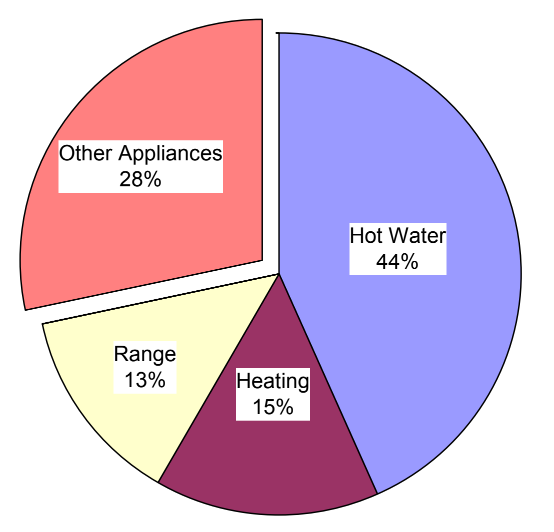
Figure 4: Electricity use per household 1946-2005[2]

The 1971/72 survey was undertaken at a time when electricity consumption had been growing rapidly since the end of World War II. Figure 4 shows this growth and the subsequent levelling off of residential electricity demand per household. In the past 35 years there have been major changes in household energy use, but the old results continue to support both Government and electricity industry policy. As the 1971/72 study monitored only electricity, the use of other fuels was left unquantified.

Figure 5 shows the breakdown in electricity end-uses from the 1971/72 study, while Figure 6 gives the breakdown from HEEP. The 1971/72 heating was estimated by comparing summer to winter electricity usage, as the plug-load heaters were not separately monitored. Although space heating remains close to the same proportion, there have been sizable changes in the importance of the other electricity uses.

The 'range' in a 1970s New Zealand home was free-standing, and often the main source of power sockets for the kitchen. The hot water jug, toaster, cake mixer and even the electric heater could be plugged in one of the two sockets. More than 30 years later the kitchen is likely to have a number of power sockets and this, coupled with an increase in factory prepared meals and snacks (e.g. biscuits are not now baked twice weekly), could have contributed to the reduced stove electricity use.

[2] Data extracted from "Annual Statistics Relating to Electricity Generation" for appropriate years. Courtesy Dr Jonathon Lermit.



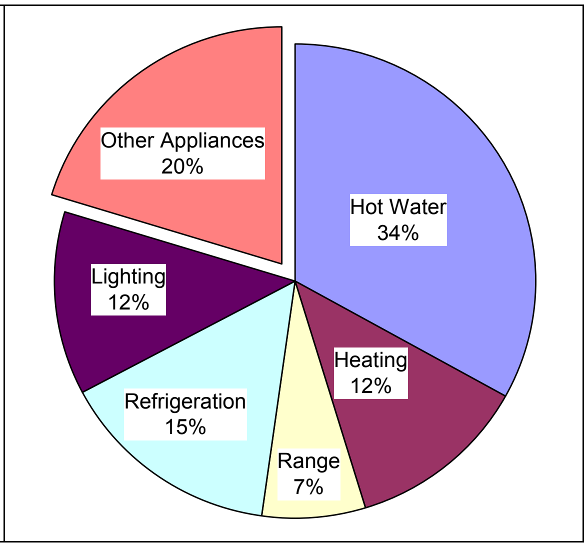


Figure 5: Electricity uses 1971/72 8,400 kWh pa

Source: NZ Department of Statistics 1973

Figure 6: Electricity uses HEEP 7,240 kWh pa

Source: HEEP analysis

Water heating electric energy use has reduced, due at least in part to the increasing use of reticulated natural gas. The use of showers has changed – in 1972/72 they were occupant reported to be 'only' or 'mainly' used in 41% of households, but are now 'mainly' used in 94% of the HEEP houses.

It is in appliances that the greatest shift has been seen. A wider range of 'modern' appliances, increased lighting, new combination fridge freezers and the increased use of electronic controls (with increased standby power demand) have all played a role – one that was undetectable by simple observation or even counting of appliances. Appliances have grown from 28% to 47% of electricity consumption.

Analysis of the HEEP data has found no simple relationship between the number of electrical appliances and either the total energy or peak power demand. The use of the electrical appliances is more important than the number e.g. the second (3rd, 4th etc) TV is used far less than the main one (which is often the largest).

Other changes have also occurred in the residential sector. The average number of occupants has fallen 22%, from 3.55 per house in the 1971 Census to 2.78 in the 2001 Census (NZ Department of Statistics 1975, Statistics NZ 2002). Electricity consumption per occupant was 2,365 kWh/year in the 1971/72 survey, and is 2,690 kWh year from HEEP, while electricity use per dwelling is stable. Manufactured (town) gas is no longer made, but about 14% of houses are now on reticulated natural gas and many others use bottled LPG. Many open fires, and old solid fuel stoves, have been replaced by more modern, efficient solid fuel burners.

3.2 Energy use distribution

Although central tendency statistics (mean, median and mode) are commonly used to help understand patterns, they do not provide any guidance on the spread. A cumulative density plot provides an easy way to visualise data, and to examine the pattern of use. In particular, the percentage of households that have energy consumption that is greater or less than any given threshold can be easily seen.

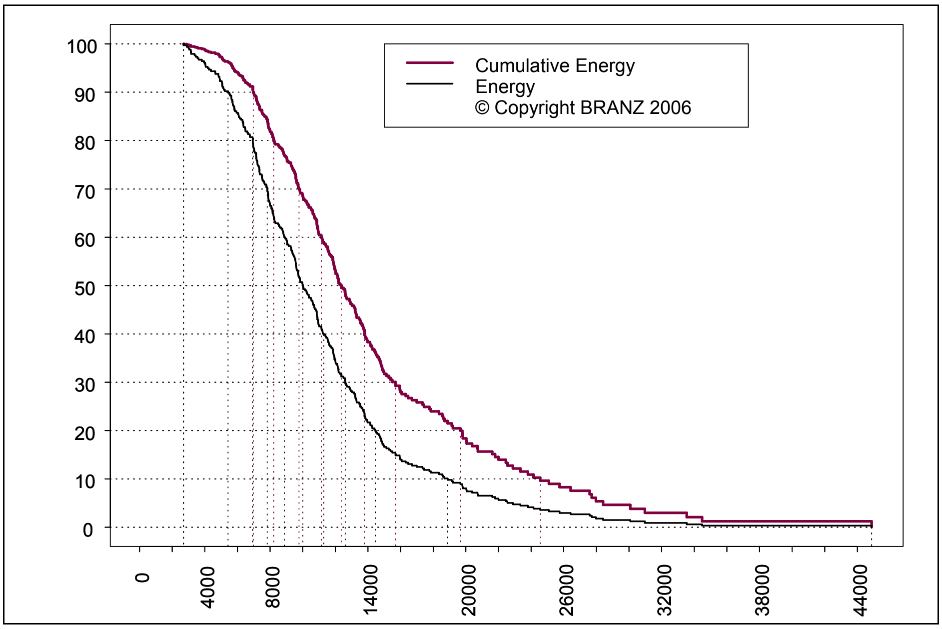


Figure 7: Energy use distribution – all fuels

Figure 7 provides two cumulative density plots on common axes. The range of household energy consumption in kWh/yr is on the horizontal axis. The heavy, topmost curve shows the percentage of total residential energy consumption used by houses at or exceeding this level of energy consumption. The lighter, lower, curve shows the percentage of houses at or exceeding this energy consumption. In both cases the relevant percentage (of total energy or households) is shown on the vertical axis.

Reference lines are drawn from the horizontal or vertical axis until they meet the relevant curve, and then traced to the other axis. For example:

- a horizontal line drawn from the 20% mark until it intersects the energy curve, then dropped vertically down to the X-axis intersect at 14,450 kWh/yr
- a vertical line up from 14,450 kWh/yr until it intersects with the cumulative energy curve, and then taken horizontally across to the Y-axis where it intersects at 36%.

Thus Figure 7 shows that the top 20% of households use more than 14,450 kWh/yr, and these households account for 36% of the energy used in all households. Conversely, the bottom 20% (80% on the Y-axis) of households use less than 6,940 kWh/yr, but they account for only 9% of the total household energy use. These results are also tabulated in Table 2.

The cumulative density plot also shows the maximum and minimum energy use for the houses monitored. In Figure 7 the maximum energy use measured is about 45,000 kWh/yr, where the line drops to 0%, and the minimum is about 2,500 kWh/yr where the line is at 100%. Since HEEP only monitored 400 houses, it is highly unlikely that either the highest or lowest energy-using household in New Zealand was monitored. The national maximum will be higher, and the national minimum lower. Thus Figure 7 maximum and minimum values are not reliable national estimates. However, statistical arguments suggest that, with a 95% confidence, less than 0.75% of houses fall outside the observed range of 2,500 kWh/yr to 45,000 kWh/yr.

In practical terms there will always be a few houses that use no energy at all for a particular end-use. For example, there are houses in New Zealand that have no electricity supply, and houses with no hot water service of any type. In terms of the maximum, there is no practical maximum. There may also be some VERY large houses in New Zealand using HUGE amounts of energy e.g. over 100,000 kWh/yr – we just didn't find them in HEEP as they are very rare. It might be possible to track down these houses through power company records. Large 'mansions' with indoor heated swimming pools, spa pools and air-conditioners are the types of houses that could be expected to have such high energy consumption.

Table 2 provides information on the highest and lowest 20% for total fuels and separately for electricity, gas, LPG and solid fuel. The total and the individual fuels demonstrate skewed distributions, with high users consuming more per house than the smaller users. The ratio of the energy use per house for the top 20% of houses to the bottom 20% of houses ranges from 2.1 to 12.8.

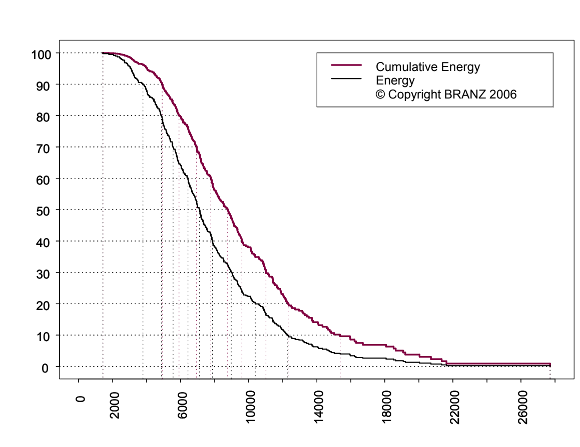
Figure 7 and Table 2 suggest that for a goal of reducing total household energy use (i.e. energy conservation), it is likely that the largest absolute reductions will come from the high energy using top 20% of houses.

Fuel	**Bottom 20%**		**Top 20%**		**Ratio**
	Use under:	**% of energy**	**Use over:**	**% of energy**	**Top: Bottom**
Electricity	4,860 kWh/yr	10%	10,380 kWh/yr	35%	2.1
Gas	2,580 kWh/yr	5%	9,900 kWh/yr	34%	3.8
Solid fuel heating	450 kWh/yr	1%	5,740 kWh/yr	57%	12.8
LPG heating	180 kWh/yr	3%	1,110 kWh/yr	50%	6.2
All fuels	**6,940 kWh/yr**	**9%**	**14,450 kWh/yr**	**36%**	**2.1**

Table 2: Fuel use – top and bottom 20%

The following four figures provide energy and cumulative energy density curves for:

- Figure 8: electricity
- Figure 9: gas (mains natural gas and large cylinder LPG)
- Figure 10: small cylinder LPG (free standing, unvented, LPG heaters)
- Figure 11: solid fuel (including wood and coal).



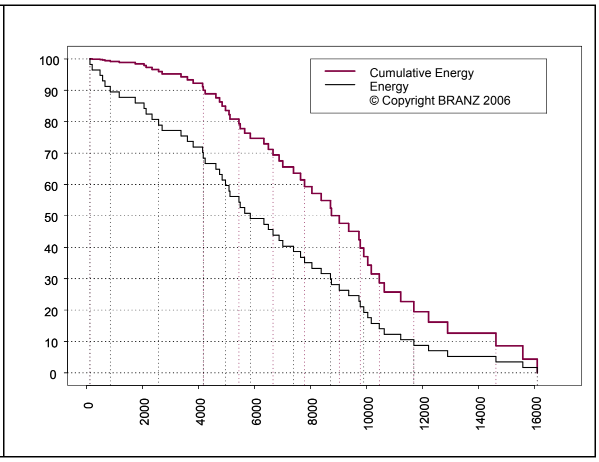
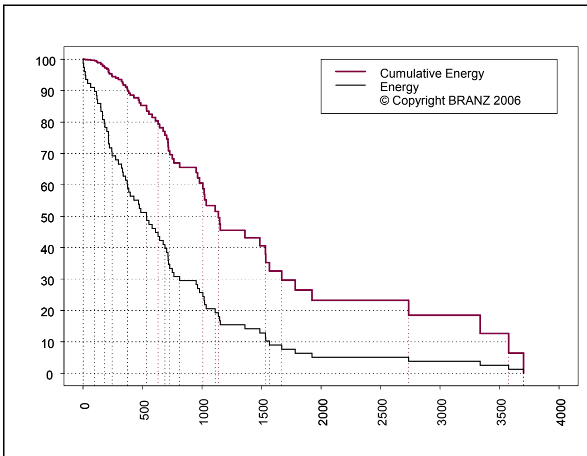


Figure 8: Energy use distribution – electricity

Figure 9: Energy use distribution – gas (natural gas & large bottle LPG)



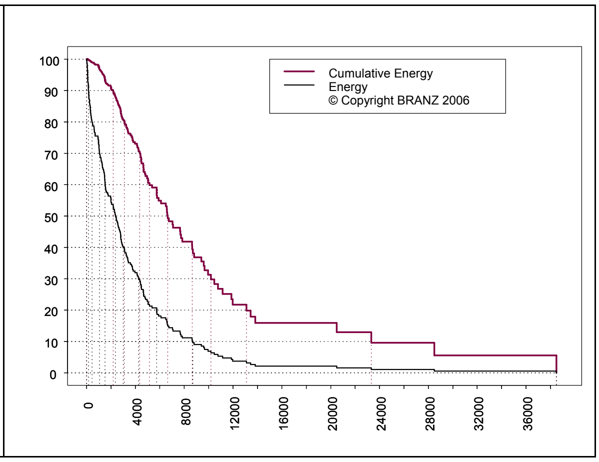


Figure 10: Energy use distribution – LPG (small bottles)

Figure 11: Energy use distribution – Solid fuel

3.3 Patterns of energy use

Although the average energy use for a given fuel or end-use provides a quick overview, it can disguise the actual use if it occurs only in a limited number of houses. For example, if one house out of 100 uses 100 units of a fuel, but the other 99 do not use that fuel at all, then the average use is 1 unit – which although a useful number, is not meaningful. Table 3 provides an estimate of circuit energy loads for houses that have that fuel end-use i.e. not averaged over all houses.

Isaacs et al 2003 (Section 4.2) provided analysis of the proportions of energy (electricity and natural gas only) by end-use for Auckland, Hamilton, Wellington and Christchurch. It has not been possible to provide a more detailed regional overview until the monitoring and data analysis has been completed for all fuel types. This has now been completed, and a comprehensive statistical analysis undertaken.

It has been found that for some end-uses the household use variability makes it impossible to provide a detailed regional breakdown. This issue can only be resolved with a larger scale, or more detailed regional monitoring programme.

Description	Annual kWh	Standard error
Total – reticulated gas	6227	189
Range – electricity	536	57
Range – reticulated gas	706	63
Range – solid fuel	942	69
Night store – electricity	2198	112
Fixed wired – electric heating	860	124
Open fire – solid fuel	886	105
Heating – reticulated gas	4204	192
Heating – LPG	746	90
Other heating – solid fuel	4446	217
Heating – oil	1188	1306
Large miscellaneous – electricity	2065	154
Spa – electricity (circuit)	1986	146
Small miscellaneous – electricity	28	13
Hot water – electricity	2778	114
Hot water – reticulated gas	5338	146
Wetback – solid fuel	908	100
Hot water – oil	3348	1674

Table 3: Energy end-use by fuel for houses with that end-use

Note: standard error of the mean (SE) are estimated.

Total energy and electricity use appears to vary little by region, although on a per occupant basis a different picture emerges. The reason for this might be due to the increased use of solid fuel heating in the colder parts of New Zealand.

Figure 12 provides an overview for all fuel types of the different energy end-uses. The locational variables are discussed in Section 1.1. As would be expected, Figure 12 shows that in the cooler regions (Dunedin/Invercargill cool clusters) space heating is close to half of the total energy use. In the warmer areas, water heating is the largest single energy use.

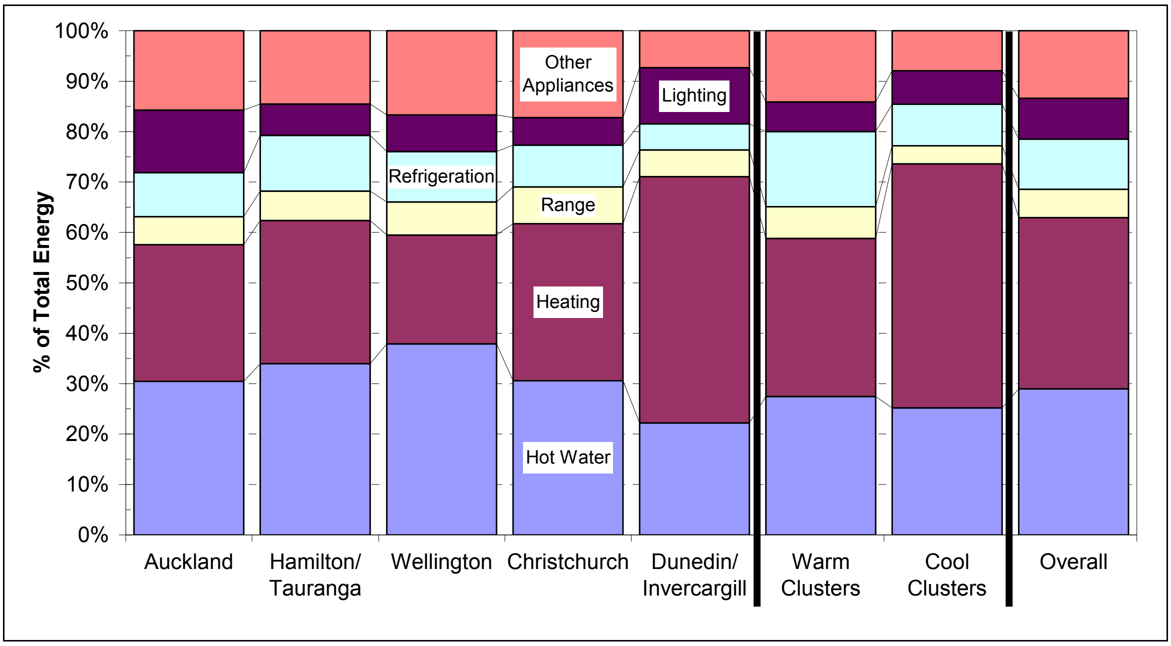


Figure 12: Regional patterns of energy end-uses

The total annual energy consumption for all fuels is given in Table 4 on a national and regional basis. The national average is 11,410 kWh per year. Note that the differences between most of these locations are not statistically significant. This does not necessarily mean that there is no difference, but simply that the estimate precision is insufficient to establish whether a difference exists or, if so, its direction.

Location	Average energy use (kWh/occupied dwelling/year)	Standard error
National (Cities and Clusters)	**11,410**	**420**
Auckland	10,660	520
Hamilton/Tauranga	10,750	840
Wellington	10,860	790
Christchurch	11,010	750
Dunedin/Invercargill	14,580	1,450
Clusters	**11,740**	**810**
Warm clusters	9,960	790
Cool clusters	13,780	1,170

Table 4: Total annual energy consumption – all fuels

When the number of HEEP occupants is taken into account a different picture emerges. Table 5 shows that there is higher energy consumption per person in the locations with colder climates, and less for those in warmer climates, and these differences are statistically significant for most locations. Auckland has the highest average number of occupants at 3.34 per occupied dwelling, and it appears plausible that this has the effect of increasing the total annual energy consumption in Table 4.

Location	Number of occupants	Average energy (kWh/occupant/yr)	Standard error
National	**2.90**	**3,930**	**140**
Auckland	3.34	3,190	210
Hamilton/Tauranga	2.33	4,610	440
Wellington	3.00	3,620	280
Christchurch	3.00	3,670	290
Dunedin/Invercargill	2.65	5,500	620
Clusters	**2.86**	**4,100**	**300**
Warm clusters	3.00	3,320	230
Cool clusters	2.70	5,100	450

Table 5: Total annual energy consumption per person – all fuels

Table 6 shows the results are similar when only electricity is considered. The national average annual electricity consumption is 7,800±420 kWh per year. In most locations, the electricity use is not statistically significantly different, meaning that regional differences cannot be held to have been established (with the possible exception of Dunedin/Invercargill).

Location	Average electricity (kWh/occupied dwelling/year)	Standard error
National	**7,800**	**420**
Auckland	7,970	520
Hamilton/Tauranga	7,270	840
Wellington	7,840	790
Christchurch	8,710	750
Dunedin/Invercargill	10,610	1,450
Clusters	**7,300**	**810**
Warm clusters	6,740	790
Cool clusters	7,950	1,170

Table 6: Total annual energy consumption – electricity only

Scaling by the average number of occupants changes the results (Table 7), and now there are statistically significant differences between various locations, with a general trend for higher electricity consumption per person in colder climates.

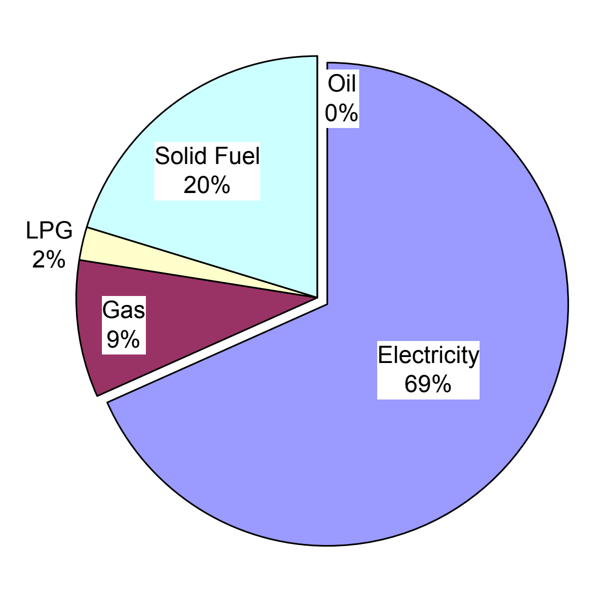
Location	Number of occupants	Average electricity (kWh/occupant/year)	Standard error
National	**2.90**	**2,690**	**140**
Auckland	3.34	2,390	160
Hamilton/Tauranga	2.33	3,120	350
Wellington	3.00	2,610	260
Christchurch	3.00	2,900	240
Dunedin/Invercargill	2.65	4,000	620
Clusters	**2.86**	**2,550**	**260**
Warm clusters	3.00	2,250	220
Cool clusters	2.70	2,940	410

Table 7: Total annual energy consumption per person – electricity only

The HEEP breakdown of New Zealand household energy consumption by fuel type is given in Figure 13. Electricity use accounts for 69% of total residential national fuel use, followed by solid fuel at 20%, reticulated gas at 9% and bottled LPG at 2%. Heating oil is used in very few houses. The breakdown by location varies greatly, depending on the types of fuels that are used in houses, particularly for space heating (see Section 6.1.2). Many locations do not have a reticulated gas supply, and other fuels are used instead for space heating, cooking and water heating.

The HEEP breakdown of New Zealand household total energy consumption by end-use is given in Figure 14. The largest portion is space heating at 34%, then hot water at 29%, and refrigeration, other appliances, lighting, and range at around 10% each. The proportions vary by location, with less space heating energy used in warm and more in colder climates – up to 70% of energy use in the coldest climates.

Combining water and space heating, Figure 14 shows that on average that just under two-thirds (63%) of household energy use is for low grade heat (less than 100°C).



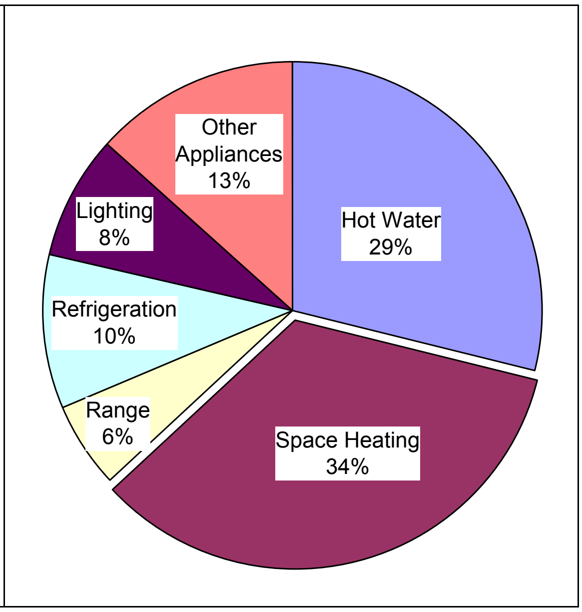
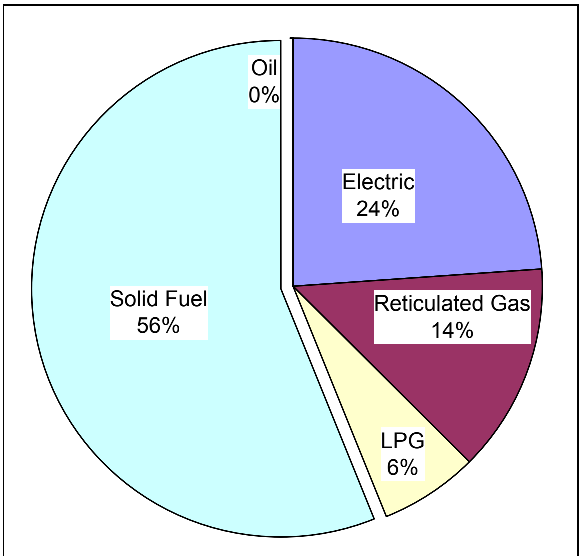


Figure 13: Total energy use by fuel type

Figure 14: Total energy use by end-use

Figure 15 provides an overview of the relative importance of the major heating fuels based on the gross energy. Figure 16 makes conservative allowances for the efficiencies of different appliances – while 100% of electricity is converted to heat, a reasonable quality enclosed solid fuel burner would convert 60% of wood into heat.



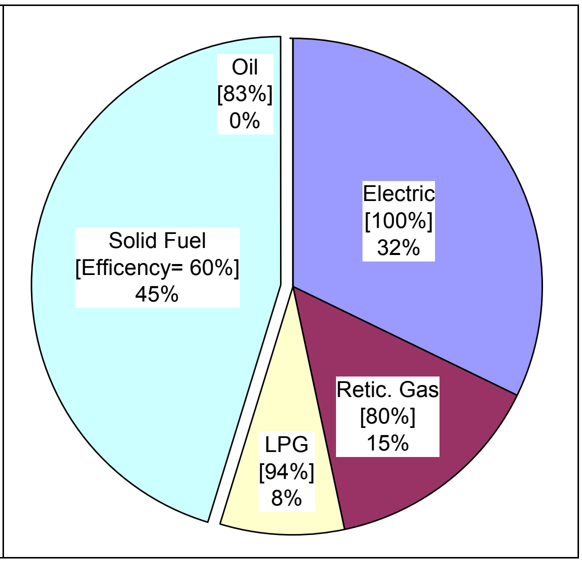


Figure 15: Space heating gross energy by fuel

Figure 16: Space heating delivered energy by fuel

Figure 15 shows that solid fuel is the most important heating fuel with about 56% of gross[3] space heating, followed by electricity at 24%, reticulated gas at 14%, LPG at 6% and oil under 1%. After allowances for conversion efficiency (in square brackets [ ]), Figure 16 shows that the proportions change, but solid fuel remains the most important space heating fuel in New Zealand dwellings. Heat pumps (which produce more heat output than electricity use) are currently found in very few houses.

The relative importance of the different space heating fuels varies by location. In the clusters (selected from locations with a population of less than about 50,000), which represent half of New Zealand's population, about 77% of space heating gross energy consumption is supplied by solid fuel and only 10% by electricity. In the clusters in cooler climates this is even more pronounced, with 81% of gross space heating supplied by solid fuel. Of the cities, Christchurch had the highest percentage of solid fuel use, at 54% of gross space heating energy use.

Appendix 2: Energy Consumption Tables (Section 17) provide HEEP estimates of average annual gross energy use for total energy, hot water, space heating and selected appliances. Due to the small sample size, fuel oil is not separately reported. The tables provide analysis for the national and locations as described in Section 1.1:

- Table 63: the average total energy use per house for all fuels, electricity, gas, LPG and solid fuels
- Table 64: the average annual hot water energy use by house for all fuels, electricity, gas and solid fuels
- Table 65: the average annual space heating energy use by house for all fuels, electricity, solid fuels, gas and LPG
- Table 66: the average annual energy use per house for all cooking, range, lighting and refrigeration.

These tables provide the average over all houses in the location (national or regional) – NOT the average use in houses that use that particular fuel or end-use. For example, for Table 63 (average total energy use) 100% of HEEP houses used electricity, 17% gas (mains natural gas or large cylinder LPG), 32% LPG (small 9 kg cylinders) and 55% solid fuel.[4]

3.4 Energy consumption over the year

Household energy consumption varies seasonally, most noticeably with increased space heating, hot water heating and lighting during the winter months. Total energy consumption (all fuels) rises by a factor of nearly three times from summer to winter. Most of this increase is due to space heating, which is very low in the summer months but rises (on average) to 280 kWh per month in July. Range energy use increases by about 50% from summer to winter, lighting by about 2.5 times, and hot water by about 60%.

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[3] Gross energy is the energy content of fuel before it is used in a heating appliance. Solid fuel and gas burners have efficiencies under 100% – some energy is lost during burning and only part is released as heat to the room. Typically gas burner efficiency is about 80%, and solid fuel burners 50-70% e.g. for approval in Christchurch clean air zone 1, over 65% heating efficiency is required (see www.ecan.govt.nz).

[4] Solid fuel is used in: enclosed solid fuel burner; open fire; solid fuel burner with wetback water heating; chip heater; solid fuel hot water cylinder; or wood/coal range.

It is expected that space heating energy use will increase due to colder temperatures, peaking in the coldest month (July), as shown in Figure 17. The response of the other energy uses is not so clear. Why should range energy increase by 50% in winter? Why should average water heating energy use increase by 60%?

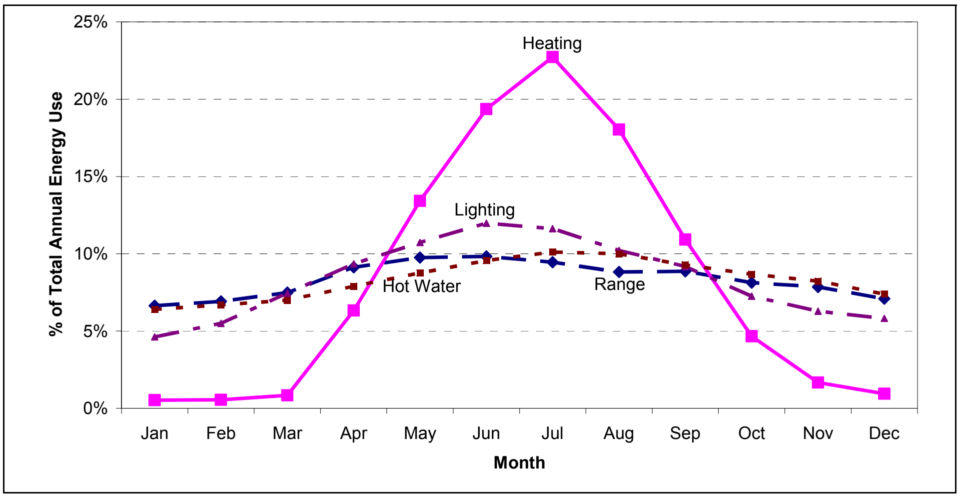

Figure 17: Energy use by end-use and month

It will take a little more energy to heat food or water from lower winter temperatures, but most of the increase must be due to changes in cooking habits – more range use means cooked meals, and these are more common in the cooler winter months (just as BBQ meals are more common in the warmer summer months).

Lighting energy use increases due to shorter daylight hours, and peaks in June (the month with the shortest day), a month earlier than heating. Hot water energy use increases markedly in winter, with some of the increase due to colder water temperatures (more energy is needed to heat the colder water) and higher standing and pipe losses due to cooler indoor air temperatures. These effects might account for about a 20% increase in hot water energy consumption. Behavioural changes might account for the rest – perhaps longer showers to compensate for colder weather, or perhaps more clothes washing and drying.

The summer months of December, January and February include summer holiday periods, and for many households there will be a period of vacation, often of several weeks. February energy consumption is perhaps most typical of summer energy consumption for most households, but in most cases the February energy use is very close to the January one. There could be a number of possible reasons for this e.g. retired people taking their extended summer holidays in February.

3.5 Appliance electricity use

Table 8 lists the different energy end-uses monitored in the HEEP houses, and the titles under which they are amalgamated into a smaller number of functionally similar groups. It should be noted that the 'Large miscellaneous' and 'Small miscellaneous' appliance groups include wide ranges of disparate end-uses, any one of which may only be found in a limited number of households.

Group	End-use	Group	End-use
Entertainment	Computer Computer + access DVD Games console Sky/Saturn decoder Stereo Television TV and video Video	**Other climate control**	Cupboard heater Electric blanket Extractor fan Fan Heated towel rail Heat lamp Rangehood Ventilation system Waterbed
Heating & cooling	Heat pump Ceiling heater Central heating Dehumidifier Gas heater controller Heater Night store heater Underfloor heating	**Other cooking**	Bench top oven Blender Bread maker Crockpot Deep fryer Electric coffee maker Frying pan Juicer Sandwich maker Toaster
Large miscellaneous	Arc welder Electric water pump Pool pump Sauna Spa bath Spa pool	**Small miscellaneous**	Electric fence Espresso machine Iron Kiln Oxygen machine Security system Sewing machine Vacuum cleaner Waste disposal
Lighting	Portable lamp Lights		
Refrigeration	Freezer Fridge Fridge freezer		

Table 8: Appliance groups

The HEEP study included measurements of the energy consumption of individual electrical appliances. One, two or three individual appliances were monitored each month in the 100 end-use monitored houses (i.e. one in four of all HEEP monitored houses). Due to the many different types of appliances and the limited monitoring equipment available, for some appliances only a few (or sometimes none) were monitored in each location. As a result, the coverage of individual strata (cities) or cluster (outside major cities including rural) locations is not adequate to separate them out for comparison. However, nation-wide figures have been calculated by individual appliances.

The average electricity consumption per house for the various appliance types is given in Table 9. This is the consumption for each appliance type or group, on a per house basis, so for example the ‘Entertainment’ group includes all TVs in the houses (see also Table 8 for more detail on the appliance groups). The larger electricity uses of hardwired lighting, hardwired range and refrigeration are reported separately (see Figure 6).

Appliance type	Average (kWh/year)	Standard error
Computer/games	227	43
Dishwashers	107	18
Dryers	119	23
Electric jug	152	12
Entertainment	364	57
Large miscellaneous	73	58
Microwave	62	6
Other climate control	119	70
Other cooking	52	8
Small miscellaneous	40	9
Spa pools	123	52
Washing machines	63	12
Lighting (hardwired)	915	87
Range (hardwired)	497	42
Refrigeration	1,119	72

Table 9: Average appliance electricity consumption per household

For some appliances enough data was collected to provide estimates per appliance. Note that the standard error is only an estimate, as for technical reasons it is very difficult (or in some cases, impossible) to calculate a valid standard error.

The 'per appliance' estimate is also difficult to interpret as there may be more than one of that appliance in a house, but one or more may be virtually unused. Notable examples are plug-in lighting, heaters and 'Other entertainment' appliances. Appliances that were stated by the occupants to be never used were generally not monitored and are not included in the averages. However, some monitored appliances never recorded any power consumption. The HEEP focus was on per household energy use; use 'per appliance' may not always be a meaningful concept.

Appliance	Average (kWh/year)	SE	Appliance	Average (kWh/year)	SE
Computer/games	196	27	Lighting (plug-in)	40	10
Dehumidifier	554	281	Microwave	78	5
Dishwasher	211	28	Other climate control	289	105
Dryer	173	32	Other cooking	19	6
Electric blanket	49	9	Other entertainment	114	23
Electric jug	157	12	Range hood	27	7
Portable heater	71	64	Refrigerator	367	62
Freezer	663	39	Small miscellaneous	4	2
Fridge freezer	621	30	Spa	398	288
Heater	488	81	Toaster	20	3
Iron	11	2	TV	132	13
Large miscellaneous	116	57	Vacuum cleaner	21	4
			Washing machine	59	7

Table 10: Average electricity consumption per appliance

Figure 6 (Section 3.1) provides a breakdown of average electricity use, showing that the 'Other Appliances' grouping accounts on average for 20% of HEEP household electricity use. This 20% is further analysed in Figure 18 and Table 11 below.

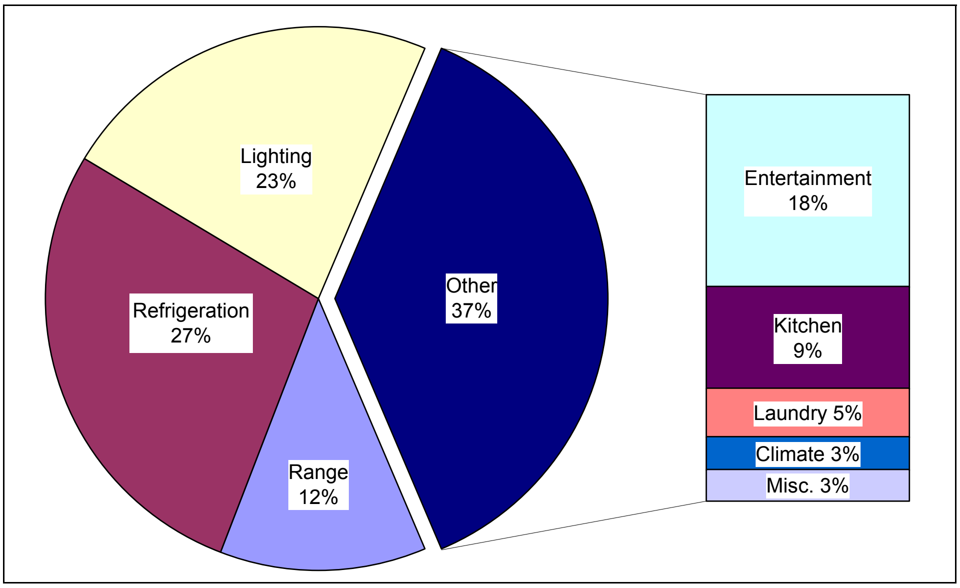

Figure 18: Electric appliances

Broad category	Electric appliance groups included:	Other appliance %	Electric appliance %
Entertainment	Entertainment, computer/games, spa pools	48%	18%
Kitchen	Dishwasher, other cooking, electric jug, microwave	25%	9%
Laundry	Dryer, washing machine	12%	5%
Climate	Other climate control	8%	3%
Miscellaneous	Small, large	8%	3%
Larger load	Lighting (hardwired)		23%
Larger load	Refrigeration		28%
Larger load	Range (hardwired)		12%
	TOTAL	**100%**	**100%**

Table 11: Average appliance category proportion of electricity

Table 11 and Figure 18 show that in the average home, the three larger loads (lighting, refrigeration and range) account for 63% of the non-spacing heating or water heating electricity use. Of the remaining appliances, the entertainment category is the next largest user of electricity. The 'Other Appliances' group includes a large number and variety of appliances, suggesting that any electricity efficiency or conservation activity will need to be well focused to achieve real benefits.

3.6 Lighting

Lighting energy use provides a variety of benefits in houses. As well as allowing activities to be carried out when there is no sunlight, it is also used for security in parts of the house in common use but lacking good daylight, and in dark spaces such as cupboards that are infrequently used.

Figure 19 illustrates that average fixed wired lighting power demand varies over the year, with the highest lighting energy load occurring during the winter months (June and July).

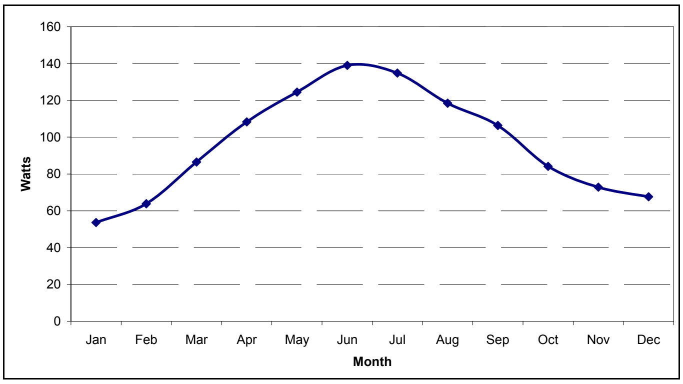

Figure 19: Average monthly lighting power – all New Zealand

Table 12 provides a regional breakdown of lighting power demand. Lighting energy use was collected only in the end-use monitored HEEP houses (one in four houses), and is highly variable between houses, so the standard errors are quite high. The power demand in most locations is not statistically significantly different from the national average, and only Auckland stands out. It would be expected that the further south (and hence the longer the winter evenings), the higher the winter lighting energy use would be. However, this effect cannot be proven from the monitored HEEP data. The main drivers of lighting energy consumption are the number of occupants and the floor area (see Table 60 and associated text).

Location	Annual average Watts	Standard error
Auckland	167	34
Hamilton	100	19
Wellington	101	29
Christchurch	60	15
Dunedin/Invercargill	177	17
Warm clusters	64	13
Cool clusters	80	17
All New Zealand	**104**	**10**

Table 12: Lighting power by region

3.7 Changing official New Zealand energy statistics

Figure 13 (Page 19) showed that based on the HEEP monitored data, electricity accounts for 69% of total residential national fuel use, followed by solid fuel at 20%. This new estimate is based on all HEEP data, and replaces the estimate given in the HEEP Year 9 report (Isaacs et al 2005) that solid fuel was over 15%. It was pointed out in the HEEP Year 9 report that this value differed significantly from the national energy statistics published by the MED for the residential sector.

Figure 20 (for 2004) and Figure 21 (for 2005) are calculated from the published MED Energy Data File (MED 2005, MED 2006). The 'Other' category includes geothermal and solar.

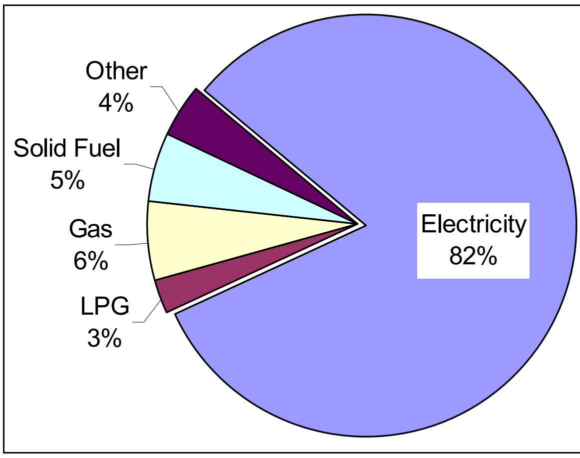

Figure 20: Fuels all end-uses December year 2004

Source: MED 2005

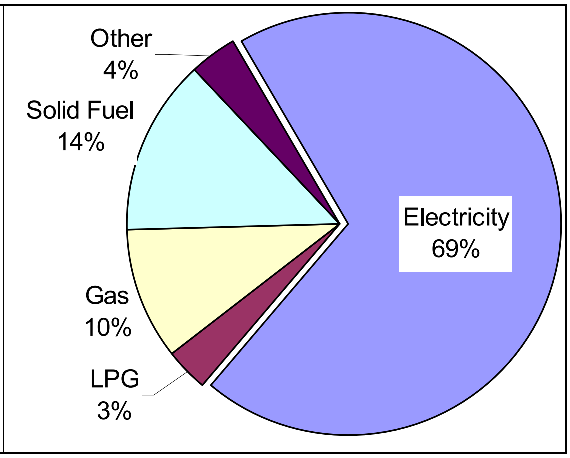

Figure 21: Fuels all end-uses September year 2005

Source: MED 2006

Figure 20 shows the official estimate for wood and coal ('Solid fuel') used in the December 2004 year was 5% of total residential energy use. For Figure 21 it has increased to 14% – but this is not due to an increase in the actual residential use of wood or coal. The difference is explained in the supporting text (MED 2006 189-90): [5]

> *In previous editions of the Energy Data File the figures for residential wood use included in the Energy Balances were based on an average use of 4.3 GJ per household using firewood. This figure had been estimated by an industry analyst in 1996. The 'Household Energy End-use Project' (HEEP) carried out by BRANZ monitored actual firewood use and reported average annual use of 13.7 GJ.*
>
> *Due to the BRANZ figure having more validity than the earlier figure, values published in this edition have been re-calculated using this new figure.*

This result of the HEEP research has led to a reported national increase in wood use of 5.6 PJ – equal to a 1% increase in total observed consumer energy, or a 9% increase in residential sector consumer energy.

If this wood was burnt in solid fuel burners with an efficiency of 50%, it would be equivalent to a 530 MW thermal power station feeding conventional resistance heaters or a 180 MW station feeding heat pumps. For comparison, the Huntly power station is 960 MW.

In energy terms, this heating load would be a 6% increase in residential sector electricity demand if used in conventional resistance heaters, or 2% if used in heat pumps (COP 3).

The under-estimate of solid fuel use in the residential sector has critical implications for assumptions relating to the services it provides. Solid fuel is principally used for space heating, although as noted earlier in some houses it also provides a significant proportion of hot water (about 5% of all hot water energy consumption).

[5] Available at www.med.govt.nz/templates/MultipageDocumentTOC____15181.aspx#.

4. SOCIAL IMPACTS AND DYNAMICS OF HOUSEHOLD ENERGY END-USE

The social analysis of HEEP data in Year 10 has moved beyond exploring the correlations between social, energy and temperature variables for integration into the HEERA model (see Section 12). Instead, it has concentrated on three areas of considerable policy concern:
- fuel poverty
- Māori households' use of energy, and
- solid fuel usage in New Zealand homes.

The Luxemburg method (Atkinson et al 1995) has been used to calculate equivalised household income to control for household size effects. The equivalised income is calculated by dividing total household before tax income by the square root of the number of occupants. Table 13 gives quintile boundaries for the HEEP households:

Quintile	Boundaries
1	$1,118 - $15,653
2	$15,654 - $24,749
3	$24,750 - $35,000
4	$35,001 - $49,498
5	$49,499 - $90,001

Table 13: HEEP equivalised income quintiles

4.1 Fuel poverty

Fuel poverty is indicated where:
- residents expend, or would be required to expend, excessive levels of their income on heating to achieve and maintain healthy indoor temperatures, and/or
- unhealthy indoor temperatures prevail because residents constrain energy expenditure to affordable levels, and/or
- residents are unable to achieve healthy indoor temperatures even where their heating expenditure constitutes an excessive proportion of income.

Internationally, there has been a consistent problem with the measurement of fuel poverty because few surveys into energy consumption and expenditure have measured temperatures within dwellings (Hunt and Boardman 1994). HEEP does precisely that and, in doing so, provides a unique evidential platform for grasping the nature of fuel poverty in New Zealand.

At its simplest, fuel poverty exists when households are not able to afford comfortable domestic warmth. Warmth, and more particularly *comfortable* warmth, is clearly a matter of subjective perception. There are, however, some critical thresholds around acceptable temperatures related to health. Temperatures that are:
- lower than 16ºC appear to impair respiratory function
- below 12ºC place strain on the cardiovascular system
- below 6ºC place people at-risk of hypothermia (Collins 1986).

The impacts of low temperatures are exacerbated where individuals are vulnerable through illness, disability or age. Low temperatures also pose greater risks when exposure is for extended periods (Raw et al 2001). The World Health Organisation has concluded that the optimum indoor temperature is in the range 18ºC to 24ºC (WHO 2003).

The Working Group appointed by the Watt Committee on Energy in the United Kingdom recommends:

- 21ºC for 13 hours a day in living rooms
- 18ºC for eight hours at night and an additional five hours during the day in bedrooms
- 18ºC for 13 hours a day in other spaces
- 14.5ºC in all spaces at all other times.

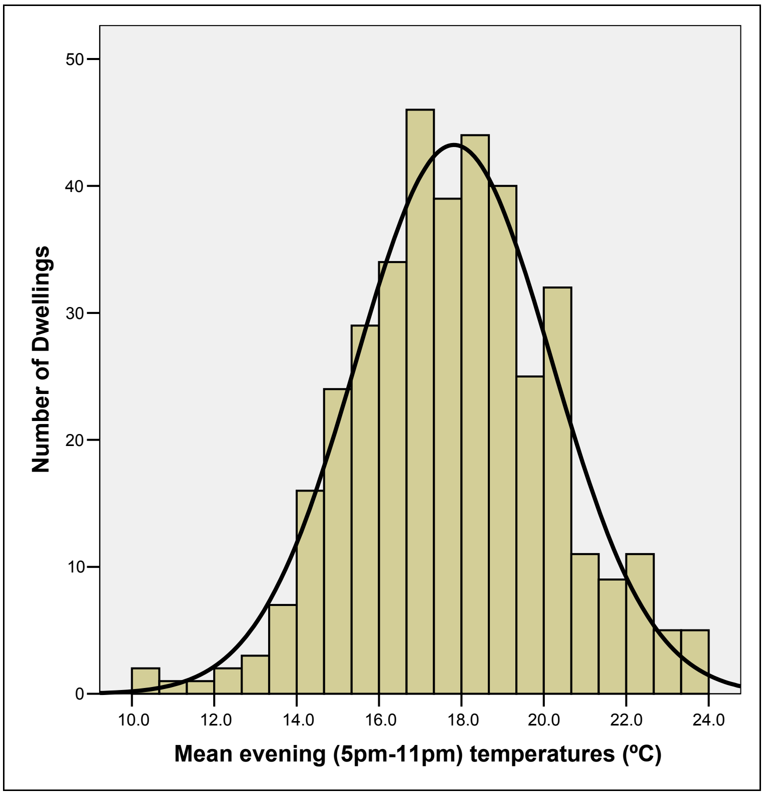

Figure 22: Winter evening living room average temperature distribution

Of the 386 HEEP dwellings for which mean winter evening living room temperatures could be calculated, only 68 (18%) had temperatures in excess of 20ºC and 34 (9%) over 21ºC. Figure 22 shows the distribution of winter living/family room mean evening temperatures among the HEEP dwellings. For Figure 22 the mean is 17.8, the Standard Deviation 2.37 and the count is 386.

Table 14 shows the below 16ºC dwellings are over-represented in the two lowest income quintiles. Analysis by the number of occupants found that one-person households are also over-represented in the below 16ºC group, while households with 3-4 occupants tend to be under-represented in this group. Dwellings below 16ºC are also more likely to be accommodating tenant households rather than owner-occupiers.

Equivalised income quintiles	Mean evening living room temp less than 16°C		Mean evening living room temp 16°C or more	
	n	%	n	%
Quintile 1: <= $15,653	24	32.4	49	18.1
Quintile 2: $15,654-$24,749	19	25.7	62	22.9
Quintile 3: $24,750-$35,000	7	9.5	53	19.6
Quintile 4: $35,001-$49,498	13	17.6	62	22.9
Quintile 5: $49,499 +	11	14.9	45	16.6
Total	***74***	***100***	***271***	***100***

Table 14: Equivalised income by at-risk mean temperatures

These associations between below 16ºC mean evening winter temperatures in living rooms and income, household size and tenure respectively are statistically significant. Houses with very cold winter living room temperatures are also more likely to be situated in urban rather than rural areas (Table 15).

Variables: Below 16ºC mean temperatures and:	Pearson chi-square statistic	DF	p-value
Equivalised incomes (n=345)	10.1	4	0.038
Household size (n=386)	11.3	3	0.010
Tenure (n=386)	5.5	1	0.019
Location (n=386)	4.6	1	0.032

Table 15: Socio-demographic variables and winter evening living room at-risk (<16ºC) mean temperature

Table 16 summarises the proportion of average weekly expenditure for the seven groups and, for the 'Domestic fuel and power' sub-group, both the proportion and average weekly expenditure were reported in the Household Economic Survey (HES).

As household incomes increase, the proportion spent on domestic fuel and power decreases, from 5.3% for the 1st quintile to 2.2% for the 5th quintile. However, while the average income increases by 660%, the expenditure on fuel and power increases by only 65%.

HES income quintile	1	2	3	4	5
Lower end	Open	$23,000	$37,900	$58,900	$87,600
Upper end	$22,999	$37,899	$58,899	$87,599	Open
Average	$11,500	$30,450	$48,400	$73,250	$87,600
Expenditure group and sub-group					
Food group	17.0%	18.4%	16.3%	16.7%	14.5%
Housing group	24.0%	23.7%	26.0%	25.1%	23.5%
Household operation group	15.6%	14.7%	12.4%	12.1%	11.5%
Domestic fuel and power	**5.3% $43.80**	**4.6% $51.60**	**3.4% $54.60**	**2.8% $59.10**	**2.2% $72.20**
Apparel group	2.5%	2.1%	3.4%	3.2%	4.3%
Transportation group	13.9%	15.5%	16.7%	15.5%	16.7%
Other goods group	10.2%	10.3%	10.8%	11.7%	11.5%
Other services group	16.8%	15.3%	14.5%	15.7%	18.0%
Total net expenditure	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 16: HES average weekly expenditure by income group of household

The HES collects expenditure data but nothing on conditions, notably temperatures, within the houses. What the HEEP data reveals is that while low income households appear to value increased warmth, they are unable to achieve warm indoor temperatures (despite expending proportions of their income on energy which would be considered overseas to place the household in the fuel poverty category). Moreover, the higher proportionate expenditure of low income householders does not assure those households a warm house or even a warm living room.

HEEP finds that households in dwellings with very cold indoor temperatures during winter (under 16ºC) appear to spend a greater proportion of their income on energy than the HEEP households overall. The households with very cold living rooms on average expend 5.6% of income in winter on energy compared to on average 4.3% of income for the total set of HEEP households.

There is a statistically significant relationship between equivalised income and self-reported winter energy expenditure (Pearson test, r = -0.621, p<001). Among the lowest income quintile of HEEP households, 28% expended 10% or more of their monthly income on winter energy, but none of the top three quintiles expended in excess of 10% or more of their income (Table 17).

Equivalised income quintiles	Winter energy expenditure <10% of monthly income		Winter energy expenditure ≥10% of monthly income		Total
	n	%	n	%	
Quintile 1: <= $15,653	46	72	18	28	64
Quintile 2: $15,654-$24,749	65	97	2	3	67
Quintile 3: $24,750-$35,000	52	100	0	0	52
Quintile 4: $35,001-$49,498	60	100	0	0	60
Quintile 5: $49,499 +	48	100	0	0	48

Table 17: Equivalised income quintiles by winter energy expenditure – HEEP households

Higher proportions of energy expenditure do not appear to be a guarantee of warmer temperatures. Analysis of the HEEP data found that the mean living room winter evening temperature for households expending *less* than 10% of their monthly income on energy is 1.3ºC higher than households expending 10% or more on energy. Households expending less than 10% of income have an average mean evening living room temperature during the winter of 18.1ºC. This compares to 16.8ºC in dwellings accommodating households expending more than 10% of their incomes on electricity in the winter months.

HEEP data shows that households in dwellings with winter indoor temperatures under 16ºC appear to spend a greater proportion of their income on energy than the HEEP households overall. These households on average expend 5.6% of income in winter on energy compared to on average 4.3% of income for the total set of HEEP households.

4.2 Temperature and energy use among Māori HEEP households

The number of Māori households in HEEP is small and, consequently, the data can not be statistically generalised to Māori households in New Zealand. This analysis of Māori households is largely descriptive, as the small sample size means that test variables have multiple categories and the cell sizes for the Māori households are too small to enable significance testing. Where the difference is statistically significant this is noted in the text.

Nevertheless, the experience of the HEEP Māori households does provide an opportunity to consider the importance of ethnicity as a determinant of energy end-use patterns, and the extent to which certain ethnic groups have particular energy end-use patterns because they tend to be over-represented in certain vulnerable socio-economic positions.

Applying Statistics NZ's definition of a Māori household as one in which one or more members identify themselves as having Māori descent, there are 61 Māori households within the total HEEP sample of 394 households.

Although HEEP is not a representative sample, the characteristics of the Māori HEEP households are consistent with national figures for Māori households. The Māori HEEP households tend to be larger and younger than the HEEP sample as a whole, and more likely to be over-represented among the lower income quintiles.

The number of people living in each of the 394 HEEP dwellings ranges from 1-11. While the range in size for Māori HEEP households is less (1-9 people), Māori HEEP households tend to be larger in size on average. The average household size for all households in the HEEP sample is 2.9, while the average household size for Māori households in the sample is 3.4.

The predominant household composition type in the 394 HEEP dwellings is the couple-with-children household. Those households make up 35.7% of the households, followed by couple-only households (31.3%) and one-person households at 13.3%. Data on household composition is available for 59 of the 61 Māori HEEP households. The predominant household composition type in the 59 dwellings with Māori HEEP households is the couple-with-children household (44.1%), followed by one-parent-children households (18.6%) and couple-only households (11.9%).

Figure 23 compares the household composition profile of all HEEP households with Māori HEEP households and with New Zealand households as recorded in the 2001 Census.

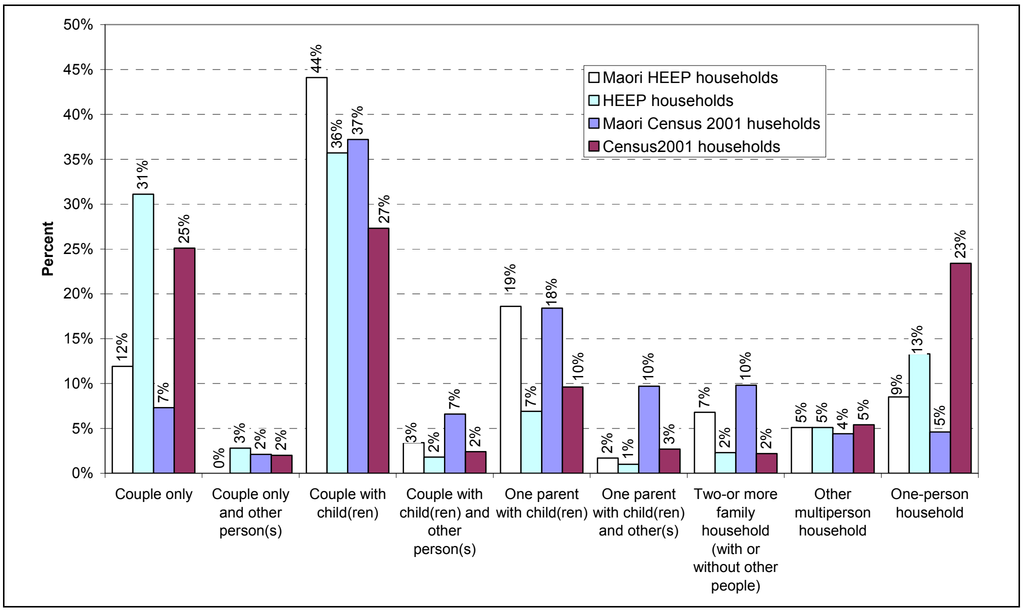

Figure 23: Household composition – HEEP & 2001 Census

Life stage analysis can be a useful tool for exploring assumptions about individuals or households by categorising them into groups based on criteria such as age or accomplishment of some life event, for instance graduating school or purchasing a first home. For the HEEP households there were some assumptions about the different behaviours of retired households compared to say households with young children. All HEEP households were divided into one of four life stages based on the age of the youngest person in the house. The four life stages are as follows:

- pre-school age (0-4 years)
- school age (5-14 years)
- working age (15-64 years)
- retirement age (65 years and over).

The household composition profile for Māori households within HEEP shows a higher proportion of households with young dependants. Around three-quarters (74.6%) of Māori HEEP households have household compositions including children compared to less than half (47.7%) of all HEEP households.

The proportion of Māori HEEP households with youngest members in the school age (5-14 years) category is more than double the proportion of these households in the wider HEEP sample. Consequently Māori HEEP households have much lower proportions of households in the working age and retirement age life stage households compared to the HEEP sample as a whole.

Figure 24 sets out the profile of all HEEP households and Māori HEEP households in relation to critical life stages associated with the youngest household member.

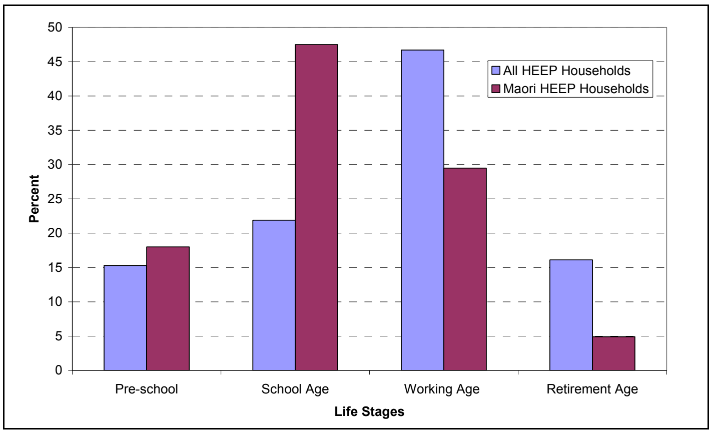

Figure 24: Age of youngest household member – all & Māori HEEP households

Just over a quarter of all HEEP households had no adult member (aged 15 or above) of the household in employment (25.3%), while 46.1% were households in which all the adult members were in employment. In the remaining households (28.6%) there was a mix of adults in employment and not-in-employment.

A fifth of Māori HEEP households had no adults in employment, while half were households in which all the adult members were in employment. The marginally higher proportion of Māori HEEP households with a household member in employment is likely to reflect the somewhat younger age structure of Māori households.

The Luxemburg method (Atkinson et al 1995) equivalised household income quintile boundaries for the HEEP houses are given at the start of this section. Analysis of the income data in relation to the 61 Māori HEEP households suggests Māori households are over-represented in the lower equivalised income quintiles and consequently under-represented in the upper income quintiles. Figure 25 shows the quintile for equivalised household income for the whole HEEP sample compared with households where one or more members of the households are Māori.

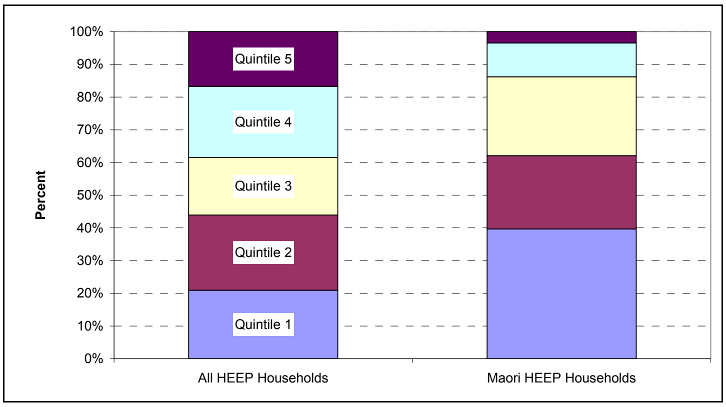

Figure 25: Equivalised household income – all & Māori HEEP households

Three bedroom houses are the most common house size among the 394 HEEP dwellings and also among the subset of Māori HEEP dwellings. However, on average, the Māori HEEP dwellings tend to be smaller than HEEP dwellings overall. The average floor area of the 394 HEEP dwellings is 121 m² compared to 106 m² for Māori HEEP dwellings. Moreover as Table 18 shows, despite having on average larger household sizes, Māori HEEP households tend to be clustered in dwellings with fewer bedrooms.

Size of house	Māori HEEP households*		All HEEP households^	
	n	%	n	%
<3 bedrooms	13	22.0	70	17.9
3 bedrooms	31	52.5	198	50.6
>3 bedrooms	15	25.4	123	31.5
Total	***59***	***99.9***	***391***	***100***

* Two missing cases ^ Three missing cases

Table 18: Number of bedrooms for Māori & all HEEP households

The majority of the 394 HEEP dwellings are over 25 years old. The Māori HEEP households tend to be over-represented among households living in pre-1978 dwellings (Table 19).

Age of house	Māori HEEP households*		All HEEP households^	
	n	%	n	%
Pre-1978	46	83.6	274	72.9
Post-1978	9	16.4	102	27.1
Total	***55***	***100***	***376***	***100***

* 6 missing cases ^ 18 missing cases

Table 19: Age of house for Māori & all HEEP households

Table 20 shows the majority of HEEP households have some level of ceiling or roof insulation, but Māori HEEP households are significantly over-represented among households that have none. Insulation, particularly in the ceiling or roof cavity, can result in increased indoor temperatures and more efficient use of energy. Thermal insulation has been mandatory in new houses since 1978 (Isaacs 1999).

All or part of roof insulated	Māori HEEP households*		All HEEP households^	
	n	%	n	%
Yes	36	62.1	296	80.0
No	22	37.9	74	20.0
Total	***58***	***100***	***370***	***100***

* 3 missing cases ^ 24 missing cases

Table 20: Roofing insulation status of house for Māori & all HEEP households

At 17.4°C the average evening winter living room temperature for Māori HEEP households is 0.4°C degrees cooler than the average for all HEEP households (17.8°C). Further analysis of evening temperatures confirms Māori HEEP households do tend to have a cooler evening living room temperature profile compared to HEEP households overall. Figure 26 shows the average winter (June to August) evening living room temperatures for all HEEP households and Māori HEEP households. The comparison of average temperature groupings in Figure 25 shows Māori HEEP households tend to be over-represented in average and colder-than-average households and under-represented among warmer-than-average households.

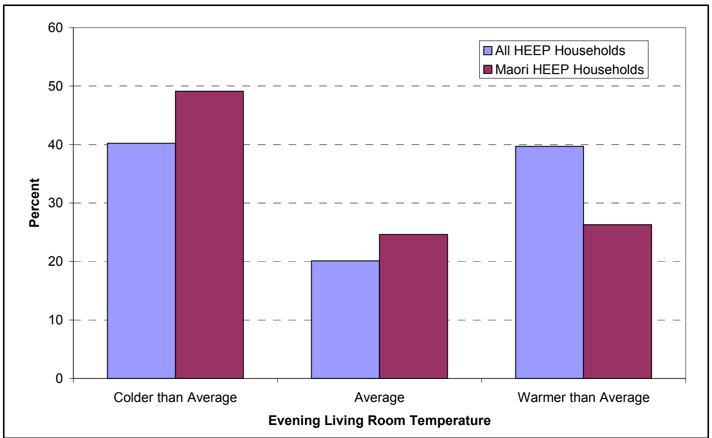

Figure 26: Winter evening living room temp – all & Māori HEEP households

When the 'colder-than-average' and 'warmer-than-average' dwellings are analysed, it is clear that 'cold' is the most common mean winter evening living room temperature category for Māori HEEP households (see Table 21).

Nearly half (49.2%) of Māori HEEP households have mean winter evening living room temperatures categorised as 'below average' or 'cold', compared with two-fifths of all HEEP households (40.2%).

Temperature	Māori HEEP households*		All HEEP households^	
	n	%	n	%
Warm	9	15.8	74	19.8
Above average	6	10.5	74	19.8
Average	14	24.6	75	20.1
Below average	12	21.1	76	20.4
Cold	16	28.1	74	19.8
Total	***57***	***100.1***	***373***	***99.9***

* 4 missing cases ^ 21 missing cases

Table 21: Winter evening living room temperatures for all & Māori HEEP households

Table 22 shows there appears to be some considerable variations in mean evening indoor winter temperatures by fuel type among the Māori HEEP households. Although the numbers of households are small, the mean winter living room temperatures for Māori HEEP households, particularly those heating predominantly with LPG or electricity, appear to be lower than for all HEEP households.

Fuel type	Māori HEEP households*		All HEEP households^	
	n	Temperature °C	n	Temperature °C
LPG	13	16.6°C	54	17.0°C
Electricity	16	16.5°C	114	17.2°C
Solid fuel	23	18.5°C	156	18.7°C

Table 22: Winter evening living room temperatures by fuel type for all & Māori HEEP households

Figure 27 shows there are no significant differences in the energy use profiles of Māori HEEP households as compared to all HEEP households.

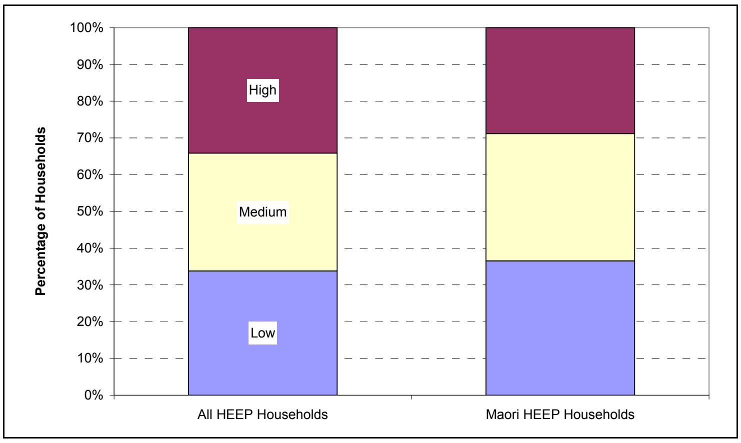

Figure 27: Total gross annualised energy use for all & Māori HEEP households

Although Māori HEEP households are slightly over-represented among low and medium energy households compared to all HEEP households, Figure 27 shows that overall the energy use profile for the Māori is broadly similar to that for all HEEP households. The mean annual gross energy use for all HEEP households is 11,223 kWh compared to 10,112 kWh for Māori HEEP households.

Figure 28 compares the heating energy use profile for all HEEP households with Māori HEEP households.

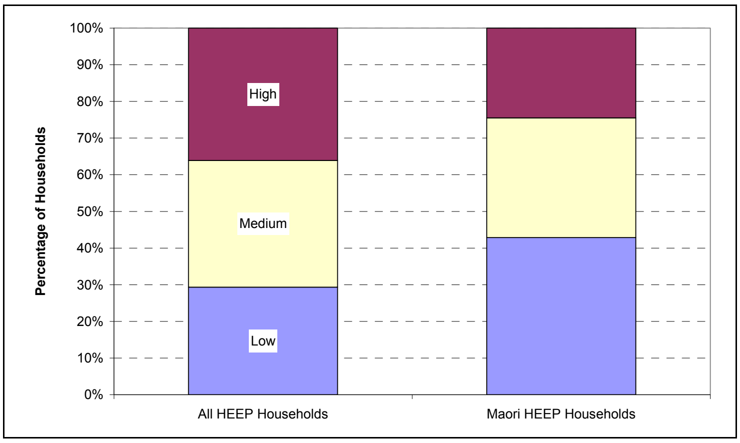

Figure 28: Total gross annualised heating energy use for all & Māori HEEP households

The mean annual gross heating energy use for all HEEP households is 3,827 kWh compared to 3,001 kWh for Māori HEEP households.

As Figure 28 shows, Māori HEEP households appear to be over-represented among low heating energy use households compared with all HEEP households.

Over two-fifths (42.9%) of Māori HEEP households are low heating energy use households compared with under one-third (29.4%) of all HEEP households.

Māori HEEP households are over-represented in the 'cold' winter evening living room category (Table 21). There are a range of negative health impacts associated with colder temperatures, as noted earlier. Condensation, damp and mould are associated with low temperatures. Damp and mould are associated with a range of illnesses including toxic reactions, allergies, inflammatory diseases, gastroenteritis and other infections (Bonnefoy et al 2004).

4.3 Solid fuel

Historically New Zealand households have relied heavily on solid fuels to heat their homes. The increased availability of electricity and gas in the second half of the 20th century resulted in a shift away from reliance on solid fuel. However, solid fuels continue to be used by a substantial proportion of New Zealand households to heat their dwellings. Census 2001 figures show over two-fifths of households (45%) report using wood and about 9% of households report using coal (either solely or in combination with other fuels) to heat their home.

In September 2005 National Environmental Standards for air quality in New Zealand came into effect. The national standards are aimed at reducing pollution and improving air quality by 2013. Traditionally the use of solid fuel in residential homes has been identified as a major contributor to poor winter air quality. In locations in which the occurrence of visible winter smog is common (such as Christchurch or Nelson),[6] concerns about the polluting effects of solid fuel use have prompted programmes to shift users to other forms of heating, usually electricity based. The rationalisation for these programmes has been two-pronged – air quality improvement for the local area with improved heating efficiencies and increased occupant comfort.

This approach has been based on a number of assumptions – most importantly that solid fuel heating is inefficient, associated with poor temperature performance, and represents a heating mode of the past with its appeal and use in gradual but inevitable decline. The evidence from HEEP, however, shows that the use of solid fuel is considerably more widespread than previously believed. Moreover, the indoor temperatures associated with solid fuel use in enclosed burners tend to be higher than those associated with other forms of fuel use. These findings raise both challenges and opportunities for all those concerned with energy use, the warmth of New Zealand dwellings, environmental protection and the health of New Zealanders.

Two tables have been prepared to compare the available historic data with the HEEP houses. For the purposes of this analysis, the reported fuel 'kerosene' has been taken as functionally equivalent to LPG – both are used in the main for portable space heating. Table 23 compares the proportion of houses reporting the main fuel used for heating from the 1961 to 1971 Censuses and the HEEP houses. There was a jump of 28% in the proportion of houses using electricity from 10% in 1961 to 38% in 1965, but this remains reasonably stable for the 1971 Census and in the HEEP houses. The proportion of houses using mainly solid fuel (coal, coke or wood) fell by 34% from 83% in 1961 to 49% in 1966, but remained almost the same for the 1971

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6 See www.ecan.govt.nz/Our+Environment/Air/ or www.mfe.govt.nz/issues/air/programme/.

Census. Between 1971 and the HEEP survey, houses using solid fuel as their main heating fuel fell a further 40% to only 10% of the houses.

Main fuel used for heating	Census 1961	Census 1966	Census 1971	HEEP
Electricity	10%	38%	42%	43%
Gas	2%	1%	1%	16%
LPG*	2%	3%	6%	31%
Solid fuel^	83%	49%	50%	10%
Other	2%	6%	0%	
Not specified or no heating	1%	3%	1%	

Table 23: Main heating fuel – 1961 to 1971 Censuses & HEEP

*Assuming 'kerosene' in 1961, 1966 and 1971 Censuses is functionally equivalent to an LPG heater.
^ Assuming 'space heater' in 1961 and 1966 Censuses is an enclosed solid fuel burner.

Table 24 reports all the fuels used in houses – using the results from the *Survey of Household Electricity Consumption 1971-72* (NZ Department of Statistics 1973), the 1976 though to 2001 Censuses and HEEP. It is interesting to note that over the 30 year period covered by the four data sources, New Zealand homes have reported using on average 1.75 fuel types for space heating. Thus, it would appear that the majority of New Zealand homes demonstrate the application of a distributed (heat) generation system by making use of more than a single heating fuel (most likely in order to provide resilience in case of one fuel supply proving problematic).

Table 23 showed that electricity was making a dramatic inroad into the use of solid fuel as the main means of heating – shifting from 10% to 42% in a decade. Table 23 shows that solid fuel was used in only 49% of dwellings in 1976 (whether as the principal or lesser importance heating fuel), compared to 83% reporting it as the main fuel in 1961. This is a major shift in fuel use, and at least in part reflects the promotion of electricity as a multi-purpose fuel.

Table 24 shows that solid fuel use (line in **bold**) increased from the 1976 to the 1986 Census, then started to trend down to the 2001 Census where it was used in 54% of houses. It is possible that this was reflecting a change in house construction – if newer houses were less likely to have a chimney, then they would be less likely to have an open fire or solid fuel burner.

<table>
<tr><th>Fuel type used to heat dwelling</th><th>1971/72 Household Electricity Survey</th><th>1976 Census</th><th>1981 Census</th><th>1986 Census</th><th>1991 Census</th><th>1996 Census</th><th>2001 Census</th><th>HEEP</th></tr>
<tr><td>Electricity</td><td>92%</td><td>81%</td><td>72%</td><td>79%</td><td>77%</td><td>77%</td><td>72%</td><td>75%</td></tr>
<tr><td>Reticulated gas</td><td>5%</td><td>4%</td><td>5%</td><td rowspan="2">9%</td><td rowspan="2">16%</td><td>12%</td><td>13%</td><td>13%</td></tr>
<tr><td>LPG (or kerosene or oil)</td><td>15%</td><td>10%</td><td>7%</td><td>22%</td><td>28%</td><td>34%</td></tr>
<tr><td>Solid fuel</td><td>59%</td><td>49%</td><td>51%</td><td>67%</td><td>60%</td><td>62%</td><td>54%</td><td>52%</td></tr>
<tr><td>Other</td><td>1%</td><td>7%</td><td>4%</td><td>3%</td><td>2%</td><td>2%</td><td>2%</td><td></td></tr>
<tr><td>No fuels used</td><td></td><td>1%</td><td>3%</td><td>1%</td><td>1%</td><td>2%</td><td>3%</td><td></td></tr>
<tr><td>Average fuels per house</td><td>1.73</td><td>1.51</td><td>1.40</td><td>1.57</td><td>1.56</td><td>1.75</td><td>1.70</td><td>1.74</td></tr>
</table>

Table 24: Heating fuels – 1971/72 Electricity Survey, Censuses & HEEP

[1] Assuming 'kerosene' reported in the 1971/72 Survey, 1976 and 1981 Censuses is functionally equivalent to an LPG heater. Reticulated gas and LPG were not separately reported in 1986 and 1991.

About 59% of the HEEP households have a solid fuel appliance available for their use (Table 25).

Solid fuel appliance available	Self-reported data*		Monitored data	
	n	%	n	%
Yes	226	58	231	59
No	167	42	163	41
Total	***393***	***100***	***394***	***100***

* 1 missing case

Table 25: Availability of solid fuel appliances in HEEP households

The most commonly available solid fuel appliance is an enclosed wood/coal burner. About one-quarter of those households with the facility to use solid fuel have an open fire, but a significant number of those households with an open fire also have an enclosed wood burner (Table 26). Observed data includes the data from the occupant survey, house audit and monitoring. HEEP recorded all open fires in the house, whether they could be used or not. Many open fires are unusable, with cracks in the bricks, non-functional grates, or chimneys that have been blocked up.

Solid fuel appliance type	Observed data	
	n	%
Enclosed wood/coal burner	171	74
Open fire	40	17
Enclosed wood/coal burner and open fire	19	8
Total	***230***	***99***

*1 missing case

Table 26: Solid fuel appliance types in HEEP households (observed data)

There are statistically significant differences in the availability of solid fuel by region, north to south split, climate zone and urban/rural split. Table 27 shows HEEP households in Northland, Auckland and Wellington are least likely to have a solid fuel (SF) appliance available.

HEEP households with a solid fuel appliance – vocational variable	SF appliance available		SF appliance not available	
	n	%	n	%
Regional Council area				
Northland	15	50	15	50
Auckland	55	48	59	52
Waikato	35	65	19	35
Bay of Plenty	21	75	7	25
Gisborne/Hawkes Bay	17	63	10	37
Taranaki/Manawatu-Wanganui	9	90	1	10
Wellington	21	43	28	57
Nelson/Tasman/Marlborough	16	89	2	11
Canterbury	21	62	13	38
Otago/Southland	21	70	9	30
Total	***231***	***59***	***163***	***41***
North vs South Island				
North Island	173	55	139	46
South Island	58	71	24	29
Total	***231***	***59***	***163***	***41***

Table 27: Availability of solid fuel appliances by location

Table 28 shows that households in warmer climates (NZS 4218:1996 Climate Zone 1) are least likely to have a solid fuel appliance available, while houses in cooler climates (Zones 2 and 3) have a very similar likelihood of having a solid fuel burner.[7]

HEEP households with a solid fuel appliance – NZS 4218 climate zone	SF appliance available		SF appliance not available	
	n	%	n	%
Climate Zone 1	75	49	78	51
Climate Zone 2	94	63	56	37
Climate Zone 3	62	68	29	32
Total	***231***	***59***	***163***	***41***

Table 28: Availability of solid fuel appliances by climate zone

Table 29 shows that households in rural areas are more likely than households in urban areas to have a solid fuel appliance.

HEEP households with a solid fuel appliance – urban vs rural	SF appliance available		SF appliance not available	
	n	%	n	%
Urban	155	52	145	48
Rural	76	81	18	19
Total	***231***	***59***	***163***	***41***

Table 29: Availability of solid fuel appliances by urban/rural area

Two housing variables have a statistically significant association with the availability of a solid fuel appliance – the age of the house (Table 30) and the number of bedrooms in the house (Table 31).

HEEP households with a solid fuel appliance – age of house	SF appliance available*		SF appliance not available^	
	n	%	n	%
Pre-1978	180	66	94	34
Post-1978	45	44	57	56
Total	***225***	***60***	***151***	***40***
	* 1 missing case		^ 12 missing cases	

Table 30: Availability of solid fuel appliances by age of house

Table 30 shows older houses (pre-1978) are more likely to have a solid fuel appliance available. Table 31 shows that large houses are more likely to have a solid fuel appliance available. Dwellings with 1-2 bedrooms are least likely to have a solid fuel appliance available.

[7] NZS 4218:1996 *Energy efficiency – housing and small building envelope* is called as an Acceptable Solution to the NZ Building Code Clause H. Zone 1 is the upper North Island, Zone 2 is the lower North Island, and Zone 3 is the Central North Island plateau and the entire South Island.

HEEP households with a solid fuel appliance – size of house	SF appliance available*		SF appliance not available^	
	n	%	n	%
<3 bedrooms	33	47	37	53
3 bedrooms	114	58	84	42
>3 bedrooms	83	68	40	33
Total	***230***	***59***	***161***	***41***

* 1 missing case ^ 2 missing cases

Table 31: Availability of solid fuel appliances by size of house

One-person households are the least likely to have a solid fuel appliance available. Households with two or more members are over one-and-a-half times more likely to have a solid fuel appliance available than single-person households. As could be expected with the lower levels of solid fuel appliance available in single-person households, retired households are significantly less likely to have a solid fuel appliance compared to other life stages. Solid fuel appliances appear to be most common in school age households followed by working age households (Table 32).

HEEP households with a solid fuel appliance – life stage	SF appliance available		SF appliance not available*	
	n	%	n	%
Pre-school	34	57	26	43
School age	58	85	28	33
Working age	114	62	69	38
Retired	25	40	38	60
Total	***231***	***59***	***161***	***41***

* 2 missing cases

Table 32: Availability of solid fuel appliances by life stage

Households with one or more members in employment are more likely to have a solid fuel appliance available than households where all members are unemployed. Although equivalised income does not appear to have a significant association with the availability of solid fuel appliances in the HEEP households, analysis does show that solid fuel appliances are more likely to be available to the lowest household income quintile (Quintile 1) and the highest two quintiles. However, there is a different distribution of equivalised income quintiles for urban households compared with rural households, and for pre-1978 households compared to post-1978 households, which may explain any apparent differences in availability by equivalised income.

Table 33 shows open fires are much more likely to be available but not used more than enclosed wood/coal burners. Indeed, the majority of those with only an open fire did not use it for heating.

Solid fuel appliance type	Appliance used*		Appliance not used		Total
	n	%	n	%	
Enclosed wood/coal burner	153	92	14	8	***167***
Open fire	18	47	20	53	***38***
Enclosed wood/coal burner and open fire	16	84	3	16	***19***

* 7 missing cases

Table 33: Solid fuel appliance type by use in HEEP households (observed data)

Of the 188 households using solid fuel, less than one-fifth (15.4%) rely solely on solid fuel to heat their home. As Table 34 shows, the majority are using a combination of electricity/gas and solid fuel. Nearly one-fifth of solid fuel users also use LPG for heating. It is likely that in many cases electricity/gas and LPG heating appliances are being used to heat other zones of the house such as bedrooms.

Fuel types used for heating	SF appliance used*		SF appliance not used^	
	n	%	n	%
Electricity/gas and solid fuel	122	65	0	0.0
Electricity/gas, solid fuel and LPG	31	17	0	0.0
Solid fuel only	29	16	0	0.0
LPG and solid fuel	5	3	0	0.0
Electricity/gas only	0	0.0	31	89
Electricity/gas and LPG	0	0.0	3	9
LPG only	0	0.0	1	3
Total	***187***	***101***	***35***	***101***

* 1 missing case ^ 2 missing cases

Table 34: Use of solid fuel appliances by mix of heating fuels for HEEP households with a solid fuel appliance

Table 35 shows the vast majority of HEEP households (98%) reporting use of a solid fuel appliance also report that its use involves multi-space/room heating including heating the living, lounge and dining areas of their house.

Area heated	n	%
Living rooms only	75	38
Whole house/all areas	63	32
Living rooms and service areas	38	19
Living rooms and bedrooms	17	9
Bedrooms only	2	1
Service rooms only	2	1
	197	***100***

* 3 missing cases

Table 35: House areas heated by solid fuel appliances for HEEP households using a solid fuel appliance (self-reported data)

While 63 households (nearly one-third) self-report that use of their solid fuel appliance heats the whole house, of the households monitored only 29 appear to be relying solely on solid fuel for their heating. This may indicate a high proportion of other heating being used for task-specific heating such as studying or workroom heating or for spot heating. Or it could indicate that despite a perception among respondents that solid fuel heating raises the temperature throughout their whole house, this is not always warm enough for comfort in all areas.

Analysis undertaken for the Year 8 Report (Isaacs et al 2004) highlighted significant differences in evening indoor temperatures, depending on the main fuel type used for heating. That analysis, updated in Table 36, shows houses heated with gas or solid fuel tend to be significantly warmer than electric and LPG-heated houses (using Kruskal-Wallis, X^2 = 35.6 on 3 DF, p <0.0001).

Fuel type	Number of households	Temperature °C	Standard error of the mean
LPG	54	17.0	0.2
Electricity	114	17.2	0.2
Gas	36	18.1	0.4
Solid fuel	156	18.7	0.2

Table 36: Winter evening living room temperatures by heating fuel type for most used heating appliances

The earlier analysis also indicated significant variations in achieved evening indoor temperatures for different types of heating appliances. In relation to solid fuel, analysis shows the type of solid fuel appliance used results in clear differences in average evening indoor temperatures. As Table 37 shows, households using open fires tend to have evening living room mean temperatures lower than homes heated with an enclosed solid fuel burner. The evening winter living room mean temperature for households using an enclosed solid fuel burner is 18.8°C, compared with households using an open fire (15.9°C) and those using both an enclosed wood/coal burner and/or an open fire (16.4°C). These differences are statistically significant (using Kruskal-Wallis, X^2 = 31.8 on 2 DF, p <0.0001).

Solid fuel appliance type	Number of households*	Temperature °C	Standard error of the mean
Enclosed wood/coal burner	153	18.8	0.2
Open fire	18	15.9	0.4
Enclosed wood/coal burner and open fire	15	16.4	0.6

* 1 missing case

Table 37: Winter evening living room temperatures by available solid fuel appliance type for households using solid fuel

With the exception of open fires, analysis of HEEP data suggests that overall homes using solid fuel burners tend to be warmer than those using other types of heating appliances. Although further analysis may be required, this appears to be true regardless of the thermal performance of the building (evening winter living room temperatures for HEEP post-1978 houses are on average 1.0°C warmer than pre-1978 houses). Households using enclosed solid fuel burners tend to be warmer-than-average, regardless of house age.

5. SUMMER TEMPERATURES

Few New Zealand houses are heated or cooled during the summer months (December, January and February). In part this is due to only 4% of HEEP households having air-conditioners or reverse cycle heat pumps. To complicate the issue 3% of the HEEP houses heat throughout the whole year, although these tend to be in the cooler southern parts of the country.

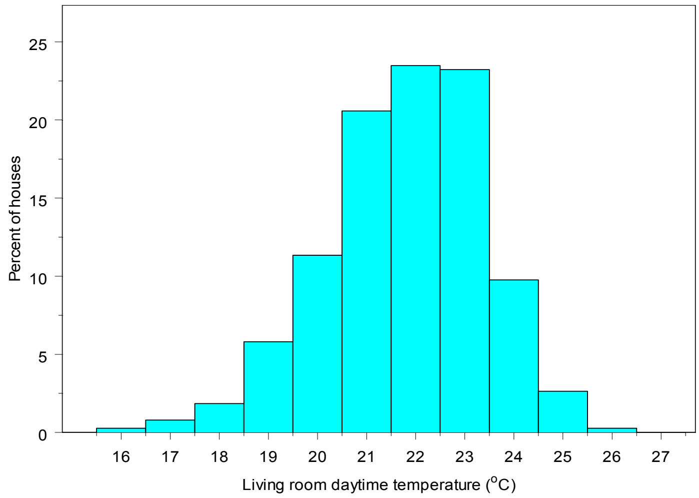


Figure 29: Mean living room temperatures

Figure 29 shows the distribution of living room mean daytime (9 am to 5 pm) temperatures over the summer months for all HEEP houses throughout New Zealand. Eighty-five percent of the houses have a mean living daytime temperature between 20°C and 25°C, while less than 1% are over 25°C and just over 14% are under 20°C. HEEP analysis has found that the average mean daytime living room summer temperature is 21.8°C, the maximum mean temperature is 25.9°C, and the lowest mean temperature is 16.3°C.

Figure 30 shows the distribution of the proportion of time between 9 am and 5 pm that the living room temperatures are under 20°C, between 20°C and 25°C, and over 25°C.

Nearly four out of five houses (78%) spend more than half of the day between 20°C and 25°C. Of the other houses (22%), over half of them (13%) spend more than half the day below 20°C. However, 1% spend over 50% (four hours per day) of the summer daytime above 25°C. This 1% can be considered to be at uncomfortably high temperatures for over half the day.

Over all the houses, the majority (80%) spend less than 25% of the summer daytime (two hours per day) at temperatures over 25°C. The majority of the houses are between 20°C and 25°C for the majority of the time. As we have not collected data on the occupants' perception of comfort or other climatic factors (such as air changes per hour, humidity and clothing levels) it is not possible to definitively conclude that these are comfortable temperatures. However, these would be considered comfortable based on overseas definitions.

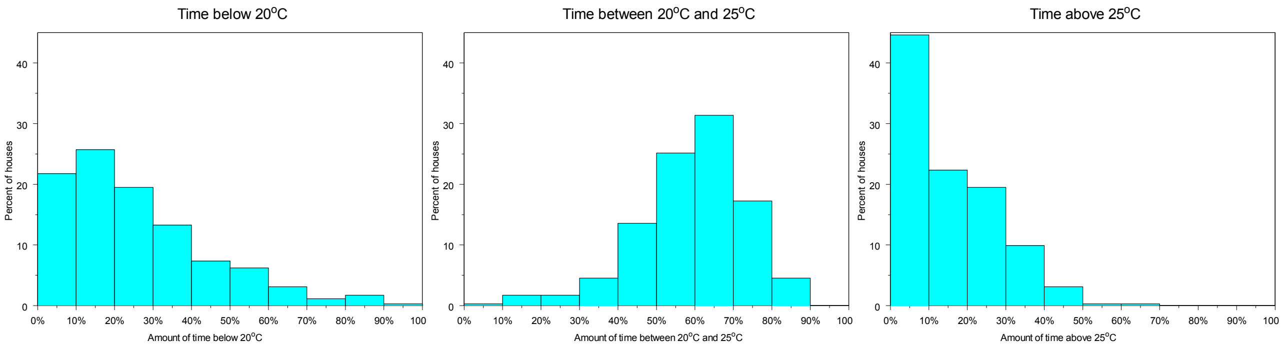


Figure 30: Time spent at given temperature ranges

Table 38 gives the mean temperatures for four different periods of the day for the ambient external temperature, the bedroom and the living room. Table 38 shows the bedroom is always slightly cooler than the living room. Analysis of the HEEP houses has found that New Zealand houses have randomly orientated windows (on average about 25% of the total glazing is in each compass direction), with living rooms also being randomly orientated. This may explain the small temperature difference between living rooms and bedrooms in summer when little or no heating is applied, as neither can be guaranteed to benefit from the sun.

The periods when the bedroom temperature is closest to the living room temperature are the night (midnight to 7 am) and the morning (7 am to 9 am) – these are times when the bedroom is likely to be occupied and therefore have internal heat gains (from TVs, clock radios, pets and human bodies). The bedroom also has less of a temperature decrease from evening to night than the living room, again likely to be caused by the internal gains.

The moderating effect of the house can be seen in the 3.9°C mean temperature range for the living room (from 19.2°C to 23.1°C), which is not as large as the 5.6°C ambient temperature range (from 14.5°C to 20.1°C). Houses with high levels of thermal mass (which will have a stabilising effect on temperatures e.g. concrete or double wall brick – see Donn and Thomas 2001) would be expected to have a lower temperature range. However, this could not be confirmed as there are only two such houses in the sample. Most New Zealand houses are timber framed with an external veneer and are considered to be low thermal mass.

	Mean temperatures for all houses			
	Morning 7 am to 9 am	**Day 9 am to 5 pm**	**Evening 5 pm to 11 pm**	**Night Midnight to 7 am**
Living room (°C)	19.2	21.8	23.1	20.3
Bedroom (°C)	19.1	21.2	22.6	20.1
Ambient (°C)	15.8	20.1	17.9	14.5

Table 38: Mean temperature during time periods

This distribution of living room and bedroom temperatures and the shift between morning and daytime is shown in Figure 31. The living room temperature distributions are shown in the two graphs on the left and the bedroom temperature distributions are shown with the two graphs on the right. The top two graphs show the distribution of morning temperatures and the lower two show daytime temperatures.

The range of temperatures for both the bedroom and the living room during the morning is approximately 14°C to 24°C, with a mean of 19°C. During the daytime the temperatures range from 16°C to 26°C and means of 21°C for both the bedroom and the living room – an increase in both the range and the mean of 2°C from the morning (shown by the dotted line and arrow on Figure 31).

The shapes of both the morning temperature distribution histograms for the living room and bedroom are similar, with the bedroom mean 19.1°C and the living room 19.2°C.

The temperature range for bedrooms is slightly lower than for living rooms, but the overall shape is very similar, with the day means of 21.1°C for the bedroom and 21.8°C for the living room.

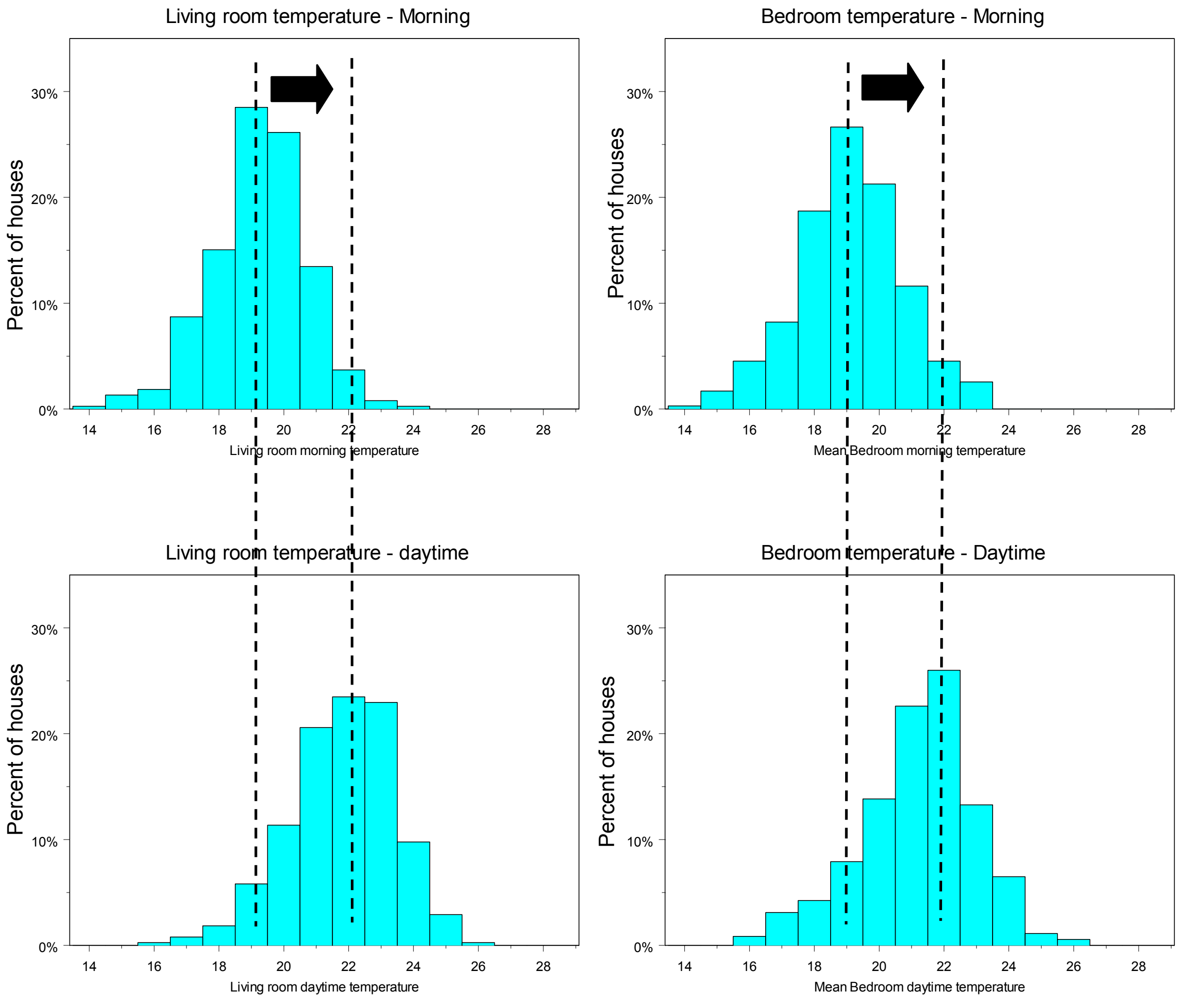


Figure 31: Living and bedroom temperature distribution for morning and day

5.1 Maximum temperatures

The time of day that the maximum living room temperature is reached and the living room maximum temperature distribution are plotted in Figure 32 and Figure 33.

The temperatures reported here are the maximum temperatures reached over the three months of summer. Data from 14 houses (3.5%) was removed from the analysed sample due to the maximum temperature being recorded when the house was being heated – often late at night – at times with the use of a solid fuel heater (producing hot water) resulting in temperatures above 40°C! However, in other houses lacking the use of the solid fuel burner to heat water, there is no obvious reason why living rooms should be heated to such high temperatures during the summer.

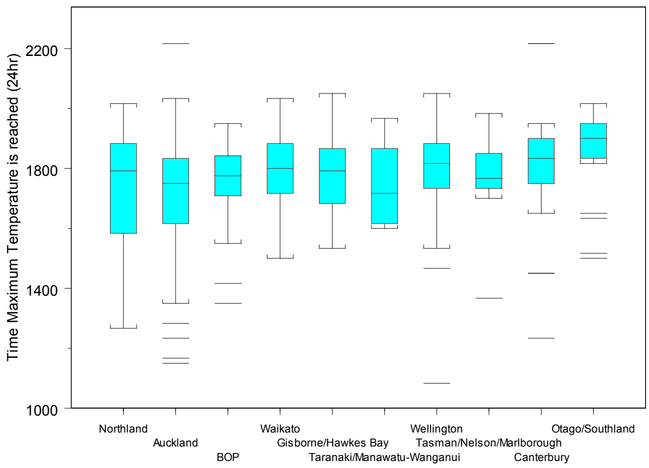


Figure 32: Time of maximum living room temperature by Regional Council

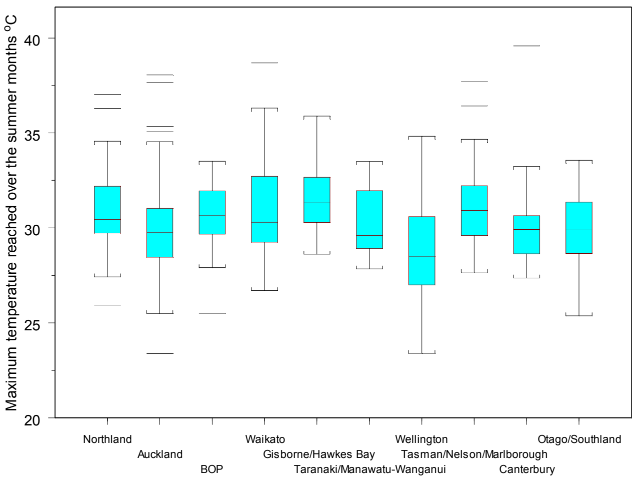


Figure 33: Maximum living room temperature by Regional Council

On average, the maximum temperature in the living room is reached at 5.40 pm, although the time of day varies by region (as seen in Figure 32).

Auckland (in the north) has a mean time of maximum temperature of just after 5 pm and the Otago/Southland region has a mean time of 6.40 pm. The sunset at the start of January varies from 7.43 pm in Auckland (36° 52' S 174° 45' E) to 8.42 pm in Invercargill (46° 25' S 168° 21' E). Although there are still outliers, the range of times is closer the further south the region.

The distribution of the maximum summer temperatures is plotted in Figure 33 by region. This variation is not a simple north to south variation, but clearly depends on other factors which may include:

- **regional geography** – both Wellington and Dunedin are hilly with some houses getting little or no direct sun inside the house. Large variations in temperatures can be seen in these regions
- **sun angles, sunrise and sunset times** – the sun sets later in the far south than the north and rises earlier in the far north country due to it being further east
- **house variations** – age (proportion of older/newer houses), window sizes and

orientation, construction and shading devices etc

- **sunshine hours** – these vary throughout the country with the upper South Island (Tasman/Nelson/Marlborough) having the highest sunshine hours, followed by the east coast of the North Island (East Coast/Hawkes Bay). Of the HEEP locations, Dunedin has the lowest sunshine hours with Invercargill next – both of these locations are in the Otago/Southland region (NIWA 2006).

5.2 Influences on indoor temperatures

The main drivers of summer living room daytime temperature have been found to be the climate and the house age.

5.2.1 Climate/regional differences

The differences in mean daytime living room temperature by Regional Council can be seen in Figure 34 (the black squares show the mean ambient daytime temperature for the region). It is clear that the warmer the climate, the warmer the living room temperature. For example, the median living room daytime temperature in Northland is 22.5°C compared to 19.5°C in Otago/Southland (3°C difference).

Figure 34 shows the mean daytime (9 am to 5 pm) temperatures over the summer months for HEEP houses throughout New Zealand. The houses are grouped by Regional Council or groups of these Councils when there are small numbers of monitored houses in their regions. The graph is ordered from the north to the south (left to right); this shows how the warmer climate in the north affects the interior temperature compared to the colder southern climate.

Figure 34 shows that the mean daytime summer ambient temperatures are similar in the southern-most region of the North Island (Wellington) and the northern-most regions in the South Island (Tasman/Nelson/Marlborough). This is at least in part a function of geography – both Nelson and Wellington are at 41°S.

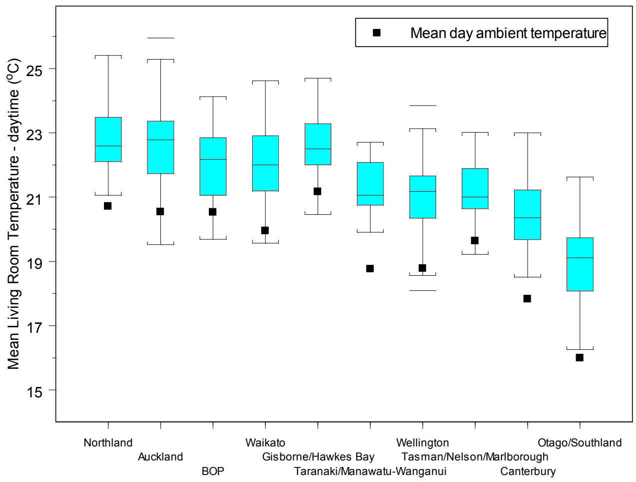


Figure 34: Mean living room daytime temperatures by Regional Council

The means of the daytime living room mean temperatures shown in Figure 34 range from about 20°C to about 23°C, apart from Otago/Southland with a mean of 16°C.

Analysis of the data shows that for each increase of 1°C for the average external temperature,[8] the mean house temperature increases by 0.81°C.

There is a 4.5°C difference between houses in Kaikohe (18.8°C mean external temperature) and houses in Invercargill (13.4°C mean

[8] Average external temperatures were calculated using NIWA CLIDB temperatures for the year the house was monitored.

external temperature) for summer daytime temperatures. Using climate alone this accounts for 68% of the variance (r^2 = 0.68, p-value = 0.0000).

5.2.2 House age

Newer houses are warmer than older houses (as seen in Figure 35). This difference is statistically significant (p-value 0.0000). It should be noted that the 'Decade house built' is the reported decade of original construction, and that many of the older houses have been significantly modified.

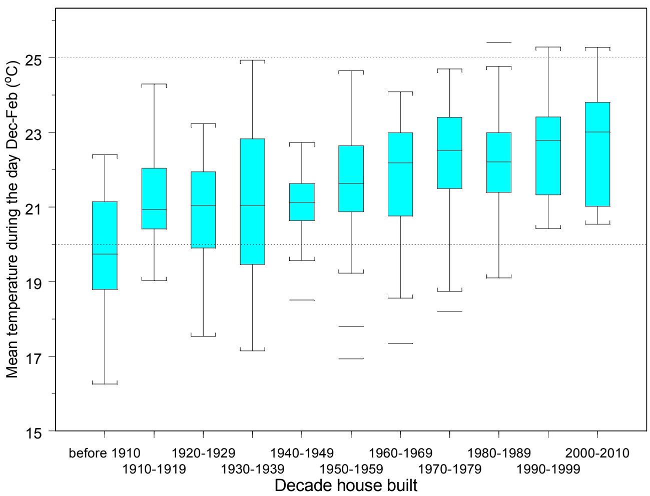


Figure 35: Summer temperatures by house age

The mean summer living room temperatures show a trend of increasing by 0.25°C per decade. This gives a difference of 2.5°C between houses built at the beginning and the end of the 20th century.

The dotted lines in Figure 35 are at 20°C and 25°C. Apart from the pre-1910 houses, the mean temperatures for all house ages are within this range. Houses built from 1990 onwards all have a mean daytime living room summer temperature of above 20°C, but the average temperature in this group is close to 23°C with extreme means above 25°C.

Examination of the difference between the living room temperature during the day and the ambient temperature found that as the house reduces in age (i.e. newer houses) there is an increase in the inside-to-outside temperature difference of 0.22°C per decade. This is not unexpected as newer houses are better insulated. There is also a climatic driver in this temperature difference, but together the two only account for 11% of the variance (r^2 = 0.11, p-value = 0.0000).

One issue not explored here, but of concern, is the possible impact of higher summer temperatures due to either climate variability or climate change. As the newer houses tend already to be warmer than the older houses, their adaptation mechanisms to increased temperatures are potentially more problematic. Air-conditioners in New Zealand are becoming more and more popular, with one supplier reporting increases in sales of up to 35% a year (Ninness 2006). If they are used to reduce high summer temperatures, this will have undesired impacts on the electricity system.

5.3 Model of summer living room temperatures

The analysis has been used to develop a simple model of summer temperatures. Equation 1 links the average external temperature for the summer months and the house age to model the expected summer daytime mean temperatures. Linear modelling found that these two variables account for (r^2 = 0.69) of the summer temperature variations (p-value = 0.0000). This equation is for the mean temperature over December, January and February for between 9 am and 5 pm.

$$SummerLivingRoomTemp. = -12.62 + YearBuilt \times 0.009 - AveExtTemp \times 0.76$$

Equation 1

Where:
YearBuilt = year the house was built e.g. 1987
AveExtTemp = average external temperature for the months of December, January and February for the year that the house was monitored.

Separate testing has found that the house age and climate are independent.

Using these two variables (house age and external mean temperature) for other times of the day (e.g. morning, evening and night) explain 60-69% of the variation, and explain 74% of the variation for a 24 hour mean temperature.

The house age without the average external temperature explains 14% of the variation in daytime living room temperatures.

5.4 Why are new houses warmer?

HEEP analysis has already shown that newer houses are warmer in both winter (Isaacs et al 2004) and summer. There are a number of reasons that could be causing this e.g:

- **improved thermal performance** – since 1978 new houses are insulated
- **airtightness** – newer houses are less 'leaky'
- **increased glazing area** – a possible trend to increased use of glass
- **larger floor area** – permit trends are showing an increasing floor area
- possibly **better orientation of windows** for passive solar heating – although no clear indication of this can be found in the HEEP sample
- **lower ceiling heights** leading to lower room volumes
- **reduced or no eaves** – due to architectural trends
- **higher income –** of the occupants
- **northward shift** – newer houses more likely to be built in a warmer climate.

Using the HEEP sample, some of these options were explored to examine their impact on summer temperatures.

5.5 Thermal insulation

The actual thermal performance of house components (roof, wall, floor, windows) was not measured. It can, however, be assumed that post-1978 houses are likely to have a higher thermal performance than pre-1978 houses as houses built from 1978 onwards were required to have insulation at construction. The difference between pre- and post-1978 houses is significant (p-value = 0.0004) for the summer day temperatures. Although only 5% of the variation in the temperatures is explained from this, when including climate, 50% of the variation (p = 0.000) in daytime living room temperatures is explained. This is less that the 69% explained by house age and climate, which suggests that there is more than just the difference in the levels of thermal insulation in pre- and post-1978 houses that affect the summer living room daytime temperatures.

5.5.1 Airtightness

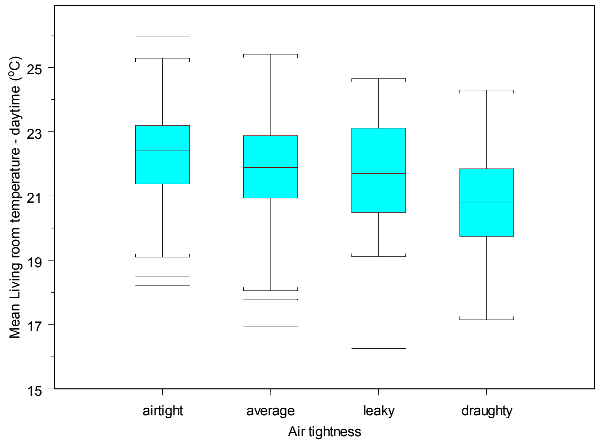


Figure 36: Mean living room temperature by airtightness

A rating of each house's airtightness was recorded during the HEEP occupant survey. Four options were provided, ranging from 'airtight' to 'draughty'. As this is a self-reported rating the accuracy is unknown, as is the consistency between houses.

The reported airtightness is plotted against mean living room daytime temperature in Figure 36. This shows that as airtightness increases, the mean living room daytime temperature also increases. However, when the outside temperature is taken into account, it overwhelms the influence of the reported airtightness. This may be due to the ability of occupants to easily alter the ventilation rate by opening or closing windows and doors. As there are many influences on door and window opening, it has proved impossible to predict the air change rate for any given house.

5.5.2 Glazing and floor area

The proportion of glazing to floor area increases with the age of the house (as shown in Figure 37).

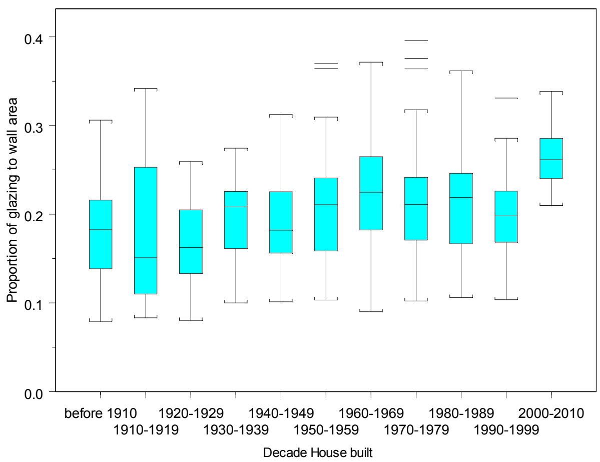


Figure 37: Glazing to wall area ratio by decade house built

There is more than just glazing influencing the increasing temperatures. There is a large increase in the amount of glazing in the houses built from 2000 onwards which cannot be seen in temperatures. There is no increasing trend in glazing for the years 1950s to 1990s, yet temperatures are increasing during this time (see Figure 35).

Solar glazing (west, north and east facing glazing) has been looked at separately, but there is no obvious relationship between large solar glazing areas and high temperatures.

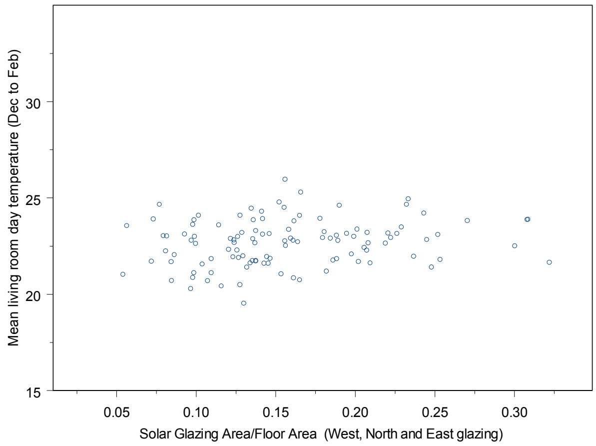


Figure 38: Solar glazing ratio vs Auckland living room temperatures

Figure 38 shows an example of preliminary work with the solar glazing area as a proportion to floor area on the X-axis and the mean daytime living room temperature on the Y-axis. This graph plots just the 114 houses in the Auckland area, so all the houses have a similar climate.

The expected pattern would be that the higher the ratio of the solar glazing area to the floor area, the higher the living room temperatures. This is not the case in Figure 38.

The data has been explored regionally, using average and maximum temperatures achieved at different periods of the day. Orientation of the living room, shading, sunshine hours and the glazing in both the proportion to floor and wall area are just some of the possible influences that have been explored. However, each has shown very little difference to the overall 'flat' pattern of temperatures as shown in Figure 38.

One issue that remains to be explored is the influence of occupants. It may be possible that through the control of windows or fans (ventilation), and the control of shading, occupants have been able to limit the temperatures reached in their houses.

5.6 Discussion

This work has examined the HEEP summer (December to February) temperature data. As few New Zealand houses are cooled (air-conditioned) during the summer, this represents a large sample of naturally ventilated houses, with the ventilation controlled by the occupants' use of windows and doors.

The majority of houses (80%) spend less than one-quarter (i.e. under two hours) of the summer daytime (9 am to 5 pm) with living room temperatures over 25°C. Most living rooms are between 20°C and 25°C for the majority of the time. As there has been no measurement of 'comfort' temperatures for New Zealand, it can only be concluded that based on overseas norms these would appear to be comfortable.

On average, bedroom temperatures are lower than living room temperatures – by as little as 0.1°C in the morning (7 am to 9 am) and as much as 0.6°C during the day (9 am to 5 pm). Inside temperatures have a smaller temperature range than the ambient, showing the temperature stabilising benefit of even low thermal mass construction.

Maximum temperatures are not only driven by solar radiation; the use of solid fuel burners led to indoor summer temperatures above 40°C in some houses. Excluding such houses, the maximum temperature is reached by 5.40 pm, although regional variation ranges from 5 pm (Auckland in the north) to 6.40 pm (Otago/Southland in the south). The variation is not a simple north to south issue, as other factors would appear to be involved, including house age.

The house age (represented by decade of construction) and the local climate (the average external temperature over summer) have the largest impacts on the summer daytime living room temperatures. Together they explain 69% of the variation in mean summer living room day temperatures. A simple model has been prepared based on these two variables.

The mean summer living room temperatures show a trend of increasing by 0.25°C per decade. This gives a difference of 2.5°C between houses built at the beginning and the end of the 20th century.

Selected reasons for newer houses being warmer have been explored. The influence of house airtightness (occupant reported) has been found to be marginal, as has the presence of thermal insulation. No obvious relationship has been found between large areas of solar (west, north and east facing glazing) and high temperatures.

Occupant influence also looks to be significant, but has not been quantified. Thermal calculation shows that houses behave differently without occupant influences e.g. opening and closing windows.

Although climate change is not a focus of this work, the local climate clearly influences the interior temperature. New houses are already warmer than older houses, so a 2-3°C temperature rise, possibly due to climate change, could make many of the newer houses uncomfortably warm. This problem is amplified with the houses that are being built today being 2.5°C warmer than those built a century ago. There is the danger that the occupants of these newer houses could become reliant on air-conditioning, with the resulting higher energy use forming a positive feedback loop into the mechanism of climate change. This is clearly an undesirable result.

6. WINTER TEMPERATURES

Past HEEP reports have reported on heating seasons (Isaacs et al 2005) and winter temperatures and heating patterns (Isaacs et al 2004). This section gives an overview of winter temperatures and explores some of the key influences. Winter is defined as the months of June, July and August, and evening is from 5 pm to 11 pm.

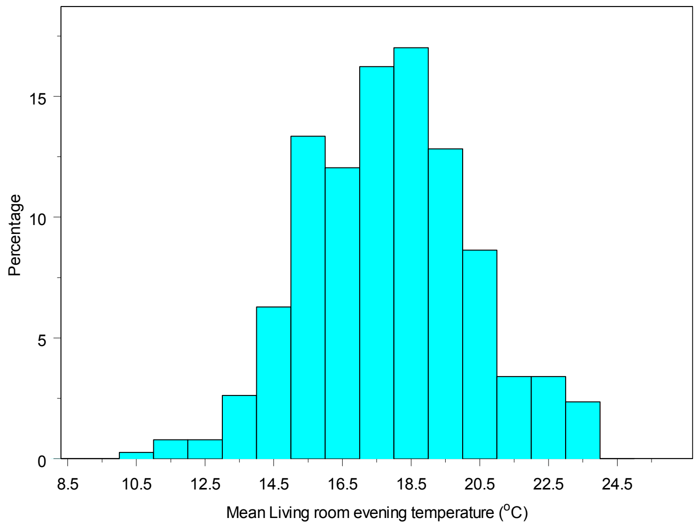


Figure 39: Distribution of winter evening living room temperatures

The distribution of living room evening temperatures can be seen in Figure 39 over the winter months. The mean and median temperature is 17.9°C. The maximum mean is 23.8°C and the minimum mean temperature is 10°C.

Table 39 gives the mean temperatures for the four different periods during the day for the living room, bedroom and ambient temperature. During the day, the bedroom is 2.2°C warmer than outside and the living room averages 3.8°C warmer than outside. These mean temperatures fail to achieve the WHO optimum indoor temperature range of between 18°C to 24°C (WHO 2003).

The mornings are the coldest time inside the average New Zealand house, although the coldest time outside is overnight. The evenings are the warmest (this is also the most common heating time). The bedrooms on average always seem to be slightly lower than the living rooms – at the most there is a difference of 3.8°C which occurs during the evening. This is most likely caused by heating occurring in the living room and typically very little or no heating in the bedrooms. The time periods are:

- **Morning**: 7 am to 9 am
- **Day**: 9 am to 5 pm
- **Evening**: 5 pm to 11 pm[9]
- **Night**: midnight to 7 am

	Mean temperatures (°C)			
Room	**Morning**	**Day**	**Evening**	**Night**
Living room	13.5	15.8	17.8	14.8
Bedroom	12.6	14.2	15.0	13.6
Ambient	7.8	12.0	9.4	7.6

Table 39: Mean temperatures: living room, bedroom and ambient

[9] The hour from 11 pm to 12 pm is not included due to software limitations.

Table 39, which shows the mean temperatures in winter, can be used to explore the changes between different periods of the day for the average living room, the average bedroom and the mean external temperatures. The mean living room temperature increases during the morning and day periods, but drops in the evening and overnight. This is a slight delay compared to the ambient temperature where the temperature drops between day and evening, and drops again between evening and night. During the day the peak ambient temperature occurs, but the peak living room temperature generally occurs during the evening period. The average time the peak temperature is reached in all houses is 5.48 pm, and there is little regional variation.

The evening heating results in increasing temperatures during both the day and evening. Only 15% of houses heat the bedroom during the night, but when coupled with the small heat gains from the occupants (and the TV, clock radio, any pets etc) the bedroom temperatures become closer to the living room temperatures overnight and during the morning. During the day the temperature difference between the two rooms is 1.6°C.

6.1 Influences on winter indoor temperatures

Occupants heat their houses, so the heating schedule plays a big part in the internal temperatures. The climate, the fuel and the heater type used in the house are also important for achieving higher temperatures, as is the age of the house and the level of thermal insulation.

6.1.1 Climate

Figure 40 shows the mean evening living room temperatures and the ambient evening temperature by region from north to south. Figure 40 shows a trend from north to south, although it is not straightforward. There are statistically significant differences between the regions, but these are not only related to the climate.

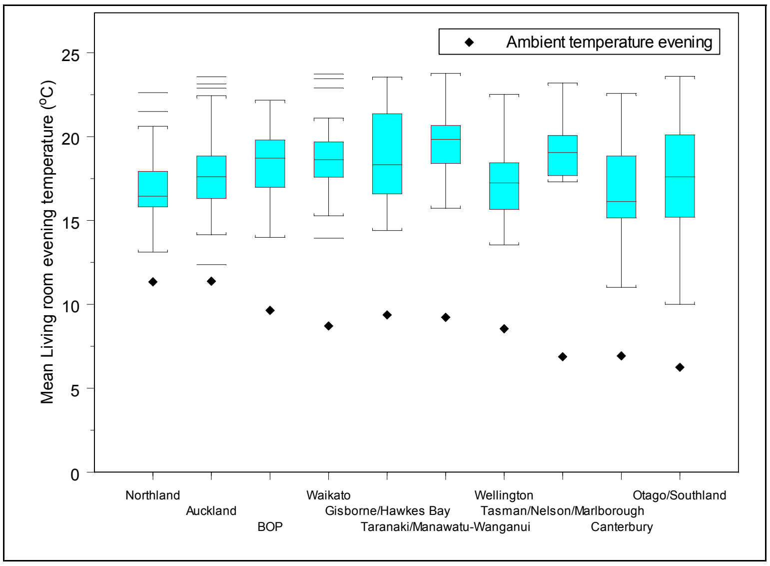


Figure 40: Mean winter evening living room and ambient temperature by Regional Council

Northland has a lower median ambient evening temperature (Figure 40 black diamonds) than the Otago/Southland with a heating season of over eight months. Houses in the north heat for a much shorter time than those in the south. They also generally have less efficient (open fires) and less powerful heaters.

There is a significant difference between the Regional Councils (p-value = 0.0000022).

6.1.2 Heating fuel and heater type

The type of heating is an important factor in the achieved temperatures. Table 40 shows average winter evening living room temperature by heater type. Living rooms heated by open solid fuel fires are coolest, averaging 16°C (61°F), followed closely by portable electric heaters. Rooms heated by enclosed solid fuel burners are the warmest, averaging 18.8°C (66°F).

Heater type	Temperature °C	Std. error of mean °C	Sample count
Open solid fuel	16.0	0.6	11
Electric	16.9	0.3	83
LPG	17.0	0.2	54
Fixed electric	17.8	0.3	18
Heat pump	18.0	0.4	4
Gas	18.1	0.5	28
Gas central	18.3	0.6	8
Solid or liquid fuel central	18.5	0.7	2
Enclosed solid fuel	18.8	0.2	142

Table 40: Winter living room evening temperatures by heater type

Table 41 shows for each heating fuel type the percentage of time the average winter evening living room spends below 16°C, in the range of 16°C to 20°C, and above 20°C. The heating system may be unit heaters (e.g. a free-standing LPG heater) or whole-house central heating (e.g. natural gas ducted air central heating).

Heater fuel	<16°C (%)	Std. error of mean	16-20°C (%)	Std. error of mean	>20°C (%)	Std. error of mean	Sample count
LPG	34%	3%	53%	3%	13%	2%	54
Electricity	33%	3%	51%	2%	16%	2%	103
Natural gas	22%	5%	51%	4%	27%	5%	35
Solid fuel	23%	2%	41%	2%	36%	2%	151
All houses	28%		47%		25%		328
NA	34%	4%	46%	3%	19%	4%	39

Table 41: Living room winter evening temperature distribution

Table 41 shows that houses heated by solid fuel burners are the warmest and for the longest time, with 77% of the time above 16°C. LPG and electrically heated houses are the coolest, being above 16°C only 66% of the time.

Although the costs of the different fuels may be relevant, the 'size' of the heater is likely to be of greater importance. Solid fuel burners are capable of producing large amounts of heat output, although it is difficult to control. Typically, solid fuel burner heat output ranges from 4 kW to 25 kW, but this is in ideal conditions. A one bar electric heater is 1 kW. Normally the HEEP houses were found to run their solid fuel burners between 3-5 kW. This could explain the high numbers of solid fuel houses spending time above 20°C.

The highest living room winter temperature measured in a HEEP house was 42°C – which is warmer than any temperature reached during summer – and this house was heated by a solid fuel burner.

Just under one in five houses (18.5%) reached maximum temperatures above 30°C in winter (81% of these had enclosed solid fuel burners). Almost half the houses (44.5%) reached maximum winter evening temperatures above 25°C.

6.1.3 House age

There is a strong relationship between house age and the winter living room evening temperature (Figure 41). This plot shows a steady increase in temperature as the houses become younger i.e. the older houses tend to be colder. There is an average rate of fall 0.20±0.05°C per decade, with a very high statistical significance (p-value 0.000045). This result is without considering any retrofitted thermal insulation, the heating fuel, region, or occupants' heating patterns.

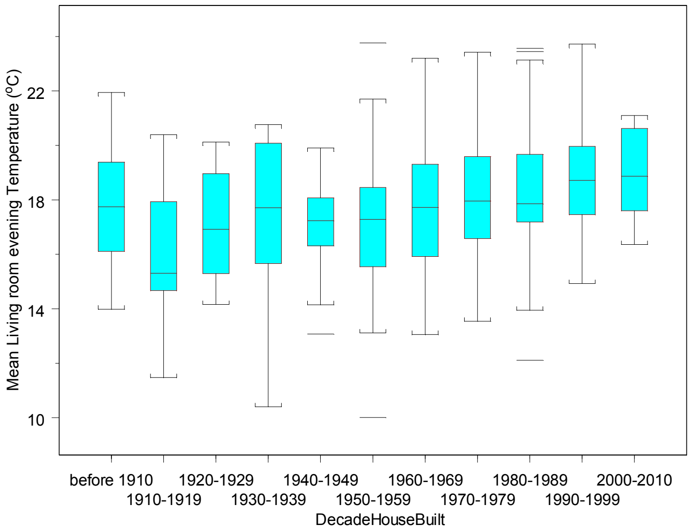


Figure 41: Winter evening living room temperatures by year built

The housing stock in the Otago/Southland area is oldest, with only 11% of houses being post-1978. Overall New Zealand, the average Regional Council will have 25% of its houses built post-1978. The older housing stock, along with climate, would help explain the low winter temperatures for some of the houses in Otago/Southland.

Section 5.4 lists a number of changes to house design and construction that may have led to higher winter temperatures.

6.1.4 Thermal insulation

Houses built after 1 April 1978 are required to include a minimum level of insulation, but the retrofitting of thermal insulation was not required in older houses. As seen in Table 42 there is a 1.0°C difference in living room evening temperatures between pre- and post-1978 houses. This pattern is still seen when the houses are separated by region (see Isaacs et al 2004 for pre-1978 and post-1978 regional breakdowns).

House age group	Average winter evening living room temp (°C)	Std. error of mean (°C)	Sample count	Bedroom overnight temp (°C)	Std. error of mean (°C)	Sample count
Pre-1978	17.6	0.1	265	13.2	0.1	243
Post-1978	18.6	0.2	99	14.5	0.2	95

Table 42: Winter temperatures by insulation level

The same pattern can be seen in bedrooms as living rooms in the pre- and post-1978 houses (see Table 42), although as discussed bedrooms are seldom heated.

6.2 Discussion

New Zealand houses have lower temperatures in winter than found in other countries with similar temperate climates. The average winter evening living room temperature is 17.9°C, while the mean range is from 10°C to 23.8°C.

About 5% of New Zealand houses have central heating systems. In the other houses, the tendency is to zone heat, with the most common room heated being the living room and the most common time of heating being the winter evening.

Solid fuel burners heat the houses well but with little control – they can produce very high room temperatures. Houses heated by open fires (solid fuel) and portable electric heaters are the coolest, with mean winter living room evening temperatures of 16°C and 16.9°C respectively. Houses heated by enclosed solid fuel burners are the warmest, with a mean winter living room evening temperature of 18.8°C.

Newer houses are warmer during winter than older houses; reasons for this may include higher levels of thermal insulation and increased airtightness.

Comparing pre- and post-1978 houses, the winter evening living room temperatures in the newer houses are on average 1°C warmer – 1978 is when the first mandatory regulations were introduced for insulation in houses. This temperature difference increases to 1.3°C in the bedrooms, which seldom have formal heating appliances (the main heating sources are human bodies, TVs, clock radios and pets).

7. STANDBY AND BASELOAD ELECTRICITY

Standby and baseload electricity consumption have been reported by HEEP since the Year 3 report (Stoecklein et al 1999). The HEEP Year 9 report (Isaacs et al 2005) provided background to the methodology and an analysis of the final HEEP database. Further analysis has since been undertaken and published as a conference paper (Camilleri et al 2006). This section provides additional analysis completed since the Year 9 report, which gives a more detailed breakdown of the standby and baseload electricity and, for ease of reading, repeats some of the material from that earlier report.

7.1 Background

Standby power is drawn by an appliance when it is not in operation but is connected to the mains. This can range from zero (e.g. a non-electronic clothes dryer) to 20 W or more (e.g. a TV). These power levels may seem trivial (1 W continuous power is approximately 9 kWh per year), but since most households have many such appliances, the actual energy consumption is usually a significant fraction of the total energy consumption of a household.

Standby mode was defined in the AS/NZ62301:2005 (Standards NZ 2005) as:

> *The lowest power consumption mode which cannot be switched off (influenced) by the user and may persist for an indefinite time when an appliance is connected to the main electricity supply and used in accordance with the manufacturer's instructions.*

The definition of standby mode is evolving as appliances become more complex e.g. some appliances have multiple low power or standby modes.

The **standby power** is defined as the average power measured in **standby mode**.

The baseload power of a house is defined here as the typical lowest power consumption of the entire house when there is no active occupant demand and all cycling appliances (e.g. refrigeration) are in off-cycle. It includes the standby power of appliances (e.g. microwave ovens, VCRs, multiple TVs, dishwashers etc), plus any appliances that operate continuously (e.g. heated towel rails, clocks etc).

The baseload is important for two major reasons: first, it defines the lowest continuous power demand that must be met by a utility grid, and so has a large part to play in the utility load factor; and secondly, it includes a group of appliances that have the potential for demand reductions.

Early estimates of standby and baseload power consumption from the HEEP project have been instrumental in raising awareness of this important energy use in Australasia (Camilleri et al 1999). Since then, standby power consumption reduction has been used as an energy conservation measure during power crises, and is being included in the joint Australian/New Zealand Minimum Energy Performance Standards (MEPS) for appliances.

The HEEP monitoring is now complete so that comprehensive and nationally representative estimates of standby and baseload power consumption can be prepared. This is a world first, as no other country has undertaken a study comparable to HEEP that could provide such estimates. Most other studies have been non-random, with limited geographical or demographic coverage, or were based on spot measurements taken of new appliances often still in the retail store.

7.2 History

Awareness of standby power began with articles in *Home Energy Magazine*. Meier (1993a) reported that utility bills during vacations were often almost as high as occupied periods due to the appliances that remain on, including electronic appliances. Sandberg (1993) published the results of a survey of some new appliances in Sweden, finding that most of them drew electricity when switched off – and described this as "leaking electricity". Meier (1993b) immediately reported these findings to a wider audience in *Home Energy Magazine* and noted that the phenomenon was an international one. The (now unsurprising) result that some appliances consumed more energy in standby mode than in use was first revealed by Sandberg (1994). The secret of standby power was out.

Meier and Huber (1997) introduced their 1 W plan at the 1997 IEA conference as a long-term target for the maximum standby power of electronic appliances. Meier, Huber and Rosen (1998) subsequently took a detailed look at the underlying technical issues and found that most standby functions could be performed with 1 W or less of power, lending weight to their 1 W plan. The IEA convened a series of workshops and formally adopted the 1 W plan in 1999, proposing that the standby power of all new devices should be below 1 W by 2010 and calling on member countries to harmonise policy and regulation in this area (IEA 2005).

Studies of standby power have been conducted in a number of countries and have been compiled in a variety of review papers (Lebot, Meier and Anglade 2000; Meier 2001). Estimates per house at the time ranged from 20-60 W (Lebot, Meier and Anglade 2000) to 32-125 W (Bertoldi et al 2002). It takes a lot of effort to track down all the appliances in a house, so many studies may have under-estimated standby.

Most reported papers were case studies of a small number of non-randomly selected houses and most also did not measure the standby of all appliances in the houses. To our knowledge the Jyukankyo Research Institute in Japan (Nakagami, Tanaka and Murakoshi 1997) and ADEME in France (Sidler 2000) have conducted the only studies of whole-house standby power consumption. Only the latter study measured a large number of houses, but as they do not appear to have been randomly selected this is not nationally statistically representative.

The pervasive nature of standby power means that every appliance in a house needs to be measured to assess the standby power consumption, and some studies have examined only a limited range of appliances. In general, studies are becoming more comprehensive in appliance coverage.

7.3 Standby power and energy

The standby power and energy for all appliances measured are given in Table 62 (see Section 16 Appendix 1: Standby Power and Energy Table) and grouped into categories. Several different numbers are reported in these tables:

- **standby power** – the power consumption in standby mode, which can be measured as a 'spot' measurement with a Watt meter or derived from monitoring records (reported as instantaneous power)
- **standby energy** – the energy used by the appliance while in standby mode. This takes into account the amount of time when the appliance is 'plugged-in' and in standby mode, opposed to operating mode or off (reported as annual average power over 8,760 hours)
- **standby energy per house** – the standby energy multiplied by the average number of appliances per house (reported as annual average power over 8,760 hours).

The reason these are reported in common units of Watts is to permit ready comparison between the different numbers. For example, this readily shows that even though a given appliance may have a high standby power, its standby energy may be low e.g. it is rarely in standby mode.

Appliance ranked by standby or off-cycle power	Standby power (W)	Appliance ranked by use of standby or off-cycle energy	Standby energy (W)
1. Fridge freezer	15.0	1. VCR	9.0
2. Television set-top box	13.3	2. Television	6.3
3. Refrigerator (single temperature)	10.6	3. Stereo	6.2
4. Video cassette recorder (VCR)	9.4	4. Combination fridge freezer	4.7
5. Instantaneous gas water heater	9.0	5. Computer (CPU & monitor)	4.4

Table 43: Top five appliances by standby power and energy

The five highest standby power appliances and the five highest standby energy appliances are listed in Table 43. These account for nearly half of the total household standby energy consumption. It is interesting that three of the top five are 'home entertainment'. These appliances have high standby power consumption, as they are common and in standby for long time periods.

It should be noted that the standby power reported for refrigeration appliances is usually termed 'off-cycle power consumption' and is usually not considered as standby power. For ease of presentation, in this report it has been included in the tables of standby power.

Table 44 and Figure 42 show the average energy use per house for standby is (57±4) W continuous i.e. the average New Zealand house is spending around $90 per year keeping these appliances powered-up waiting to be used.

Despite the prevalence of small chargers for cellular phones and other portable devices, their actual standby energy consumption is small with less than 0.5 W average continuous power per house. About half the cell-phone chargers found were plugged-in and on standby, as were about one-third of all other chargers. Generally cell-phone chargers only seem to be plugged-in when required. Older New Zealand houses (pre-1970s) often have a limited number of power outlets per room, and it is common to have only one outlet per room which might contribute to these devices not being plugged-in continuously. The more sophisticated chargers have a very low standby when not actively charging (about 0.1 W).

Appliance Group	Standby power per group (W)	Standby energy per group (W)	Standby energy per house (W)
Entertainment	56.3	39.5	27.9
Garage	8.1	2.2	0.5
Kitchen	11.3	8.5	5.1
Laundry	4.1	2.5	2.2
Miscellaneous	35.8	28.1	5.9
Refrigeration	27.4	10.6	6.9
Home office	25.2	16.9	7.5
Space conditioning	9.3	8.5	1.1
Grand total	**173**	**113**	**57±4**

Table 44: Standby energy by appliance group

Note that as the market penetration of appliances increases or decreases, the importance of their standby energy use changes. For example, VCRs are being replaced by DVD players/recorders. If each VCR is replaced by a more efficient, lower standby power DVD player, then the national standby power demand of this appliance group will fall. However, if DVD players/recorders achieve a greater market penetration than VCRs, or they have similar standby power, then the overall impact may be unchanged or possibly even result in an increase in standby power demand.

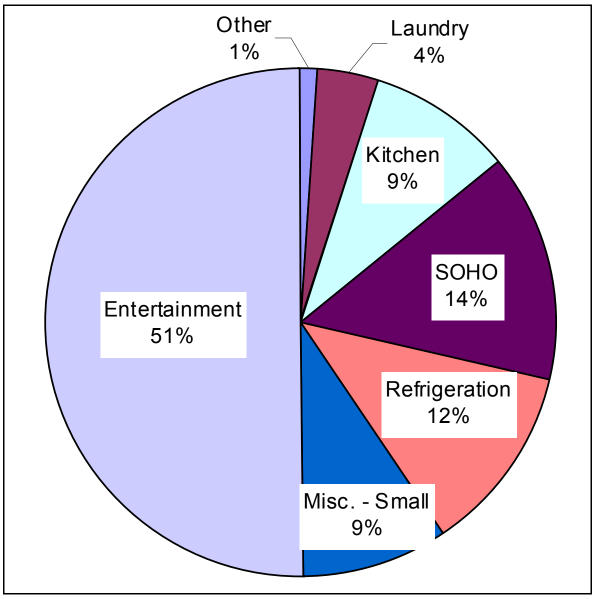


Figure 42: Standby energy per house by appliance group

If appliance standby power levels were reduced to only 1 W per appliance, other than 4 W for set-top boxes and 5 W for refrigeration appliances, this would reduce the standby load to roughly 21 W per house – a reduction of more than 60% (Cogan et al 2006). Most of this reduction would come from entertainment appliances.

7.3.1 Baseload

The average baseload demand is (112±4) W (± standard error). The baseload usually has a poor power factor, as it consists of motors in faulty refrigerators or other continuous operating devices and transformer inductive loads. In a few HEEP houses the monitoring equipment also recorded reactive power, and the power factor of the baseload was typically 0.5-0.7. Reductions in baseload and standby therefore have a larger impact on utility load than the simple power use.

7.3.2 Heated towel rails

A heated towel rail is a tubular metal towel holder with an electric heating wire used to warm towels in cold bathrooms and to dry-off damp towels in cold, damp weather.

Forty-two percent of New Zealand households have one or more heated towel rails, with an average of 1.3 per house that have them. They are more common in newer houses and most newly built houses have one or more installed during construction.

The HEEP survey questionnaire recorded the number of heated towel rails and usage category (e.g. constant, daily etc), and for the first 128 houses also the occupant self-reported hours of use. These hours of use were used to find the average hours of use for each usage category.

The average power rating of heated towel rails is also needed. This is not usually known by the occupants, and often no label is visible, and with fixed wiring it is not a simple matter to take a power measurement. From the limited measurements of labels that were recorded, the average was (70±10) W.

The hours of use per week for each category can then be used to estimate the total energy consumption. Combining the number of heated towel rails with the usage and average power rating gives the average power use per house for heated towel rails of (21±2) W. Table 45 shows the 95% confidence interval (CI) is 17 to 25 W. For the 1.4 million households this is (30±3) MW, which is almost all continuous load.

	Average (W)	95% CI (W)
Per house	21±2	17-25
Per house with heated towel rails	50±4	42-59
Per house that uses heated towel rails	62±5	53-72

Table 45: Heated towel rail average power use

About half of heated towel rails are used constantly, and as the average is only 0.6 towel rails per house, most of the energy is used in a fraction of houses. A single heated towel rail used constantly consumes about 700 kWh per annum, which can easily add 10% to the electricity bill. Reductions of energy use are readily achievable e.g. by installing a timer switch.

In the UK, about 15% of all houses have a heated towel rail (AMA Research 2003) and their electricity consumption could be as high as those in New Zealand.

7.3.3 Other standby and baseload

Some other small standby loads that were not monitored could be from the stove (notably the clock), fixed wired sensor lights, security systems and the electrical safety Residual Current Devices (RCDs) now required on all new lighting and plug circuits in New Zealand. The RCD load might account for 3-5 W. RCDs are known as Ground Fault Circuit Interrupters (GFCI) in the USA.

Some lights may be left on overnight, and these have been estimated from the lighting circuit monitoring at (7±3) W (Cogan et al 2006).

HEEP analysis (see Section 9) has found that faulty refrigeration appliances added on average (15±10) W of continuous load per house. Sixteen percent of refrigeration appliances were found to be faulty with the compressor staying on for long periods of time (days to weeks) or continuously. Repair or replacement with modern appliances would remove this unnecessary load.

7.4 Discussion

Table 46 provides an overview of New Zealand standby and baseload energy per house which totals (112±4) W continuous, equivalent to an annual cost of approximately $150 per year. The 95% confidence interval is from 104 W to 121 W. Assuming 1.4 million houses, this is equivalent to about 160 MW of continuous load, or about 10% of the total average residential power demand.

Use	Load (W)
Standby	57±4
Heated towel rails	21±2
Faulty refrigeration	15±10
Minor loads	4±1
Lights left on	7±3
Remainder	8±12
Total	**112±4**

Table 46: New Zealand standby and baseload

Standby power consumption is estimated at (57±4) W, heated towel rail use at (21±2) W and faulty refrigeration appliances at (15±10) W. Minor loads are (4±1) W and continuously on lights are (7±3) W, leaving unaccounted only (8±12) W which is not statistically different from zero. We can conclude that this is a complete inventory of standby and baseload power consumption for New Zealand houses.

For a detailed breakdown of standby power and energy for common appliances found in New Zealand homes, see Table 62 (Section 16).

8. PRE-1978 AND POST-1978 HOUSE ENERGY USE

Since 1978 all new houses in New Zealand have been required to be insulated, in an effort to improve comfort and reduce energy demand and the cost of space heating. So far in New Zealand there has been little research on the effects of this insulation requirement.

Analysis of the HEEP houses is used to quantify the differences in energy use and space heating between pre- and post-1978 houses. This analysis is difficult as there are many confounding factors e.g. post-1978 houses have larger floor areas, are more likely to be in warmer climates, are less likely to use solid fuel, and are occupied by households with higher average incomes. The analysis needs to account for such factors so that the effect of the post-1978 status can be evaluated on an "all other things being equal" basis.

Note that this is NOT a retrofit study, and the results should not be used directly in that context. Some possible implications of these results for insulation retrofit are discussed in Section 8.7.2.

8.1 The insulation status of houses

The insulation status of New Zealand houses cannot be simply defined. Pre-1978 houses were not required to be insulated, and the vast majority did not have any insulation installed when they were constructed. However, since construction many of these houses have had some insulation added in various amounts and locations, and some have had additions or alterations which are fully insulated. Overall 73% of the pre-1978 houses from HEEP had some roof insulation, although not always over the whole roof, and often of lower R-value than current Building Code requirements. About 25% of pre-1978 houses have some wall insulation, although for many of these houses it may only be in a small part of the wall in an extension or addition. Floor insulation is also uncommon, with around 15% of the pre-1978 houses having floor insulation (excluding houses with concrete slab floors which usually have R-values high enough to meet the current requirements of the Building Code without any additional insulation).

Houses built before 1978 fit into several distinct periods and types, with different construction R-values. Timber weatherboard walls have higher R-values than sheet, stucco, or brick veneer clad walls, and tile roofs lower R-values than sheet roofing materials. The use of wet framing timber, and the consequent high levels of ventilation, post-WW II resulted in lower wall R-values (Bastings 1958). Timber strip floors also give lower R-values than sheet floors, due to higher ventilation rates and less thickness of wood. It would be expected that older houses would have progressively lower airtightness with age, due to the materials and methods used in construction (e.g. strip floors, non-sheet linings, no building paper etc) and also due to deterioration with age, with gaps opening in doors and windows.

A house insulated to the Zone 1 requirements of the current Building Code (which have remained unchanged since 1978) would have about half the total heat loss of a house of identical construction, but with no insulation. The installation of ceiling and floor insulation in the pre-1978 houses reduces heat losses, but not to the same level as a fully insulated post-1978 house. It is, in fact, very difficult to equal the whole-house heat loss of a post-1978 house in Zone 1 by insulating only the ceiling and floor, even if very high R-values (>5) are used. With some wall construction types, or in Zone 3, it is practically impossible to do so with only ceiling and floor insulation.

8.2 Heat losses of the HEEP houses

All the available HEEP houses have been modelled in ALF3 (Stoecklein and Bassett 1999) to estimate their space heating requirements and heat loss. This was reported in Section 8, Isaacs et al (2005). ALF3 calculates the whole-house heat loss and the heat loss per m². Air leakage losses were included.

There was no clear cut distinction between the whole-house heat losses of pre- and post-1978 houses (Figure 43 and Figure 44). Given that the losses depend in part on the floor area this is not surprising, as floor areas vary a lot for houses. The average heat loss of the post-1978 houses (482 W/°C) is lower than the pre-1978 houses (586 W/°C). However, as can be seen from the graphs the histograms of total house heat losses are not hugely different in Figure 43. The differences are more pronounced in Figure 44 for the heat loss per m² where most post-1978 houses have a heat loss of <4 W/m²/°C, but most pre-1978 houses are >4 W/m²/°C.

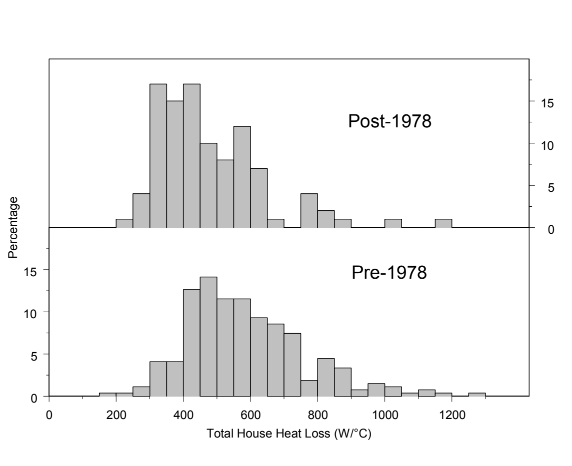


Figure 43: Total house heat loss for pre- and post-1978 houses

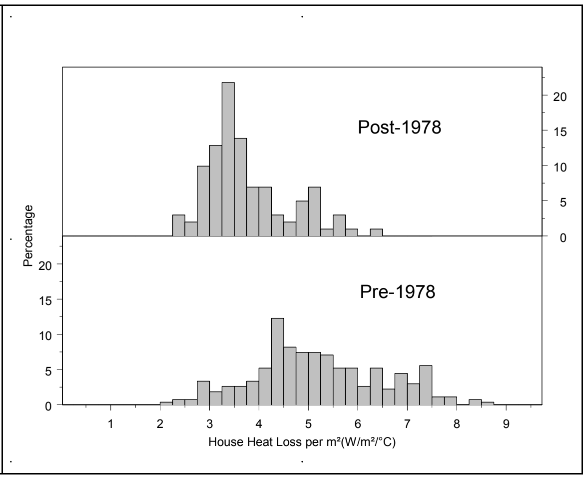


Figure 44: Heat loss per m² for pre- and post-1978 houses

8.3 Pre-1978 and post-1978 house characteristics

The post-1978 houses have (as expected) a lower average heat loss per m² of floor area and a lower average total heat loss (from ALF analysis), but are larger in floor area than pre-1978 houses. All things being equal (which they are not) they would require about 20% less energy to heat to the same temperatures and extent.

	Heat loss/m² (W/°C/m²)	SE	Total specific loss (W/°C)	SE	Floor area m²	SE
Pre-1978	5.2	0.1	586	11	119	2.5
Post-1978	3.8	0.1	482	16	132	4.6

Table 47: Heat losses for pre-and post-1978 HEEP houses

The post-1978 houses are on average 1°C warmer than the pre-1978 houses in the living rooms in winter evenings, and 1.2°C warmer over the whole winter 24 hours, with warmer temperatures for houses with larger heating systems (Table 48).

	Main fuel	Mean living evening temp °C	SE	Mean living 24 hour temp °C	SE
Pre-1978 Post-1978	Electricity	16.8 18.6	0.3 0.3	15.0 16.9	0.3 0.3
Pre-1978 Post-1978	LPG	16.8 17.7	0.3 0.3	14.8 16.1	0.2 0.3
Pre-1978 Post-1978	Natural gas	18.2 17.8	0.4 0.9	16.2 16.0	0.4 0.8
Pre-1978 Post-1978	Solid fuel	18.4 19.4	0.2 0.4	16.2 17.5	0.2 0.4

Table 48: Average winter temperatures by heating type

The HEEP Heat Index (introduced in Isaacs et al 2003) is a synthesised measure of house heating based on heating schedules and zones. It is calculated by assigning a score for each heating schedule, and adding them up. It is not a precise measure, but it does give a way of comparing the different heating schedules and zones of the houses on a simple scale. The most common schedule is winter evening living room heating only (which has a Heat Index of 7), and about half the houses also report heating the bedrooms in the evening as well (which gives a Heat Index of 14). Only about 10% of houses heat the living areas 24 hours a day, and about 5% the whole 24 hours a day (Heat Index 84).

There is no significant difference in the Heating Index between the pre- and post-1978 houses – suggesting both groups of houses are heated similarly in terms of schedules and zones, but the post-1978 houses are heated to warmer temperatures.

	Mean living room winter evening temp (°C)	SE	Mean living room 24 hr winter temp (°C)	SE	Heat Index	SE
Pre-1978	17.6	0.2	15.6	0.1	18.1	0.7
Post-1978	18.6	0.2	16.8	0.2	16.8	1.3

Table 49: Comparison of winter temperatures and Heat Index

Thus there are several conflicting factors that need to be considered:

- post-1978 houses are larger
- post-1978 houses have lower heat losses per m²
- post-1978 houses achieve higher temperatures.

The better insulation should lead to lower space heating energy use (all things being equal), but opposing this, the larger floor area and higher temperatures should lead to higher energy use.

8.4 Space heating

Space heating estimates were prepared for all the HEEP houses by comparing the summer energy use with the winter energy use, the difference being assumed to be space heating. This was done for electricity and gas. Space heating for portable LPG heaters and solid fuel burners was monitored directly for all such appliances. This is a different method to the one used for estimating the space heating for the overall HEEP estimates, and gives a slightly higher average estimate of electric space heating (by about 25%). Further information on the methodology will be reported in a later paper.

The table below compares pre- and post-1978 house use of electric and 'all' (i.e. electric, gas, LPG, solid fuel) space heating. This is net energy i.e. the energy delivered to the room after accounting for the efficiency of the heating appliance e.g. electricity is assumed to be 100% efficient in transferring the energy to the room but an enclosed solid fuel burner is about 60% efficient, an open fire about 15%, and a gas appliance about 80%. The use of net energy removes appliance inefficiencies, while permitting the house thermal efficiency to be explored.

	Electric heating (kWh/yr)	SE	All heating (net) (kWh/yr)	SE
Pre-1978	1,280	100	3,180	200
Post-1978	1,060	130	2,410	310

Table 50: Comparison of space heating energy

Comparing the pre-1978 and post-1978 houses, there is no significant difference between the electric space heating, but there is less space heating overall energy in the post-1978 houses. However this is seriously confounded by the location of the post-1978 houses as there are more pre-1978 houses in colder climates, so merely on the basis of the colder climate they would be expected to use more space heating. This is now explored in more detail.

8.4.1 Statistical models of space heating

Generalised linear models (GLMs) were used to develop statistical models of energy use with various physical and socio-demographic input variables, such as pre-1978 status, floor area, income etc. These models can be used to try to separate out the effects of various competing variables to allow the effect of the pre-1978 status to be compared on an "all other things being equal" basis. This process is required as it has already been shown that the larger floor areas and higher heating temperatures of the post-1978 houses lead to higher energy use, and this confounds the independent evaluation of the effect of the insulation in the post-1978 houses.

The process of developing these models involves an element of professional judgement. There were often several different possible formulations of the model using different variables and a decision has to be made as to which one to use. This decision was guided by the data, the goodness of fit, and common sense. Depending on which model was chosen as the final model the effect of the various terms may differ e.g. one model might give an apparently larger effect of the pre-1978 status than another. Hence the estimates of the effect of various variables on energy consumption should not be interpreted as precise estimates. Standard errors are given for each of the variables, which gives some idea of how precisely that particular model defines them, but a slightly different and equally valid formulation of the model might give a slightly different value (higher or lower).

8.4.2 Linear models of space heating energy

Since the relationships between space heating energy and house and household characteristics are so complex it is a sensible step to use multi-variable linear models to explore these relationships. The linear model allows for an "all things being equal" type analysis to be done by separately accounting for the effects of, for example, region, climate and floor area.

Unfortunately there are several features of the data that make the use of linear models problematic. The residuals (the difference between the actual value and the model prediction) are larger for higher heating energy consumption and they are not normally distributed. Both these features cause problems for the linear model fitting algorithm, resulting in the high values or outliers having a very large influence on the final fit. Fortunately tools are available to overcome these problems – the GLM.

8.4.3 Generalised linear models

GLMs are an extension of linear models. They work in the same general way by fitting linear models to the data, but the underlying statistical distributions are different. For example, a GLM can use a non-normal distribution for residuals (e.g. an exponential or gamma distribution). They can also fit the data in a non-linear sense by using link functions like logarithm, inverse or others. These features of the GLM allow the actual underlying structure of the data to be considered in the model and can resolve the previous problems noted with the residuals.

The particular choice of GLM is a matter of finding which type represents the structure of the data best, often by trial and error. The models used for this analysis use the gamma link function for the statistical distribution of errors, and a logarithmic function to link the predictor to the response. The logarithmic function causes the factors to be multiplicative, not additive as is usual with simple linear models. Overall these were found to best deal with the non-normal distribution of the residuals and the skewed distribution of the energy consumption.

8.5 Model results

8.5.1 Electric heating – all houses

In terms of electric heating energy consumption there is no significant difference in the national averages of the pre- and post-1978 houses (Table 51). However, this takes no account of regional variations or other factors.

GLMs were used to examine the factors influencing electric space heating. For technical modelling reasons, 45 houses that used no electric space heating at all were removed from the analysis. The final model chosen found the post-1978 to be associated with (23±15)% less electric space heating, all other things being equal. The main fuel used for heating (electricity, LPG, gas, solid fuel) had a very large effect, associated with a drop of about (45±20)% in electric space heating houses that mainly use non-electric heating (electric heating is used in most houses, although often only as back-up or secondary heating). The higher temperatures in the post-1978 houses were associated with an increased energy use of about

(10±3)%, and the larger floor area with a (6±1)% increase, so the overall difference was about (-10±15)%, which is not significantly different from zero.[10]

We conclude that there is no significant difference between the amount of electric space heating in the pre- and post-1978 houses, and that the post-1978 houses are achieving higher temperatures over larger floor areas for approximately the same amount of electric heating as the pre-1978 houses, other things being equal.

If the pre-1978 houses were insulated to the same levels as the post-1978 houses, and heated to the same higher temperature, the model predicts that the difference in electric space heating would be (-15±15)%, which again is not statistically significantly different from zero.

Part of the reason for the high statistical uncertainty is the large variation in electric space heating. Looking at houses that mainly heat with electricity should reduce this variation and give a larger difference.

8.5.2 Electric heating – houses mainly heated by electricity

The analysis was repeated for houses that use electricity as their main means of space heating. Reductions of energy use would be expected to be higher as more electricity is used, and it is used to heat warmer rooms such as living areas instead of being used mainly in cooler bedrooms and for occasional heating. This is in fact true, with the average electric heating energy much lower in the post-1978 houses (Table 51). However, this comparison is seriously confounded by differences in climate, heating temperature, and other factors. GLMs were used to try to separate out these effects. The final model had factors for post-1978 status, floor area, region (representing climate), living room temperature (24 hours), and equivalised income.

The model fitted shows a much larger effect of the post-1978 status on electric space heating, associated with a decrease of (60±25)% in electric space heating.[11] Offsetting these factors were the temperatures which were higher by 1.8°C in the post-1978 electrically heated houses, and associated with increased energy use of (48±9)%, larger floor areas increasing energy use by about (5±4)%, and higher equivalised incomes[12] associated with an increase in energy use of about (10±4)%. The net effect of the larger floor areas and higher temperatures of the post-1978 houses is associated with a difference in electric space heating of (-38±27)%, and this is statistically significantly different from zero at a 95% confidence level.[10]

If the mainly electrically heated pre-1978 houses were insulated to the same levels as the post-1978 houses, and heated to the same higher temperature (1.8°C higher), the model predicts that the difference in electric space heating would be (-41±27)%, which again is statistically significantly different from zero at a 95% confidence level.[10]

[10] Since the GLM uses exponential functions, these means and standard errors are combined logarithmically. The ratio of standard error to the mean is not used to test for statistical significance, rather the confidence levels generated by the GLM SPLUS model are reported.

[11] This is a large amount, also with a large statistical uncertainty (±42%). Other closely related models had smaller reductions.

[12] Higher equivalised incomes are, presumably, not caused by living in a post-1978 house.

Differences in electric space heating energy for houses mainly heated by electricity are quite high. The low temperatures these houses are heated to (15°C), and the comparatively small difference between inside and outside temperatures (about 5°C), means that insulation has a large effect on heating, especially given that internal and solar gains will make up a large proportion of required heating energy.

	Electric heating (kWh/year)	SE	Mean living room temperature (24 hours) °C	SE
Pre-1978	2210	260	15.0	0.2
Post-1978	1470	330	16.8	0.3

Table 51: Electric space heating energy and temperature – houses heated mainly with electricity

8.5.3 All heating fuels, all houses

There are significant differences between pre- and post-1978 houses on a national basis when all heating fuels are considered (electricity, gas, LPG, solid fuel), with the post-1978 houses using less heating energy (Table 50). This is also true on a regional basis.

A GLM was used to evaluate the effects of various factors. In isolation the post-1978 status was associated with roughly (45±11)% less space heating energy use. Higher temperatures in the post-1978 houses were associated with an increase in space heating energy use of about (32±3%), and floor area by about (6±1)%.

The net effect of the larger floor areas and higher temperatures of the post-1978 houses is associated with a difference in all fuels space heating of (-23±11)%, and this is statistically significantly different from zero at a 99% confidence level.[10]

If the pre-1978 houses were insulated to the same levels as the post-1978 houses, and heated to the same higher temperature (1.2°C higher), the model predicts that the difference in all fuels space heating would be (-28±11)%, which again is statistically significantly different from zero at a 99% confidence level.[10]

8.5.4 Total energy use excluding hot water

As the previous results for electric space heating and all space heating relied on extrapolations of energy use through the year, the total energy use (non-extrapolated) is also analysed to cross-check the results. The total net energy (all fuels) excluding hot water was used.

A GLM was used to evaluate the effects of various factors. In isolation the post-1978 status was associated with (26±4)% less (total all fuels – hot water) energy use. Higher temperatures in the post-1978 houses were associated with an increase in (total all fuels– hot water) energy use of (16±1)% and floor area of (5±1)%.

The effect of the larger floor areas and higher temperatures of the post-1978 houses is associated with a difference in total energy use (total all fuels – hot water) of (-10±6)%, which is statistically significantly different from zero at a 95% confidence level.[10]

If the pre-1978 houses were insulated to the same levels as the post-1978 houses, and heated to the same higher temperature (1.2°C higher), the model predicts that the difference in all fuels (total all fuels – hot water) energy use would be (-14±6)%, which is statistically significantly different from zero at a 99% confidence level.[10]

Another GLM was used to evaluate the effects of various factors on total electricity use, excluding hot water. In isolation the post-1978 status was associated with (13±6)% less (total electricity – hot water) electricity use. Higher temperatures in the post-1978 houses were associated with an increase in (total electricity – hot water) electricity use of about (7±1)% and larger floor area of (7±2)%.

The net effect of the larger floor areas and higher temperatures of the post-1978 houses is associated with a difference in (total electricity – hot water) electricity use of (-0.7±7)%. This agrees with the previous estimate, which was not significantly different from zero. However, this estimate is more precise as it gives greater certainty that there is either no difference or the difference is very small.

If the pre-1978 houses were insulated to the same levels as the post-1978 houses, and heated to the same higher temperature (1.2°C higher), the model predicts that the difference in (total electricity – hot water) electricity use would be (-7±7)%, which is not statistically significantly different from zero at a 95% confidence level.[10] This result does not prove conclusively that there are no savings, however if savings do exist they are likely to be small. Given that electric space heating is about 12% of total electricity consumption, and at best maybe 30% savings might be achievable (assuming the same as mainly electrically heated houses, discounted for lower insulation levels after insulation), savings of about 4% are the maximum that could be expected. Therefore a range of 0-4% savings on average is reasonable.

8.6 Summary of model results and discussion

Table 52 summarises the modelling results:

- *'Post-1978 only'* refers to the % difference in the energy quantity associated with the post-1978 status, all other things being equal
- '*Post-1978, floor area & temp*' are the combined effect of the post-1978 construction, the larger floor area and higher temperatures found in the post-1978 houses, all other things being equal
- '*Pre-1978, post-1978 insulation & temp*' considers the impact if houses built pre-1978 had the same levels of insulation and rooms temperatures as found in post-1978, all other things being equal.

Note that the differences shown in a **bold** font in Table 52 are statistically significantly different from zero at the 95% confidence level.

In all cases, the *'Post-1978 only'* was associated with a decrease in energy use. This demonstrates with a high degree of confidence that all things being equal, the introduction of mandatory insulation in 1978 has led to improvements in energy efficiency of the housing stock. However, increases in temperatures and larger floor areas in the post-1978 houses have taken up part, and sometimes all, of any potential energy reductions.

Fuel type	Quantity	House group	Post-1978 only (%)	Post-1978, floor area & temp (%)	Pre-1978, post-1978 insulation & temp (%)
Electricity	Heating	All houses	**-23±15**	-10±15	-15±15
Electricity	Heating	Elect. heated	**-60±25**	**-38±27**	**-41±27**
All fuels	Heating	All houses	**-45±11**	**-23±11**	**-28±11**
Electricity	Total – hot water	All houses	**-13±6**	-0.7±7	-7±7
All fuels	Total – hot water	All houses	-26±4	**-10±6**	**-14±6**

Table 52: Summary of model results

Note: differences in **bold** are significantly different from zero at the 95% confidence level.

The '*Post-1978, floor area & temp'* results are mixed. They give a comparison between the pre-1978 and post-1978 houses, all other things being equal, so correct for differences in climate, region, and sometimes income and life stage, between the pre-1978 and post-1978 groups. For example, since on average post-1978 houses are in warmer climates, this would reduce space heating energy consumption. With these corrections in place it can be seen that the post-1978 houses use less space heating energy for all fuels, and less (total all fuels – hot water) for all fuels. However, they use the same amount of electricity. The group of mainly electrically heated houses are the only group that show less electric space heating in the post-1978 group compared to the corresponding pre-1978 group.

'*Pre-1978, post-1978 insulation & temp'* is a prediction from the model of how the energy consumption of pre-1978 houses would change if insulated to the same level as post-1978 houses[13] and to the same warmer temperatures. This assumes no change in heating patterns and zones (we have already shown that the pre- and post-1978 houses are heated to about similar patterns and zones). Again, the overall result is mixed, with a similar outcome as the difference between the pre- and post-1978 houses. There are reductions in all fuels for all houses, but no reduction in electricity consumption, except for houses primarily heated by electricity.

In conclusion, mandatory insulation has led to warmer homes as well as reduced space heating and (total less hot water) energy. However, most of the energy reductions have come from non-electric fuels. The total energy savings for all fuels in the 27% of post-1978 houses would be about 2-3% of total energy consumption (all fuels), while the total electricity savings in the mainly electrically heated houses (about 8% of households) would be <1% of total electricity consumption.

8.7 Insulation retrofit

8.7.1 Review

The 1971/72 study by the Department of Statistics (Department of Statistics 1973) compared two groups of houses, one group insulated and the other uninsulated. However, it found that energy use was actually higher in the insulated group, although houses in this group were more likely to be in the colder climate of the South Island. Since insulation was not required at the time it is possible that the houses that were insulated had this work carried out because the occupants wanted to heat the house extensively.

[13] As noted, a pre-1978 house cannot be lifted to the same overall insulation level as a post-1978 house of the same design by only installing ceiling and floor insulation. Wall insulation, or double glazing, is also required but this is uncommon due to practicality and cost.

A retrofit study by BRANZ on one staff house found that adding insulation increased indoor temperatures slightly during winter, with little impact on energy use. Another retrofit study by BRANZ on some council run pensioner flats in Wellington found no or little increase in temperatures, and no change or a reduction in energy use. For this particular group of flats indoor temperatures were very low, and the occupants did little or no heating.

The Health and Housing study conducted by the Otago School of Medicine was designed to measure the effects on respiratory health and health care (e.g. hospital admissions, GP visits) from the retrofit of insulation. Temperatures were also measured, and some limited information on energy use collected (electricity and gas billing records, self-reported LPG, wood and coal purchase). Analysis of this information showed that temperatures increased after the retrofit of insulation, with little or no change in electricity, LPG, wood or coal use. The energy data for this study was not of high quality.

The Department of Physics, University of Otago undertook a study of 111 Housing New Zealand houses in Southland, where they retrofitted insulation and some other energy-efficiency measures. Reductions in total electricity consumption of 5-9% were observed, with increases in the 24 hour temperature of 0.6° in winter. The total energy reductions were higher but the variation in non-electricity consumption was too high to make this result significant. This is, to date, the largest and most accurately monitored insulation retrofit experiment conducted in New Zealand. Most of the houses already had some ceiling insulation, and this was enough to substantially reduce the improvement in whole-house heat losses with additional insulation (Lloyd and Callau 2006).

BRANZ is in the process of conducting a pilot study of insulation and energy-efficiency retrofits as part of the BEACON project.[14] Ten houses in Wellington are being monitored before and after retrofit, with temperatures and energy use monitored to the same high standards as HEEP. While it is doubtful that this pilot study will be large enough to give convincing proof of the scale of energy savings and temperature increases, the methodology and high resolution monitoring will enable some powerful analysis methods to be used. If the pilot is successful a larger study may follow.

In overview, all of the studies except the pensioner study have shown increases in temperatures during winter of between 0.6°C to 1°C, and small or no savings in energy consumption (often only electricity as that was all that was monitored). However, most of these studies were done on particular groups of people – e.g. elderly pensioners in council flats, low income households with low health status, Housing New Zealand clients in Southland – so these studies are not representative of New Zealand as a whole. In general, these groups use less-than-average space heating.

The question still remains unanswered: What is the effect of retrofitting insulation to New Zealand houses? The answer is extremely important as efforts are increasing to improve the energy efficiency and thermal performance of the existing New Zealand housing stock, and large policy and investment decisions are looming around

[14] See www.beaconpathway.co.nz.

electricity generation and transmission, air pollution concerns from solid fuel burners, and greenhouse gas emissions.

We cannot expect to get large energy savings from insulation retrofit of houses in New Zealand. Savings in total energy (all fuels) of perhaps 5% are feasible, with most of that saving in non-electric fuels. Potential savings in electricity are smaller still (at about 1%). New Zealand houses and people appear to be very different from other countries where residential insulation retrofits have been used successfully, and we need to develop our own knowledge and solutions.

8.7.2 Results from HEEP as a guide to insulation retrofit

The HEEP project was not a retrofit study so it cannot directly answer the question of how much energy would be saved by insulating pre-1978 houses. However, analysis of pre- and post-1978 houses gives some insight into what might be expected.

The estimates for '*Pre-1978, post-1978 insulation & temp*' from Table 52 give a rough idea of what savings might be expected with retrofitted insulation. The actual savings will likely be less, as typical insulation of ceiling and roof insulation will not bring a pre-1978 house up to the same level of insulation as a post-1978 house. Discounting the savings by 25% is perhaps a fair representation of this effect.

The analysis showed no saving in (total electricity – hot water) for all houses, with a range of perhaps 0-4% savings possible on practical grounds. Only houses heated mainly by electricity were shown to have savings in electric space heating.

Electric space heating is, on average, 12% of domestic electricity consumption for all houses, and roughly 25% of electricity consumption for houses that heat mainly with electricity. In the best case, looking at only these electrically heated houses with savings of perhaps about 30% (40% discounted by 25% for lower insulation levels) of space heating, savings in total annual electricity consumption would be about 7%. Trying to detect such a small change in total electricity consumption is difficult and requires a large sample size.

The HEEP analysis has shown that the standard errors in total electricity consumption are about ±2.5% for a sample size of 400 houses. To detect a reduction of 7% with 95% confidence would require monitoring of two separate groups of about 400 houses, with a small risk that the experiment would fail. Doing a before and after study on the same set of houses would reduce this, but a sample size of about 200 houses is still likely to be needed. Such a study could be done using billing records if they were collected and analysed carefully.

Assuming all houses achieve 4% electricity savings, the sample size is about 1,200 houses for each of two comparison groups, or about 600 houses for a before and after study. If the savings are lower than 4%, then the sample size increases rapidly.

Monitoring only space heating might be expected to give larger differences that are easier to detect. However, space heating is more variable than total electricity or energy, with standard errors of about ±10% for a sample of 400 houses. Chances are the required sample size would be about the same as for monitoring total energy use, and monitoring space heating is technically much more difficult and expensive than monitoring total energy use.

Note that the potential savings may be larger or smaller in particular areas, or for particular target groups. Targeting of insulation retrofit is likely to greatly enhance the cost benefit of any savings, particularly if the aim is to reduce electricity consumption. Targeting those houses that mainly use electricity will give larger reductions per house than targeting all households. The differences in heater types across the country also offer a sobering message about the potential for reductions in electricity consumption from insulation retrofits. In many parts of the country (particularly colder climates and outside major cities) solid fuel burners are very common and a relatively small fraction of heating is done with electricity, so potential reductions in electric space heating in these areas are likely to be very small or zero.

Clearly, any study trying to prove that savings in electricity or energy will need a large sample size, as well as ensuring all necessary information is available.

9. FAULTY REFRIGERATION APPLIANCES

All consumer appliances eventually fail and need replacement. For many appliances poor performance or failure is obvious, and there is no reason to believe that they are not discarded or repaired as needed. For example, if a VCR stops playing, or has a poor image, it is obvious. Likewise, a clothes dryer motor or controller that fails stops the appliance working at all.

However, for refrigeration appliances the signs are not so obvious. Even though insulation degrades or gets wet, coolant leaks, door seals fail, or the thermostat or controller fails, the appliance may continue to operate (i.e. make noise and keep food cool) for years. In reality, the signs of faulty older refrigeration appliances are poor temperature control and the compressor running continuously for long periods, especially in warm weather.[15] Since most refrigeration appliances do not have internal thermometers, there is no sign of poor temperature control except for perhaps a freezer compartment that doesn't freeze or food that doesn't last as long as it should. Many people may not be aware that a continuously running compressor is a sign of faulty operation.

Refrigeration is a significant use of energy in New Zealand houses. Table 9 provides the HEEP estimate of (1,119±72) kWh per household per year, or approximately 15% of household electricity (Figure 18) or 10% of total household energy use (Figure 14). Table 10 gives average annual electricity consumption for refrigerators of (367±62) kWh, fridge freezers of (621±30) kWh and freezers of (663±39) kWh per appliance.

While installing monitoring equipment and surveying the HEEP houses, a number of old and potentially faulty refrigeration appliances were found, and visual inspection of the monitored HEEP data confirmed that a number of refrigeration appliances stayed on continuously for long periods of time and were faulty. The following analysis seeks to answer the questions of what proportion of refrigeration appliances are faulty, how much energy they waste, and what (if any) distinguishing characteristics these appliances may have.

9.1 Review

There are many schemes internationally that target old or faulty refrigerators for replacement, and this is routinely done as part of household energy audits. The challenges for the assessor are many: 1) remove poor performing appliances; 2) do not remove properly performing appliances; 3) do not leave behind too many poor performing appliances by being too conservative; 4) complete the evaluation without spending too much time and money.

A large variety of criteria have been developed to evaluate the need for replacement e.g. colour of refrigerator, age based on position of name plate, age based on defunct manufacturers or models, age based on colour. These methods are mainly designed for ease of implementation. Cavallo and Mapp (2000) proposed an analytic method for determining if a refrigerator needed replacement, using energy and power monitoring over a two hour period. Other schemes have required the monitoring to continue for a number of days, which obviously becomes increasingly costly and

[15] Some modern refrigeration appliances use variable pumping rate compressors, which may slow down enough so as not to require a stop and start.

difficult. Very few of these schemes have been properly evaluated to determine the performance of the scheme in terms of targeting faulty or high-consuming appliances, or for estimating the achieved energy savings. Both of these metrics are needed if the success of the scheme is to be evaluated in economic terms.

9.2 Data

Refrigeration appliance data was taken from the HEEP database. Data from approximately 400 houses was available, and of these 25% had end-use monitoring of individual appliances, which usually included one or more refrigeration appliances.

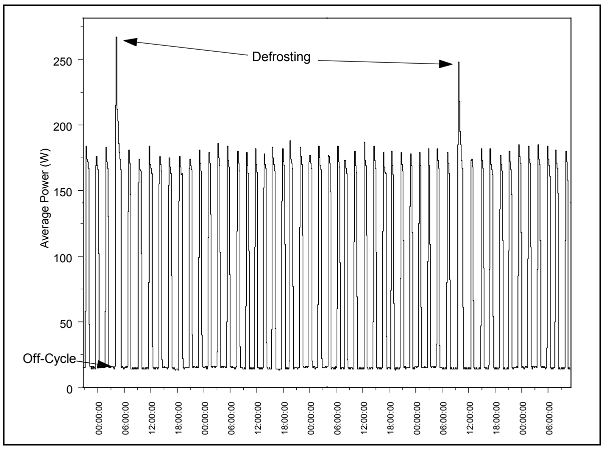


Figure 45: 10 minute time series of refrigeration appliance power

Appliance power was monitored for 147 separate refrigeration appliances. The length of the monitoring period varied, from as little as one month (approximately) to up to one year, on a random basis. Two types of equipment were used (Section 1.1):

- Australian manufactured EUM transponders (using current transducers) with a nominal resolution of 1 W, and
- Siemens SA100 domestic tariff meters modified to have a resolution of approximately 10 pulses per Wh (1.6 pulses per W per 10 minutes).

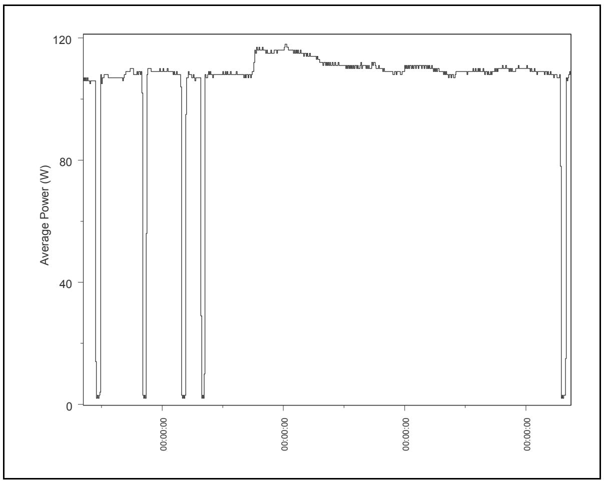


Figure 46: Faulty freezer – 10 minute time series

Collected data is stored as 10 minute resolution time series. A typical example of the time series of a refrigeration appliance in normal operation is given in Figure 45. In this case, the compressor power is approximately 170 W, the off-cycle power consumption is about 15 W, and defrosting occurs about once every three days.

An example of a faulty freezer is given in Figure 46, in which the compressor stays on for long periods of time, and occasionally switches off. Some faulty refrigeration appliances never switch off.

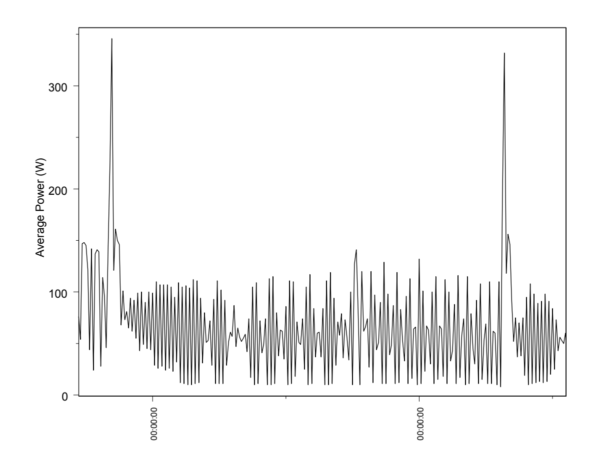


Figure 47: Fridge freezer 10 minute time series – cycles under 20 minutes but not faulty

Some refrigeration appliances have a very short switching cycle, and if the off period is less than 20 minutes then the cycles cannot always be properly resolved at a 10 minute sampling interval. An example of such a time series is in Figure 47.

Since the length of the off-cycle is close to 10 minutes, its start and finish do not always coincide with the datalogger's 10 minute interval. This is a difficult situation to deal with, and three such cases were removed from the analysis due to this problem.

9.3 Methodology

First, the data from all 147 refrigeration appliances was graphed and visually inspected, and an initial decision made about whether or not they were faulty. This was used as the control data set for the development and testing of an algorithm.

The algorithm of Cavallo and Mapp (2000) was initially tested, and adapted to be more suitable for the HEEP data. Modifications were needed as this algorithm estimates the duty cycle by comparing the average power over a two hour period to the average power when running (on-cycle power consumption). In contrast, HEEP measurements are the average power over a 10 minute interval taken over many weeks. The long-term average power consumption can be taken as the average power. However, as the start and end of a compressor on-cycle will not normally coincide with the start and end of an interval, the average power when running as recorded by the 10 minute time series will under-estimate the on-cycle power consumption. Observe in Figure 45 how the compressor power does not usually jump up from the off-cycle to the on-cycle power consumption, but has an intermediate step. The power consumption while the refrigerator is in the on-cycle can also be seen in this graph to vary from cycle to cycle – in this example the on-cycle power consumption is around 160 W.

To estimate the on-cycle power consumption, the intermediate steps in power consumption must be ignored, and some type of average of the observed on-cycles taken. To do this, the mode (statistical) of the refrigeration appliance power was calculated, ignoring the off-cycle mode. The refrigerator in Figure 45 has an on-cycle mode of 176 W and an off-cycle mode of 19 W.

Other modifications were needed for the algorithm of Cavallo and Mapp (2000), as many refrigeration appliances also have an off-cycle power consumption (e.g. butter conditioner, fans, controllers etc) which needs to be estimated and subtracted from both the average and modal on-cycle power consumption. Cyclic defrost refrigerators normally power up a heater in the off-cycle – a heater that is not operating when the compressor is running. For some modern refrigeration appliances, particularly those with fans and micro-processor controls, the off-cycle power consumption can be large compared to the on-cycle power consumption, and if the off-cycle power consumption is not removed, could be wrongly classified as faulty.

Equation 2 gives the modified calculation for the duty cycle:

$$\text{Duty Cycle} = \left(\frac{\text{Average Power} - \text{Off-Cycle Power}}{\text{Modal On-Cycle Power} - \text{Off-Cycle Power}} \right)$$

Equation 2

9.4 Results

From the visual data inspection, 7% of refrigeration appliances were found to be faulty, and 9% were marginal, showing faulty operation for short periods of time. The breakdown of the proportion of faulty appliances by type is given in Table 53. The sample and proportion of faults was not large enough to determine if there were differences in the proportions of faulty and marginal appliances by type. However, after combining groups, there is a significant difference between freezers and other types in the overall proportion of faults (Faulty or Marginal), with freezers being more likely to be faulty than other types. (Chi-square test, $Chi^2 = 4.54$, DF= 1, p=0.033).

Type	Count	Faulty	Marginal	Sum	Faulty	Marginal	Sum
Freezers	60	5	9	14	8%	15%	23%
Fridge freezers	70	3	5	8	4%	7%	11%
Fridges	17	1	0	1	6%	0%	6%

Table 53: Breakdown of faulty appliances by type

The age of the faulty refrigeration appliances is based on sparse data, with only 10 out of the 18 faulty and marginally faulty refrigeration appliances able to be dated. Despite these limitations, the data shows a statistically significant variation in the proportion of faulty appliances by decade, with the 1960s appliances being approximately 67% faulty (note this has a very large statistical uncertainty). This supports the commonly held idea that the older the refrigeration appliance, the more likely it is to be faulty.

Decade	Working	Faulty	Total	% Faulty
1960s	1	2	3	67%
1970s	10	1	11	9%
1980s	20	1	21	5%
1990s	31	6	37	16%
2000s	14	0	14	0%

Table 54: Breakdown of refrigeration appliances by decade

Six refrigeration appliances (12%) from the 1990s were faulty, of which three were running continuously and three were marginal. This is potentially alarming, as modern refrigeration appliances are expected to have a working life of more than 10 years. Perhaps the change to non-CFC refrigerants in 1994 affected their reliability. Given the small sample size of 1990s appliances, it is possible that this high number has just occurred by chance.

No appliances from the 2000 decade were faulty.

A Chi-squared test for a difference of proportions shows that the increase in faults for older appliances is a real effect. (5-sample test for equality of proportions without continuity correction Chi-square = 12.5, DF = 4, p-value = 0.014.)

There was insufficient data to analyse refrigeration type and age together.

9.5 Testing Cavallo and Mapp algorithm

The algorithm of Cavallo and Mapp (2000) for deciding whether a refrigeration appliance was due for replacement was applied to the refrigeration appliance data to compare with the visual inspection. The parts of the algorithm relevant to New Zealand refrigeration appliances are as follows:

1. Wattage when running >250 W
2. kWh usage in one hour >0.15 kWh (two hour test)
3. kWh usage in one hour divided by kW when running is >0.7 (two hour test)
4. Any model with an anti-sweat device (5 to 40 W when not running)
5. Runs continuously for more than one hour.

The anti-sweat device criterion is not relevant for most New Zealand refrigeration appliances. Many models have fans or electronic controls which give an off-cycle power consumption of, typically, 5-20 W. In addition, many older refrigeration appliances have a butter conditioner, which is a small compartment (about 1 litre), that has a small 10-15 W heater that runs continuously to keep butter soft. This off-cycle power consumption was subtracted from the net power consumption of each refrigeration appliance.

The exact algorithm tested was: Replace if:

1. Wattage when running >250 W, or
2. Average wattage >150 W, or
3. Average wattage divided by average wattage when running >0.7.

All wattages are exclusive of the off-cycle power consumption. The performance of this algorithm is given in Table 55:

Correctly identified faulty	15
Correctly identified OK	118
Incorrectly identified faulty	8
Incorrectly identified OK	6

Table 55: Performance of algorithm at threshold of 0.7

The faulty indication threshold of an >0.7 duty cycle falsely identifies eight refrigeration appliances as faulty, and six as OK. On inspection, the duty cycles of the faulty appliances (compressor running continuously for long periods) are all 0.9 or greater. A duty cycle threshold of 0.9 (Table 56) will only pick up faulty refrigeration appliances, although many marginal appliances are not detected.

Correctly identified faulty	14
Correctly identified OK	123
Incorrectly identified faulty	1
Incorrectly identified OK	9

Table 56: Performance of algorithm at threshold of 0.9

The refrigeration appliances that were obviously faulty and stayed on for long periods of time had duty cycles of more than 0.9. Only one refrigeration appliance with a calculated duty cycle >0.9 was not in fact faulty, but had a very short compressor cycle that could not be resolved at the 10 minute time resolution.

9.6 Energy waste from faulty refrigeration appliances

When a refrigeration appliance is faulty, the compressor stays on-cycle for longer than it should, perhaps continuously. By comparing a normal duty cycle with the faulty duty cycle the energy wastage could be estimated. However, most of the faulty refrigeration appliances do not have a period of normal operation from which a normal duty-cycle could be observed. To establish a normal duty cycle, the average duty cycles of all the normally functioning appliances were calculated. They are 47%±2% for all non-faulty refrigeration appliances, or by appliance type 48%±4% for freezers, 48%±4% for fridge freezers, and 40%±10% for fridges. The variations between appliance types are not statistically significant. Duty cycles average 47%, so a faulty refrigeration appliance would use about double the normal energy for refrigeration (excluding off-cycle power consumption).

On average, the normally working refrigeration appliances averaged (63±2) W, the marginal ones (101±7) W and the faulty ones (108±15) W. The faulty and marginal refrigeration appliances used on average (42±17) W more than they would if operating properly, which would cost the owners about $56 per year in electricity. As a national average, the excess power consumption would be about 12 W per household or 17 MW of continuous load. This is a sizable amount, about 1% of domestic energy consumption.

This excess energy consumption is on average about 11% of domestic refrigeration energy consumption.

If we assume that the faulty appliances are replaced with modern ones that use 50% of the energy of the old ones, then there would be savings of roughly 35 W per appliance, which would be about an additional 20 MW of load nationally. If we assume that half of the appliances are disposed of and not replaced, then the savings, including reductions for units that are replaced, would be about 53 W per appliance, for nation-wide savings of about 30 MW. The total net savings of a nation-wide program that withdrew faulty appliances, and replaced half of them with modern replacements, would be about 50 MW of continuous load.

9.7 Implications for energy savings programs

Clearly, identifying and repairing or decommissioning faulty refrigeration appliances should be part of any domestic energy savings, with substantial savings of up to $25 million dollars per year. One in every six (16%) New Zealand refrigeration appliances are faulty or marginally faulty. This is higher than it should be, and it would suggest that households are keeping refrigeration appliances too long before disposal.

The National Energy Efficiency and Conservation Strategy (NEECS) has a target of improving energy efficiency overall by 20% by 2012. Replacing faulty refrigeration appliances alone would improve efficiency by at least 1.5% (assuming the same or lower energy consumption than the original model). If some are not replaced (many appear to be under-utilised), then the savings would be higher, possibly 2-3%. Replacing faulty refrigeration appliances can and should make a significant contribution to the NEECS target.

9.8 Greenhouse gas emissions

In addition to energy savings, refrigeration appliances manufactured before 1994 were charged with CFCs, which are both highly potent greenhouse gases, and ozone-depleting substances. If refrigeration appliances are left to fail completely before disposal, the refrigerant may leak before it can be safely recovered. From the HEEP age estimates, about 60% of refrigeration appliances were made before 1994, so roughly 1.5 million still-in-use refrigeration appliances have CFCs. As a rough estimate, based on 100 gm of CFC-12 per appliance, there is about 150,000 kg (150 tonne) of CFC-12 still stored in refrigeration appliances. With a global warming potential of about 10,600 times that of CO_2, this is equivalent to 1,590 kt CO_2. At the peak, New Zealand used about 2,500 tonnes of CFC-12 Ozone Depleting Potential (ODP) equivalent per week –150 tonnes is about three weeks of peak use.

Recovery of CFCs refrigerants from refrigeration appliances is poor. Refrigerant appears to be lost either as the unit fails, during storage before disposal (corrosion of tubing), or from damage during removal and transport, especially for units that had exposed rear coils. Where they are put out for curbside collection, the refrigerant is lost completely during the scavenging of recyclable materials. At this stage, it is impossible to know the proportion of losses at each stage. In addition, foam use in pre-late-1994 appliances contained CFCs. Recovery of the CFCs from the insulation (and the HCFCs from the insulation of some imported 1994 to 2002 refrigerators) is non-existent in New Zealand.

If this situation continues, then most of the estimated 150 tonnes of CFC-12 remaining in refrigeration appliances will be lost to the atmosphere, which will be equivalent to the global warming potential of 1.3 Mt of CO_2. Recovering this refrigerant will require a new program that encourages the recycling of refrigeration appliances before they fail, and that also puts in place proper procedures for handling refrigeration appliances without damage.

9.9 Discussion

In New Zealand, approximately 7% of domestic refrigeration appliances are faulty, and 9% operate marginally. The excess power consumption of faulty and marginally faulty refrigeration appliances is estimated at about 17 MW nation-wide, and is about 11% of domestic refrigeration energy consumption. The potential for energy savings from decommissioning these refrigeration appliances is large enough to support a nation-wide decommissioning program. The energy savings would be even larger if some of these appliances were not replaced, perhaps as high as 50 MW.

Faulty refrigeration appliances can be identified by unusually long periods (weeks or months) where the compressor is on continuously, and can easily be identified by inspection or short-term monitoring. Marginally faulty refrigeration appliances have short periods (about few days) when the compressor does not switch off, and are less likely to be identified. The algorithm of Cavallo and Mapp (2000) has been adapted to New Zealand refrigeration appliances, tested and found to identify faulty refrigeration appliances reliably. Their suggested duty cycle threshold of 0.7 identified most marginally faulty refrigeration appliances as well as those that run almost continually.

Older refrigeration appliances appear to be more likely to be faulty, with two-thirds of 1960s refrigeration appliances being faulty (note that this has a large uncertainty).

It is not known what proportion of refrigeration appliances is faulty in other countries, and we can only speculate that in a country with a similar age distribution of appliances, the proportion that is faulty would be similar. It would therefore be worthwhile to investigate the potential for energy savings and CFC recovery as part of energy-efficiency programs.

It is also worth noting that the energy savings from replacement of older refrigeration appliances with modern appliances will benefit from the improved energy performance of newer appliances. Figure 48 shows that the sales-weighted energy use of new fridge freezers has reduced over time, benefiting first form the energy labelling requirements and more recently from minimum energy performance standards (MEPS). Over the past 26 years, the sales-weight average energy use has fallen by two thirds (Pers. Com. Lloyd Harrington; Energy Efficient Strategies 2006).

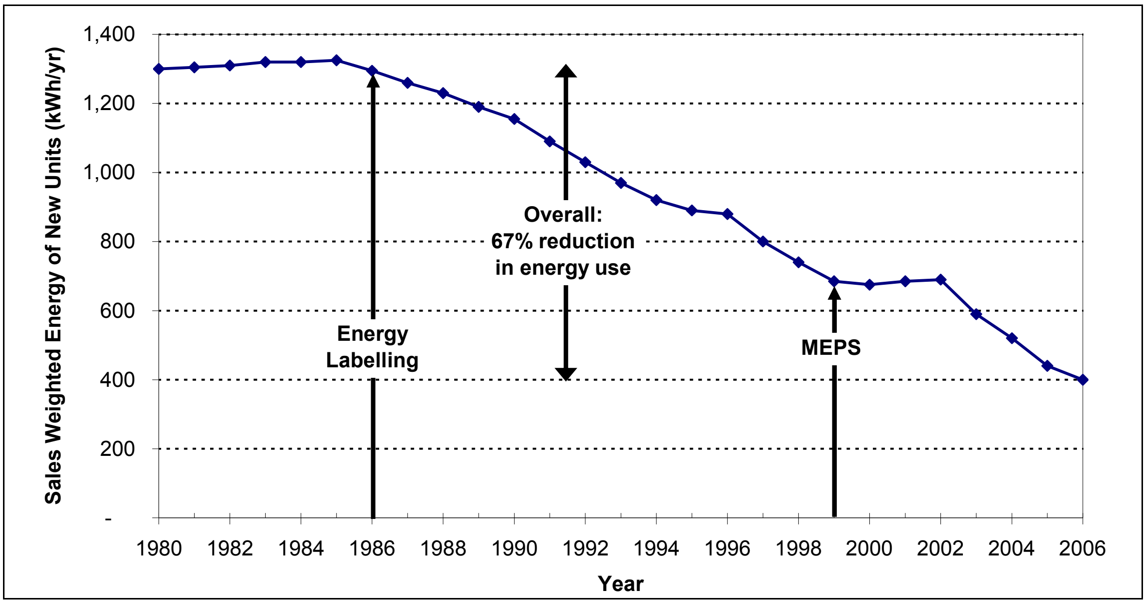


Figure 48: Energy use of new frost-free fridge freezers 1980-2006

10. POWER FACTORS

For each of the last three years of the HEEP installations, in three houses the electricity use was monitored with equipment (TML meters)[16] capable of measuring both real and reactive power and consequently reporting household power factors. This equipment is described in the HEEP Year 6 report (Section 4.2, Isaacs et al 2002) which also provides some results from an initial examination of one of these (House 1) installations (Section 7.2, Isaacs et al 2002).

10.1 Power factors

The load on an electricity network grid is made up of both resistive (real power kW) and inductive or capacitive (reactive power kVAr) loads. The total burden (apparent power kVA) on the network is the vector sum of both the real and reactive components. The ratio of the real load to the total burden is called the 'power factor' and will be 1.0 for a purely resistive load (like the heating element in a hot water cylinder or an incandescent light bulb) and 0 for a purely inductive or capacitive load. Household appliances which contain motors (e.g. a vacuum cleaner) will have an increased inductive load and will have a low power factor.

AC power is transmitted with the least losses if the current is undistorted and exactly synchronised with the voltage. The lower the power factor, the more current is required to deliver the same amount of power. The overall power factor for a household will depend on how many reactive and resistive appliances are used within the house and when, and for how long, these appliances are used. These factors can vary considerably between households so the variation of the power factor between households will be of interest.

The households into which the TML meters were installed were chosen for a number of practical reasons (such as space around existing metering etc), and preference was given to households with electricity being a major fuel use in the house. As the TML metered households were not randomly selected this analysis is exploratory of the power factor issues and should not be regarded as representative. This study, however, provides an indication of the variation of power factors between different households and may be useful to determine an appropriate sample size for a more detailed (statistically representative) study of the issues involved.

In 2002 the TML meters were installed into three households in Auckland and the North Shore. In 2003 the equipment was relocated to Whangarei, but due to a monitoring problem data is only available from two of these households. For the final year (2004) of monitoring, the equipment monitored three Thames households. During this final year, the occupants in one of these houses (House 7) moved out and were immediately replaced with new occupants. There was a change in how much reactive power was used with this change of occupants, so the data from the two households (denoted as House 7a and House 7b) is analysed separately.

The households into which the TML meters were installed varied. The households ranged in size from 1-5 people. The floor area of the houses ranged from 56-172 m^2, averaging 106 m^2. Household incomes varied with the equivalised income (see Section 4) and differed by a factor of more than seven from lowest to highest.

[16] Now renamed Energy Intellect – see www.energyintellect.com.

An important source of inductive load within a household is from the operation of electrical motors in appliances. Refrigeration appliances are typically always switched on and the compressor motors within these appliances are frequently running. For the nine households examined, four had two refrigeration appliances (two had fridge freezers with a separate freezer and the other two had refrigerators with a separate freezer). The remaining five households had a single refrigeration appliance, being a fridge freezer for four of the households and a single door refrigerator for the remaining household. The ownership of particular appliances for each household is shown in Table 57.

House	1	2	3	4	5	6	7a	8	7b
Refrigerator								1	1
Fridge freezer	1	1		1	1	1	1		
Freezer	1		1			1			1

Table 57: Ownership of refrigeration appliances

Other frequently operated motorised appliances that may be contributing to the reactive load by the household could include clothes dryers, dishwashers, vacuum cleaners, sewing machines, cooling fans, extractor fans, dehumidifiers, air-conditioners, fan heaters, electric garden tools and power tools. The number of these types of appliances varied within the households examined; four households had clothes dryers and four had dishwashers, and only one household had a dehumidifier.

Lighting was predominantly incandescent (resistive), with all of the houses having a number of incandescent fixtures. Only two households had compact fluorescent lighting (inductive, not electronic ballasts), but these households had only one CFL fitting each. Two other households had fluorescent strip lighting (inductive), one of which also contained a number of halogen lights (resistive).

Heating methods within the selected households varied and included two households with woodburners, two households with portable LPG cabinet heaters, one household with reticulated natural gas and one household with an air-conditioner.

With one exception, all of the households used electricity for their water heating and cooking. The remaining house had a reticulated gas supply which provided water heating, cooking hobs and gas heating.

In addition to motors and fluorescent lighting, many electronic devices can provide a poor power factor, although good design can minimise this effect.

10.2 Measured reactive power and power factor

Over the course of a measurement period within an actual household, the real power and reactive power will vary and consequently the apparent power and power factor will also vary. The magnitude of the real power is generally much greater than the magnitude of the reactive power.

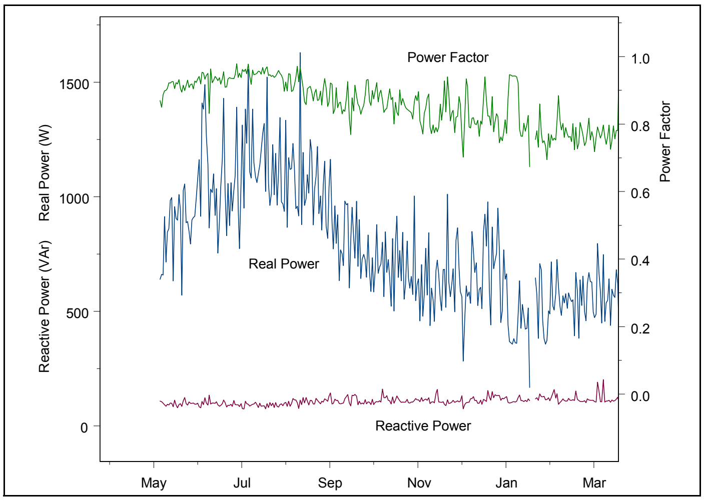


Figure 49: Household daily average real and reactive power and power factor

Figure 49 shows a time-series graph of the daily average reactive power, real power and power factor for one house. It can be seen that for this household there is a seasonal variation in power factor and that the high power factor during the winter months coincides with high values of real power. The reactive power is largely constant throughout the year, although seven out of the nine households (including the house in Figure 49) had some reduction during the winter.

Figure 50 provides a series of histograms of the 10 minute power factors for each household. Overall the mean power factor varied from 0.76 (for House 1) to 0.97 (for House 2). The mean of the power factor for the nine households was 0.86.

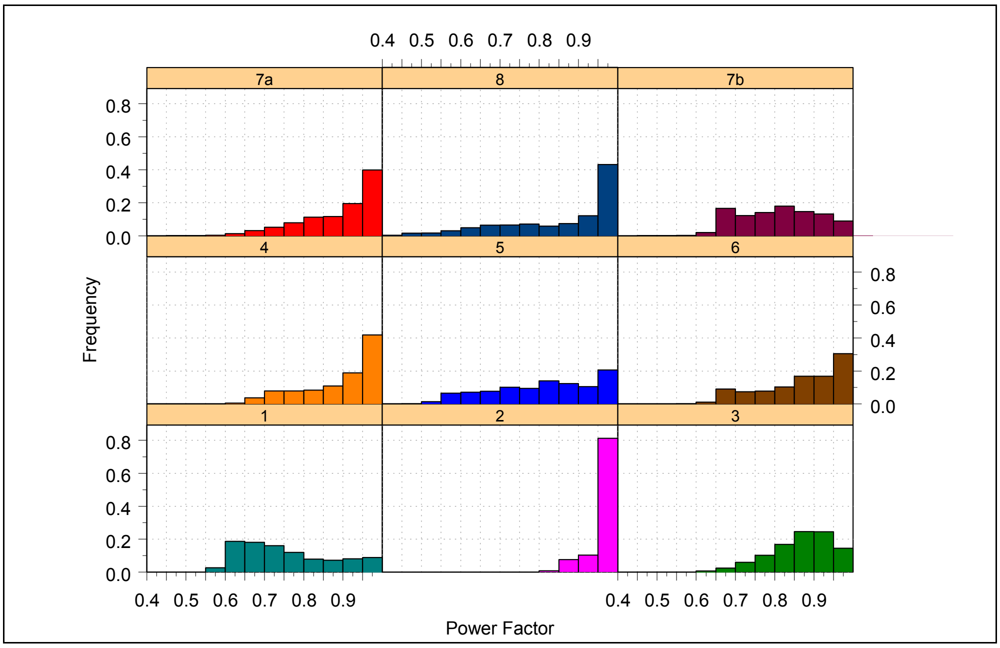


Figure 50: Histograms of the 10 minute power factors by household

Figure 51 compares the mean real power and the mean reactive power for each household. The average power factor for each of the houses is also shown in brackets after the house designator. It should be noted that the Y-axis (the reactive power) has been exaggerated to allow the spread of the reactive data to be better examined.

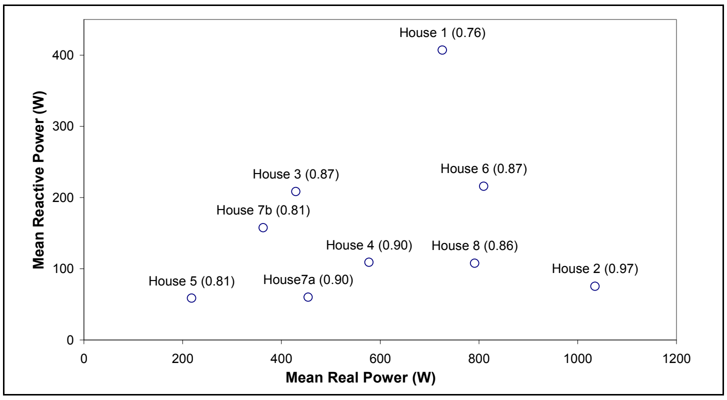


Figure 51: Mean real and reactive components for each household

Note: mean power factor shown in brackets.

The relationship between the real and reactive power is further examined for each individual household in Figure 52, which provides scatter plots of the 10 minute data of the real and reactive power plotted against one another. Again the Y-axis (the reactive power) has been exaggerated, this time to magnify any trend of increasing reactive load with increasing resistive (real) load.

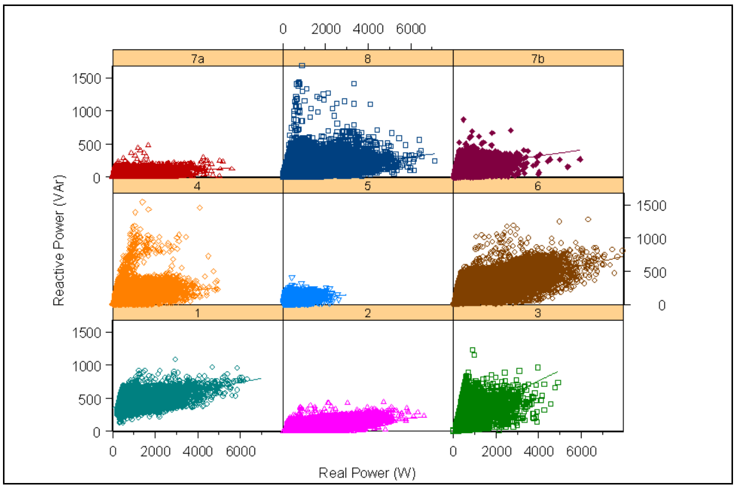


Figure 52: Real vs reactive power by household

House 1 (shown in the bottom left hand corner of Figure 52) has the lowest mean power factor of all the households examined (0.76) and is the only household which appears to have a reactive power and real power offset. The minimum real power in any 10 minute period is 222 W, with the minimum reactive power being 120 VAr. The minimum apparent power is 344 VA. It is probable that a constant load (which had a reactive component) was running all the time. HEEP has previously identified old freezers as frequently being faulty and running all the time (Isaacs et al 2004). House 1 has an old freezer in the garage and this may be a contributing cause to the high reactive energy use in this household.

Figure 53 shows a time-series plot of the real power, reactive power and power factor for one particular day in summer for House 1. Figure 54 shows the same variables for another household (House 6). Both House 1 and House 6 have one combination fridge freezer as well as a separate freezer. The background pattern of the reactive power for House 1 is a regular switching event with a constant offset. This is consistent with a fridge freezer operating correctly with a faulty freezer operating continuously. The background pattern of the reactive power for House 6 differs in that there are times when there are high peaks and zero usage (both appliances operating at the same time) and times when there are smaller peaks and non-zero usage (appliances operating at overlapping times), which is consistent with both appliances cycling operating at slightly different frequencies.

To examine the costs of running this constant load in House 1, a dataset was constructed that extracted the bottom 5% of the data (based on the total apparent energy). This data set had a mean real energy use of approximately 2300 kWh per year, a mean reactive energy use of 2500 kVArh, an overall mean apparent energy use of 3400 kVAh, and a mean power factor of 0.67. Taking the average retail electricity cost as 17 cents per kWh, this constant load not only costs the householder approximately $390 to run but also adds a considerable (and possibly avoidable) reactive load to the electricity network. This in turn adds costs to the distribution, transmission and generation systems.

The power factor of this large household (House 1) is degraded by the inclusion of a number of reactive motorised appliances e.g. clothes dryer, dishwasher, as well as the omission of resistive appliances (such as heaters, hot water cylinders, cooking hobs), due to these services being supplied by reticulated gas.

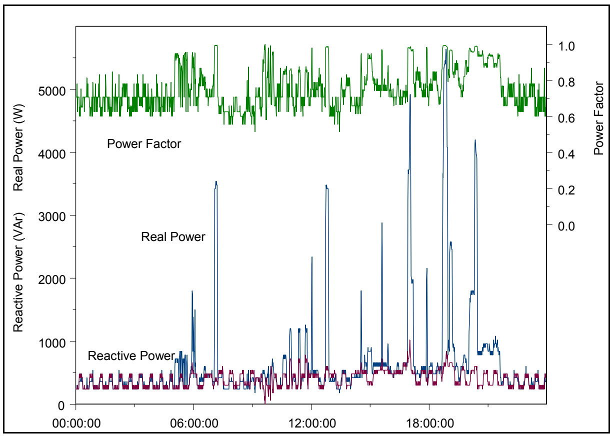


Figure 53: House 1 summer day – real & reactive power, power factor

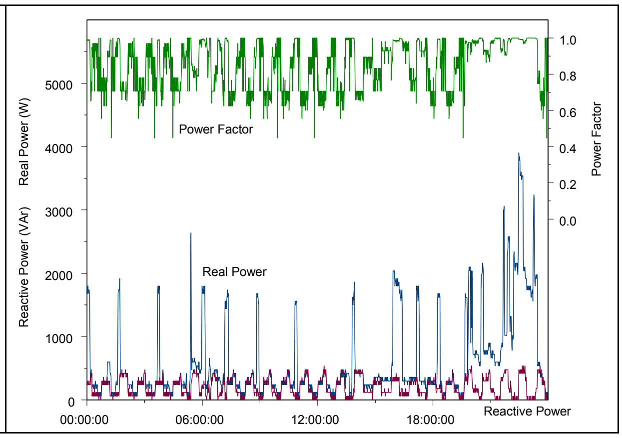


Figure 54: House 6 summer day – real & reactive power, power factor

At the other extreme from House 1 is House 2 which has a power factor of 0.97. This is a single-occupant household with a single modern fridge freezer (made in 2001), with no clothes dryers or dishwashers. Heating is provided by a number of portable electric heaters with no fan heaters, air-conditioners or dehumidifiers.

The monitoring for the TML metered households was undertaken at household level with no specific appliance monitoring undertaken. It may be beneficial in future studies to also undertake appliance monitoring to assist with determining which appliances most contribute to poor power factors at a household level.

Figure 55 provides average time of day profiles for the reactive power, real power and power factors for each household. Over the course of a day, the reactive power has a flatter profile than the real power, suggesting that fixed (permanently operating) loads made up a sizeable proportion of the reactive energy consumption. These fixed loads could be made up from appliances left in their standby mode and other appliances that are left permanently on. Table 58 provides an estimate of the reactive energy from the appliances that are permanently on. This estimate has been constructed by taking the minimum value of the reactive energy profile as an estimate of the constant reactive load along with an estimate of the varying reactive load (the average difference of the reactive energy profile from this constant reactive baseload).

House 1	House 2	House 3	House 4	House 5	House 6	House 7a	House 8	House 7b
85%	70%	70%	67%	77%	79%	72%	63%	86%

Table 58: Average fraction of reactive energy from constant load

The average daily profiles of the power factor are also shown in Figure 55, and are frequently of a similar shape to that of the real power. However, they appear to have broader peaks than is the case for the real power.

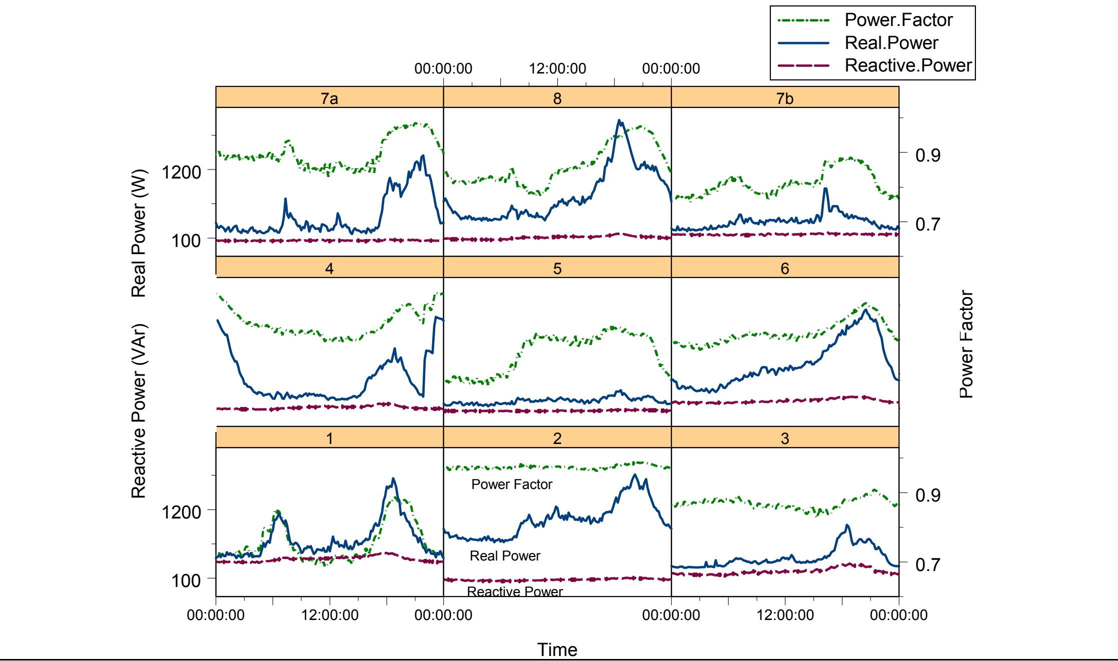


Figure 55: Average daily profiles by house – real and reactive power, power factor

11. HEEP APPLIANCE OWNERSHIP MODELS

The HEEP appliance ownership models are an attempt to understand some of the factors that influence the type and number of appliances that households have. For example, do households with more occupants have more TVs?

These models were developed for use in the HEERA model (see Section 12). However, practical issues have prevented their full inclusion at this time.

The modelling is challenging, as there is often not a strong reason based on obvious physical or behaviour factors for variation in the ownership of a particular appliance. When people’s behaviour or personal choice dominates variation then almost anything is possible.

There are often correlations between variables e.g. income and floor area, and floor area and number of occupants. Sometimes these mask other relationships, or make a model appear to be nonsense. Relationships may also be non-linear (e.g. a large number of occupants (>5) is often associated with overcrowding), so the number of appliances might increase with the number of occupants up to a point, then level out or decrease.

11.1 Data

The data is from the HEEP occupant survey and the power measurement audit, depending on the appliance type.

HEEP occupant appliance ownership information was collected as part of the HEEP survey questionnaire done during the installation of the monitoring equipment. The occupant was asked from a list of major appliances how many they had, and how often they were used. Appliances included heaters, cooking appliances, whiteware, and other common or major appliance types.

Another source of information is the HEEP power measurements. This involved an auditor going through the house and noting down all the electrical appliances in the house, recording various details such as type, make and model, label details and power measurements. This gave information on appliances that were not part of the occupant appliance survey, and also sometimes picked up appliances that the occupants had not reported. A total of 11,891 appliances were surveyed (see Camilleri, Isaacs and French 2006).

11.2 Methods

The modelling methods were various modelling techniques from S-Plus. The main techniques used were multi-variate linear models.

Various other modelling techniques were tried. Principal component analysis and factor analysis failed to give a compact set of transformed variables for the data sets trialled. Cluster analysis also failed to give cluster groupings that did not overlap extensively. These techniques seem to be of no practical value for modelling or exploring the HEEP appliance stock data. Decision tree models were trialled with some success, and have the advantage of being intuitive and visual, but could not be practically implemented in the HEERA model and so were not developed further.

Some data required by the HEEP models for individual houses will not be available on a regional basis. This is particularly problematic with tree models (initially trialled as appliance ownership models) as these models cannot work from aggregated data. To overcome this limitation, the data was aggregated on a location-by-location basis (groups of 6-24 houses depending on the strata or cluster size), and then linear models were applied to this data. This approach was very successful.

There are several other modelling methods that could be applied. Binary logistic regression could be used to model Yes/No categories of ownership. However, for many appliances some houses have more than one of a particular appliance type. Ordinal logistic regression could be used in these cases. Another approach is to use Poisson regression models to model the number of appliances per house. Unfortunately these types of model are more difficult to use than linear regression, and the interpretation of the model terms is not always easy to understand. For these reasons linear models on the average number of appliances by region were used.

The individual models were developed by exploring the effects of the various variables, keeping those that explained the most variation and discarding ones that did not make a useful contribution to the model. In cases where two separate terms were competing, with one tending to displace another, a decision was made on practical grounds – which variable is the most sensible one to use in a particular model considering which appliance type it was.

11.3 Overview of models

These models are based on regional average data so the averages per region are used e.g. average floor area. For categorical variables such as **LifeStage** it is the fraction of households in each region that belong to each category.

These models are not valid for individual households, as they will give nonsense answers e.g. negative numbers of appliances or very large numbers. They can only sensibly be used for the averages of large regions.

The model terms used are:

Degree Days: heating Degree Days base 15°C – the more the number of Degree Days, the colder the climate

Floor Area: total floor area excluding garages

Floor Area × No. of Occupants: interaction between floor area and number of occupants

Equivalised Income: total income divided by the square root of the number of occupants

Equivalised Income Q3 etc: fraction of households in the region that are in each quintile

LifeStage 'pre-school': fraction of household whose youngest member is pre-school age

LifeStage 'school age': fraction of household whose youngest member is school age

LifeStage 'working age': fraction of household whose youngest member is working age

LifeStage 'retired': fraction of household whose youngest member is of retirement age (>64)

Number of Adults: average number of adults per house

Number of Occupants: average number of occupants per house

Built before 1978: fraction of households that were built before 1978

Tenure: own with mortgage: fraction of households that are owned with a mortgage

Tenure: own without mortgage: fraction of households that are owned without a mortgage

Tenure: rent or lease dwelling: fraction of households that rent or lease.

An example is provided of how the calculation works for the number of TV decoders per house. The model terms are an intercept of 0.47, Equivalised Income Q5 term of 0.47, and LifeStage 'school age' term of -0.54. In a region with 20% of households in the school age, and 10% of houses in Quintile 5 for equivalised income, the model prediction would be:

0.47 + 0.47*0.1 - 0.54*0.2 = 0.41 TV decoders per household average for the region.

The model terms are given for all the models in Table 59. These models give some limited insight into why households have the appliances that they do.

The Model R^2 value describes how much of the variation in appliance ownership by region is explained by the model. Most are around 0.4, so about 40% of the variation is explained by the model. Some are a bit better, some not as good. The best by far at 0.81 is for heated towel rails.

Only clothes dryers appear to be influenced by climate, including in the model a term for Degree Days (which range from 195 in Kaikohe to 2,146 in Invercargill). None of the other appliance ownership models show any influence of climate.

Four models (computer, dishwasher, electric blanket and towel rail) show an influence of floor area. Other models that might be expected to include floor area, such as the various refrigeration models, do not. Floor area is weakly related to the number of occupants, and sometimes other terms (e.g. life stage) in some way also capture relationships around floor area and number of occupants. What is clear is that the socio-demographic characteristics appear in the models more often than house physical characteristics, such as floor area or house age.

The number of adults and number of occupants only appear in one model each. This is perhaps surprising. Ownership of many appliances might reasonably be expected to be influenced by the number of occupants, but this does not appear to be the case. Other socio-demographic characteristics appear to take precedence.

So what is going on here? Are factors such as life stage, income and tenure really more important or better predictors of appliance ownership than factors like floor area and number of occupants? It seems so. Acquisition of appliances is likely a very complex process, compounded by the various life stages that a household goes through as it forms, develops and breaks up, and the long operational life of many appliances. These life stages are often associated with particular activities – such as starting or ending careers, starting or raising a family, and retirement – and these activities can have a profound impact on the consumption patterns in a household. For example, a retired household might not have the means to acquire a large house or a lot of appliances, but may have acquired them in a previous life stage and still have them. Retired people may not have the means or need to replace them if they break, but may keep them until they break down or they move house.

The refrigeration models are particularly interesting. None of the four models show any influence of floor area or number of occupants, as might be expected. More people consume more food so it would be reasonable to expect some effect. This effect may be coming through the life stage and income factors. The school age term appears in all of them, and is a negative term for fridge freezers, so school age households are more likely to have a separate fridge and freezer than a combined fridge freezer. This makes sense in terms of the volume of food required for a school-age household with growing children. Also, a fridge acquired during previous life stages like pre-school or working age might have worn out or be too small.

Retired households most often have two refrigeration appliances, even if there is only one person in the household. Maybe what is happening is that many one-person retired households used to have two people, and one has died or gone into care, and it takes some considerable time for the remaining person to adjust their refrigeration appliances, if they ever do. Overall, retired households are likely to have a freezer.

The long working life and high cost of refrigeration appliances may result in households responding slowly to changes in their refrigeration needs, particularly since major changes in household requirements may correspond to major changes of life stage at which resources may be limited (e.g. new baby, retiring).

Income is particularly interesting. We have used equivalised income, which is the income divided by the square root of the number of occupants (see Section 3.7). Total income is usually not as useful, as it does not relate well at all to disposable or discretionary income. A household with a total income of $50,000 could have one occupant or six, and probably with a very different standard of living.

Equivalised income is strongly related to life stage, with the overall pattern being much higher equivalised incomes in households at the working age life stage, and very few households at the retired life stage above income Quintile 3. Quintile 5 households often have few people e.g. a single professional or a working couple. What is often seen in the appliance ownership models (and some energy models also) is an increase in the number of appliances up to Quintile 3, then a decrease, with Quintile 5 often as low as Quintile 1. The relationship between income and appliance ownership is often not a simple one.

Note: terms in **bold** explain the most variation and those in italics the least. **Model**	**Average Number per House**	**Model R²**	**Intercept**	**Degree Days (per 1,000)**	**Floor Area (per 100 m²)**	**Floor Area × No. of Occupants**	**Equivalised Income per $10,000**	**Equivalised Income Q3**	**Equivalised Income Q4**	**Equivalised Income Q5**	**LifeStage "pre- school"**	**LifeStage "school age"**	**LifeStage "working age"**	**LifeStage "retired"**	**Number of Adults**	**Number of Occupants**	**Built before 1978**	**Tenure: own with mortgage**	**Tenure: own without mortgage**	**Tenure: rent or lease dwelling**
Computer	0.85	0.43	-0.02		0.14	*0.0013*	**0.15**				-0.94									
Dehumidifier	0.22	0.30	-0.20				**0.08**													*0.26*
Dishwasher	0.41	0.35	0.04		**0.36**				*0.57*			-0.51								
Dryer	0.64	0.53	0.40	*0.10*			**0.11**	-0.36							-0.03					
Electric blanket	0.80	0.48	1.11		**3.32**		-0.49				-2.65		*-1.4*							
Freezer	0.68	0.46	0.09					**1.10**				1.13							*0.42*	
Fridge	0.66	0.33	0.09					**0.81**				*0.58*								
Fridge freezer	0.65	0.44	1.41					-0.72	*-0.81*			**-1.03**								
All refrigeration	1.99	0.52	1.59					**1.23**				1.27					-0.55		*0.65*	
Microwave	0.90	0.24	0.94					0.23									-0.14			
TV decoder	0.41	0.42	0.47							0.47		-0.54								
Stereo	2.56	0.44	2.74					**-2.16**		0.81				*0.88*						
Towel rail	0.55	0.82	-0.82		**1.45**		*0.11*										-0.62	-0.61		
TV	2.10	0.32	1.37								*-1.33*					0.36				**-1.11**
VCR	1.13	0.40	1.31					**-1.20**											*0.67*	

Table 59: Summary of the appliance ownership models

Note: terms in **bold** explain the most variation and those in italics the least. **Model**	**Floor Area**	**Floor Area x No. of Occupants**	**Equivalised Income**	**LifeStage "school age"**	**LifeStage "working age"**	**LifeStage "retired"**	**Microwave Used?**	**Number of Adults**	**Number of Occupants**	**Tenure: own with mortgage**	**Tenure: own without mortgage**	**Tenure: rent or lease dwelling**	**Volume of Refrigerator (l)**	**Year Refrigerator Made**	**Year x Volume**	**VCR Standby power**	**Total Hot Water Volume**
Dehumidifier																	
Instant gas hot water			**Pos**						*Pos*								
Electric hot water, delivered	*Pos*			Pos	Pos	Pos			**Pos**								Pos
Gas hot water, delivered									**Pos**		*Pos*	*Pos*					
Electric hot water, wetback connected, delivered				**Pos**	**Pos**	**Pos**			*Pos*								
Dishwasher				**Pos**	**Pos**	**Pos**			*Pos*								
Dryer	Pos		Pos						**Pos**		*Pos*	*Pos*					
Electric blanket																	
Electric jug	**Pos**		Pos						Pos		Pos	Pos					
Freezer													*Pos*	**Pos**			
Fridge													**Pos**	*Pos*			
Fridge freezer													Pos		Pos		
Lighting (fixed)	Pos	Pos															
Microwave									Pos								
Range		Pos					**Pos**		Pos		*Pos*	*Pos*					
Stereo			*Pos*	**Pos**	**Pos**	**Pos**											
Toaster																	
VCR																Pos	
Washing machine									Pos								

Table 60: Summary of the appliance energy models

11.4 Entertainment equipment

The type and use of entertainment equipment is changing rapidly as new technologies are becoming available. Historically, the New Zealand Television Broadcasters Council has surveyed the types of entertainment appliances in New Zealand households in some detail (Figure 56). This tracks the gradual introduction of new entertainment appliance types: first colour TVs, which gradually displaced black and white TVs, then grew so households with more than one TV set became more common. It was not until 1998 that the TV licensing fee became per household rather than per TV fee. The licence fee was dropped in 2000.

Home videotape recorders became available in the early 1980s, and achieved a rapid uptake to stock saturation levels in excess of 80% of households. Despite this technology now being obsolete, with only a few manufacturers worldwide still making VCRs, the stock levels in New Zealand households are still very high. The DVD player was introduced around 2000, and is rapidly heading towards saturation levels, growing at 10-20% per year. The price of DVD players dropped extremely rapidly, with cheap units sold for under $80.

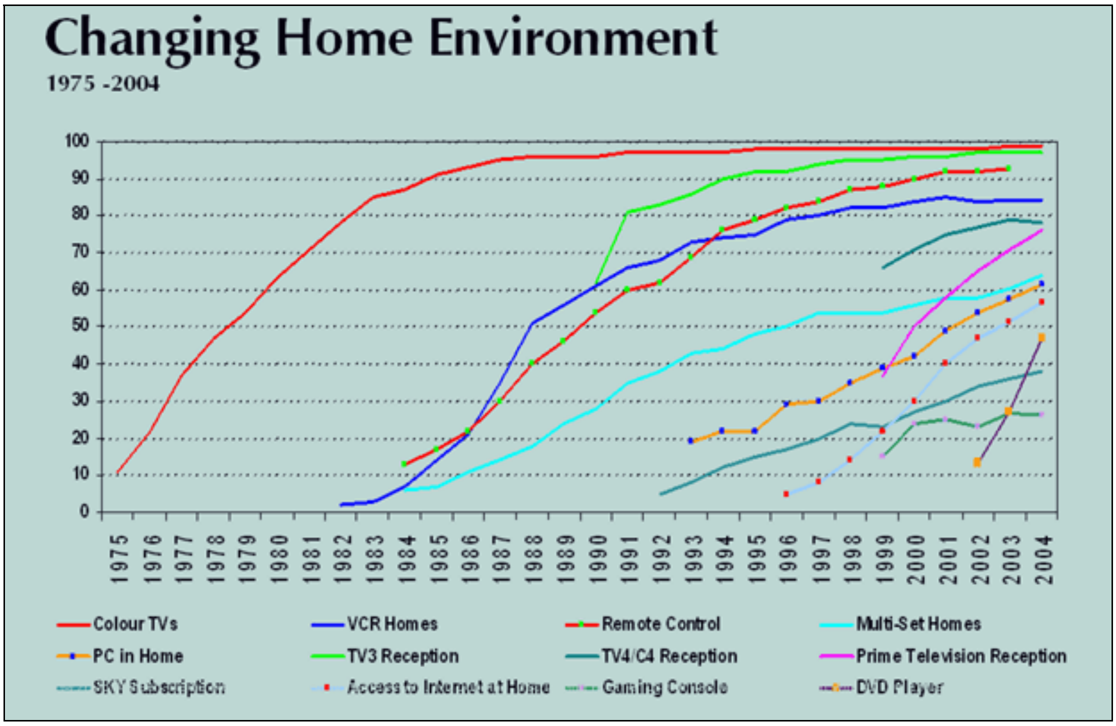


Figure 56: Long-term stock levels of home entertainment appliances[17]

How the home entertainment market will develop over the next 20-30 years is highly speculative, as new transmission technologies and new appliance technologies are rapidly being introduced.

New Zealand is expected to introduce a public digital TV network over the next few years, alongside the existing privately owned Sky (digital and analogue) and Saturn (cable) networks. This will require a new set-top box for most households, although

[17] Source: www.nztbc.co.nz/research/story.html?story_changing_home_enviroment.inc.

existing TVs should be compatible for some time. The planned switch-off date for analogue public TV broadcasts is 2012.

In home video recording, DVD recorders are becoming more common as the prices are dropping. Other technologies are set to challenge the DVD recorder, most notably at the moment various hard disk drive systems like the TiVo that is available in the US and other countries. Sky may be introducing a Sky+ decoder box with a built-in hard drive recorder. Some DVD recorders already have a large capacity hard drive installed for recording programs that are not intended to be stored and watched often. Various portable devices can also store digital video.

The home computer is also undergoing change (‘convergence’ is the technical term), with so-called media centre computers already available at a modest price premium. The media centre computer is a standard PC type computer with a front panel that looks like a stereo receiver unit with volume control and TV and radio-type controls, so that it can be used like a TV, radio or video recorder from a remote. They can record TV programs to the hard disk, like a TiVo unit. Microsoft has a version of the Windows operating system dedicated to this use, and the long-term vision seems to be a single PC/Windows-based computer that manages all video and audio media in the house, and feeds video and audio to monitors and speakers around the house by some kind of in-home network. How the average consumer will come to accept such a potentially complex set-up is debatable, given the number of people who cannot set-up a home theatre system or program a VCR.

LCD and plasma TVs are rapidly gaining market share, and leading the move to large TV sizes. Whereas 25 years ago a 21” TV was large, 25-29” TVs appear to be average sized for new TVs, and larger sizes are available in CRT, LCD or plasma models. The long-term prospect seems to be the obsolescence of the CRT screen as LCD and plasma models become cheaper, with the likelihood of other novel display technologies. The natural end point of these technologies is true flat screens printed on flexible plastic that can be hung like a poster. With their expected low cost and ease of installing it appears likely that many households could end up with many of these in rooms throughout the house, with a wireless media centre feeding video and audio. The current level of on average 2.1 TVs per house may be nowhere near saturation levels. CRT monitors currently use about twice the energy of a comparably sized LCD monitor (one-off measurement of 28 W for a 17” LCD monitor and 68 W for a 17” CRT monitor).

This is a future dramatically different from a slow saturation of current technology, with a gradual replacement by improved technologies that do the same thing as the previous technology. Trying to represent these possible futures in the HEERA model is a big challenge.

Anticipated trends are:

1) Rapid increase in digital TV receivers once free-to-air transmission starts
2) Increase in the number of TV screens per household
3) Increase in the average size of TV screens
4) A gradual phase-out of CRT TVs as LCD, plasma and other types take over, possibly with reductions in energy use per TV
5) VCRs to eventually disappear, likely all but gone within 10 years, and replaced by DVD recorders, various types of hard drive systems, or media centre computers

6) Large growth in home wireless networks for computers and audio-visual media.

Unless these new appliances have much lower power consumption and standby power than their existing equivalents, then energy consumption for entertainment appliances will increase beyond the current 3-5% of electricity consumption (see Section 3.5).

Proposed interim targets for the standby and power consumption of set-top boxes in Australia are 1 W for off-mode, 4 W passive, and 11 W on in 2006, and 0.3 W, 1 W, and 6 W respectively by 2012. It would be a good idea to bring these targets forward or introduce a MEPS to ensure that the first wave of set-top boxes for free-to-air digital TV use the best available technology with the lowest power consumption, otherwise extra generation may be required.

12. HEERA MODEL DEVELOPMENT

The development of a residential database and scenario model to store HEEP project information and to enable the stakeholders to utilise it to their best advantage is an essential part of the project and the subject of this report. This residential scenario model is referred to as the Household Energy Efficiency Resource Assessment (HEERA) model and database.

The HEERA model and database can be summarised as a modelling framework with which it is possible to:

- construct a set of energy use scenarios for the residential sector of New Zealand
- analyse and compare the energy use of these scenarios
- develop energy-efficiency actions and estimate the impact of the actions on scenarios.

The background and theoretical basis of the HEERA model and database, and the development of an Excel version of the HEERA model, have been described in the HEEP Year 8 (Isaacs 2004) and Year 9 reports (Isaacs 2005). This report summarises the work undertaken in Year 10 of the HEEP project and addresses the following aspects:

- development of the basic HEERA Access model structure
- demonstration of the use of the HEERA model to construct four scenarios.

12.1 Overview

The relationships, variables and drivers that determine the stocks and energy demand of the energy-using appliances used in the HEERA model have been discussed in the HEEP Year 8 report (Isaacs 2004). These relationships, variables and drivers have been incorporated in dwelling and appliance stock algorithms, and in the energy use algorithms for the different residential end-uses. The algorithms are employed in the HEERA Access model and database.

The HEERA modelling structure is divided into three modules as shown in Figure 57:

- **Module 1: HEERA Excel model and database:** in this module raw data is processed with Excel spreadsheets into HEERA Excel business-as-usual (BAU) scenario-dependent and scenario-independent tables. These tables serve as input to the HEERA Access database. The HEERA Excel model validates the HEERA Access model algorithms and BAU scenario database tables, and checks that the data led to the correct values if the algorithms are applied to it.
- **Module 2: HEERA Access model and database**: this is the main module which provides the following capabilities:
    - constructs energy use scenarios for the residential sector of New Zealand
    - analyses and compares the energy use, energy supply and GHG emissions of the constructed scenarios
    - constructs energy-efficiency actions and estimates the impact of these actions on the BAU and other scenarios
    - constructs standard format output tables that contain the results of scenario analyses and comparisons, and the impact of energy-efficiency actions.

- **Module 3: HEERA Output processor and database**: the module uses the HEERA Access database standard format output tables to produce formatted output tables and charts according to the requirements of a HEERA user. This module could be in terms of Access or any other suitable modelling framework.

Module 1	***HEERA Excel model and database:*** • Process raw data into business-as-usual (BAU) scenario and supporting scenario-independent database files • Validate HEERA Access model algorithms and BAU scenario database • Input prepared for the HEERA Access model and database
	↓
Module 2	***HEERA Access model and database:*** 1. BAU scenario and database files used to construct energy use scenarios 2. Analyse energy use and GHG emissions and compare values 3. Create energy-efficiency actions and estimate impact on BAU and other scenarios 4. Construct standard format output tables
	↓
Module 3	***HEERA Output processor and database:*** • Produce formatted output tables and charts

Figure 57: HEERA modelling framework

12.2 Database design

The interactions between the representative blocks of tables, queries and forms that are incorporated in the three modules of Figure 57 are shown in Figure 58. In the final database design diagrams the interactions between the individual tables, queries and forms of these blocks are shown. These are not given in this report.

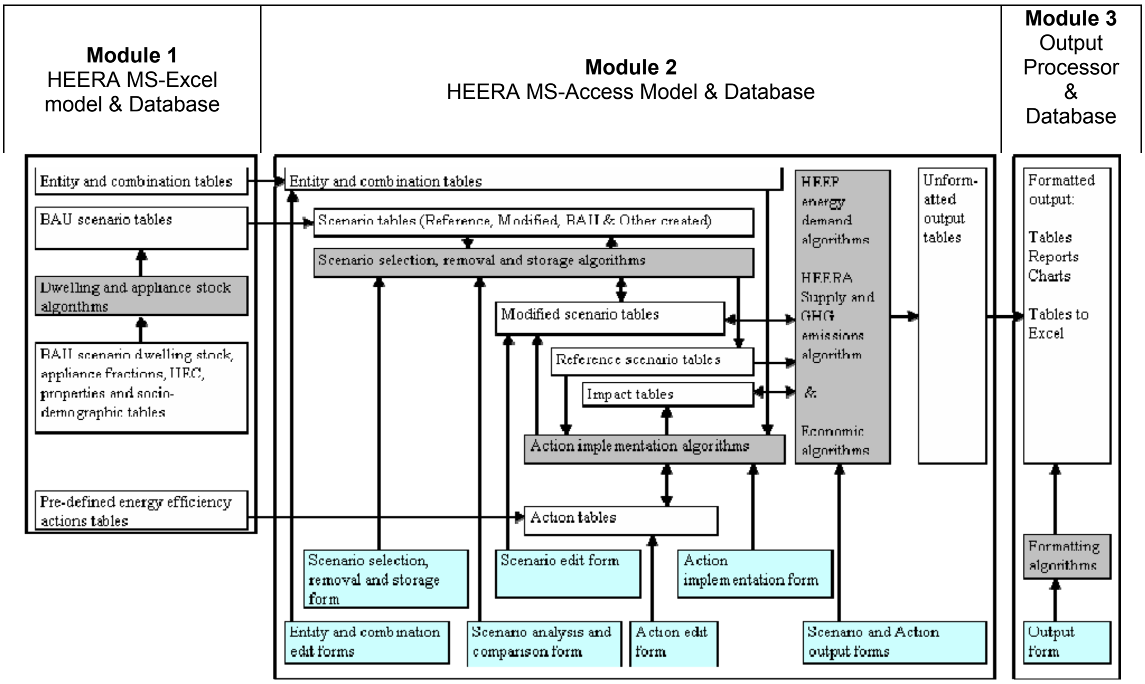


Figure 58: HEERA flow diagram with representative tables, algorithms and forms

12.3 Excel and Access database tables

The database information is organised in terms of records pertaining to scenarios, energy-efficiency actions and those independent of scenarios and energy-efficiency actions.

12.3.1 Scenario dependent data

The scenario and energy-efficiency dependent data is time-dependent and covers the period 1950 to 2050. In the HEERA BAU scenario, the historic period is from 1950 to the last available historic data point and from this point to 2050 contains projected data. Due to the fragmentary nature of some of the historic data, sometimes representing only a few disjointed years, interpolation of historic data is also required.

Scenarios contain energy use records for a wide range of appliances for all residential end-uses, where the total delivered end-use energy of a scenario is aggregated over appliance records. The energy use records are divided into dwelling, appliance fraction and energy intensity records.

In addition to energy use records, records characterising the thermal envelopes used in the scenario in terms of dimensions, thermal insulation, infiltration, thermal set point and heating schedule, and other miscellaneous records are required.

12.3.2 Energy-efficiency dependent data

Action records define all the implementation details of an energy-efficiency action unless the economic impact of the action is required, in which case records specifying the capital and annual costs of implementing the action are also needed.

12.3.3 Scenario independent and energy-efficiency independent data

These tables can be entity tables, tables joining entity indices such as supply to demand ratios and GHG emission ratios, energy prices, report specifications and references.

12.4 Graphic User Interface forms and VB procedures

Users interact with the HEERA Access model and database through forms, which act as the Graphic User Interface (GUI). Control objects on these forms are used to input data. In most forms these controls are connected to Visual Basic (VB) procedures which call macros that execute the algorithm queries.

12.5 Demonstration

Four scenarios were constructed and compared to explore what would happen to dishwasher electricity demand in Auckland if the household life stage changes linearly from ‘Working’ in 2004 to 100% ‘Retired’, ‘School’ and ‘Pre-school’ life stages in 2020. For all scenarios the household size (four people) and dishwasher appliance stock remain the same over the whole period. These scenarios were also used to demonstrate the HEERA Excel model and database in the HEEP Year 9 report.

12.6 Discussion

The development of the HEERA Excel model and database during the HEEP Year 9 phase proved very useful for the development of the HEERA Access version. This provided essential tests for the type, use and format of the HEERA Access data and algorithms, against which the results of the Access version could be evaluated. This is especially the case for the ALF3 space heating algorithm, where data has to read from many sources and choices and accurate relationships are needed for the dwelling heating energy to be correctly calculated.

This is part of the most challenging section of the HEERA Access development, namely finding the best ways of calculating the HEEP and HEERA energy demand algorithms, where these are required for estimating the unit energy consumption of appliances.

The next phase of the HEERA Access model and database consists of adding and testing the input and output GUI forms for the HEERA Access model.

13. DOMESTIC HOT WATER

The HEEP Year 9 report provided a detailed historical and current review of hot water systems and energy use (Section 11) and updated information on standing losses of different hot water systems (Section 12). This year we review the proportions of the different fuels used for hot water supply, and compare New Zealand hot water fuels to those used in other countries.

13.1 Energy use for domestic hot water

Figure 14 (Page 19) showed that hot water uses on average 29% of household energy. Although DHW is not the largest single household energy use, it is often the largest energy use in a single appliance in the home. This proportion of household energy was consumed in one cylinder in 90% of the HEEP houses, two cylinders in 9% and in three cylinders in only 1% of the HEEP houses.

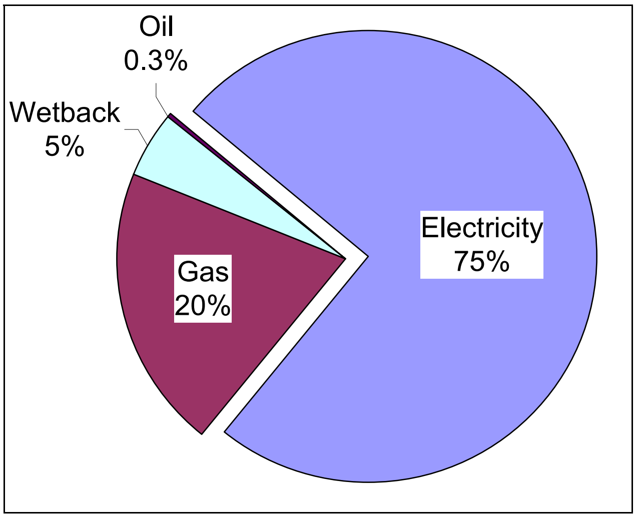


Figure 59: New Zealand domestic hot water fuels

Hot water fuels are dominated by electricity, as shown in Figure 59. Three-quarters (75%) of the ‘purchased’ energy is from electricity (i.e. the energy as delivered to the cylinder, not as delivered into the hot water after taking account of appliance efficiency). In 2004, 14.1% of New Zealand households had a gas mains connection (Statistics NZ 2004h). Unfortunately, the Household Economic Survey has only recorded the presence of hot water systems since 1998 (Statistics NZ 1999h), and does not publish the fuel types used for the production of hot water.

Only a few energy end-use estimates have been prepared prior to the HEEP work:

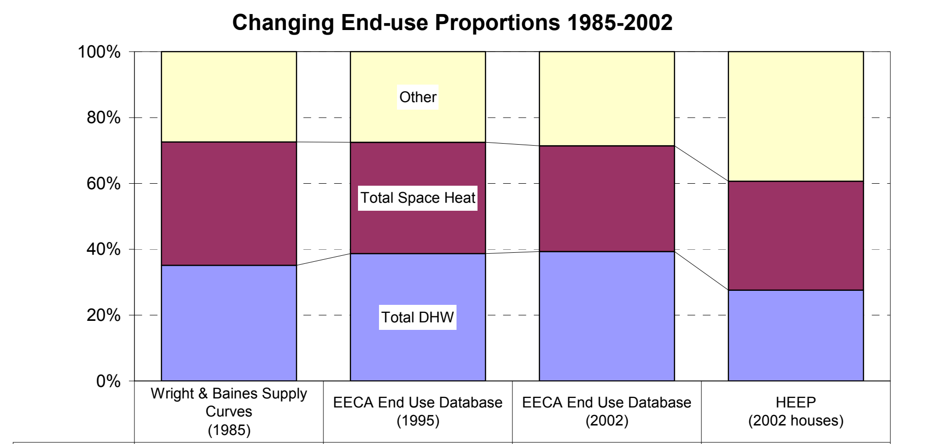
- **Supply curves of conserved energy:** Wright and Baines (1986) provided the first comprehensive estimate of energy end-uses in the residential sector. They note that “data for estimating energy use in domestic water heating are not plentiful” and reference their data to the 1971/72 Household Electricity Study (NZ Dept of Statistics 1973), and electric supply authorities which meter water heating separately.

- **EECA End-use Database:**[18] The EECA database is a top-down estimation of more detailed information, allocating energy use to different sectors, regions, end-uses, technologies and fuels based on known information about the distribution of sectors and what energy they use and how they use it. First prepared in 1995 (Aulakh 2000), it has been updated to 2002 and made freely available through the EECA website. It splits New Zealand energy use by 11

[18] Available at: www.eeca.govt.nz/enduse/EEUDBMain.aspx.

fuels, 32 sectors, 20 end-uses, 25 technologies and by all local authority geographical areas.

Figure 60 provides a comparison between the end-use data from Wright and Baines (1986), the EECA End-use Database for 1995 (Aulakh 2000[19]) and 2002 (web accessed), and the HEEP results.



	Wright & Baines Supply Curves (1985)	EECA End Use Database (1995)	EECA End Use Database (2002)	HEEP (2002 houses)
Other	12.9	14.2	16.8	24.8
Total Space Heat	17.6	17.5	18.8	20.9
Total DHW	16.5	20.0	23.0	17.4

Figure 60: Changing estimates of New Zealand residential energy end-uses

It can be seen from Figure 60 that the measurement-based HEEP work suggests a lower proportion of household energy is used by DHW than was previously thought – HEEP at 28% compared to 39% for the EECA End-use Database or 35% for Wright and Baines. It is not possible to determine whether this difference is due to changes over time or the different assumptions made in the earlier reports. It should be noted that the HEEP results do not necessarily suggest a decrease in hot water energy use, but rather a relative decrease due to increases in other energy uses.

13.2 International comparisons

It is easy to assume that the use of DHW and the systems used to provide hot water are internationally comparable. In order to explore this issue, data was obtained for an international comparison from the sources listed below:

- **Australia** – data for 2003 (ABS 2005)
- **Canada** – Energy Use Handbook 2005 (NRC 2005)
- **Europe** (selected countries) – various data sets from 1992 to 1995 (Lechner 1998)
- **England** – 2001 English House Condition Survey (ODPM 2003)
- **New Zealand** – 1996 Census (Statistics NZ 1998)
- **USA** – 2001 Residential Energy Consumption Survey (EIA 2004).

It should be noted that the different sources cover different time periods, and it is likely that different definitions have been used in the selection of statistics. As far as

[19] Table C8 *New Zealand energy end-use estimates by fuel type and by sector 1995.*

possible, appropriate adjustments have been made to ensure consistency based on the available documentation.

In particular, Lechner (1998) notes that their hot water system data for Germany and Portugal are of less certainty than for the other countries.

Figure 61 provides an international comparison of the percent of houses using electric hot water storage systems. The data sources are listed at the top left of Figure 61. The percentages of houses with electric hot water storage systems range from 5% in Greece through to 77% in New Zealand. The average for all Europe is 32%, while the two countries closest to New Zealand are Australia and Canada, both with 51%.

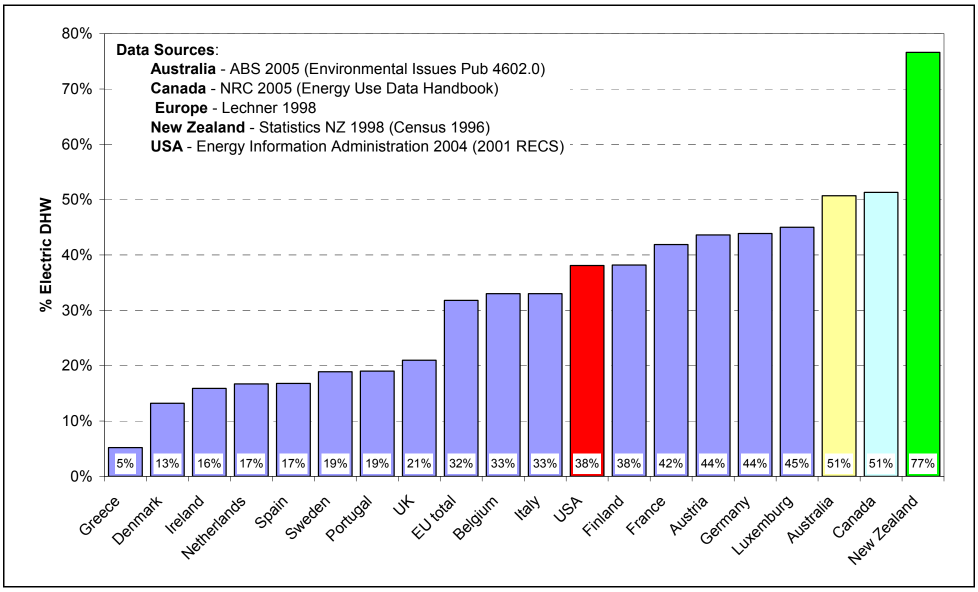


Figure 61: Residential use of storage electric hot water systems

Figure 62 and Table 61 compare the proportions of households (or 'dwellings') with the different fuels used for water heating in the USA, England, Australia, New Zealand and Canada.

DHW fuel	USA RECS 2001	England EHCS 2001	Australia ABS 2005	NZ Census 2001	Canada NRC 2003
Electric	38%	12%	51%	77%	51%
Natural gas	54%	76%	36%	7%	44%
Fuel oil	4%				4%
LPG	3%		3%		
Other (inc Don't Know, Solid)	1%	12%	12%	17%	0%

Table 61: DHW fuels – international comparison

New Zealand stands out as having the highest (77%) proportion of electric hot water systems, while England has the highest proportion of natural gas (76%) fuelled systems. Australia and Canada have similar proportions of electric systems (51%), but differ in the greater penetration of natural gas in Canada. The 'Other' fuels in Australia include solar water heating, bottle LPG and solid fuel systems.

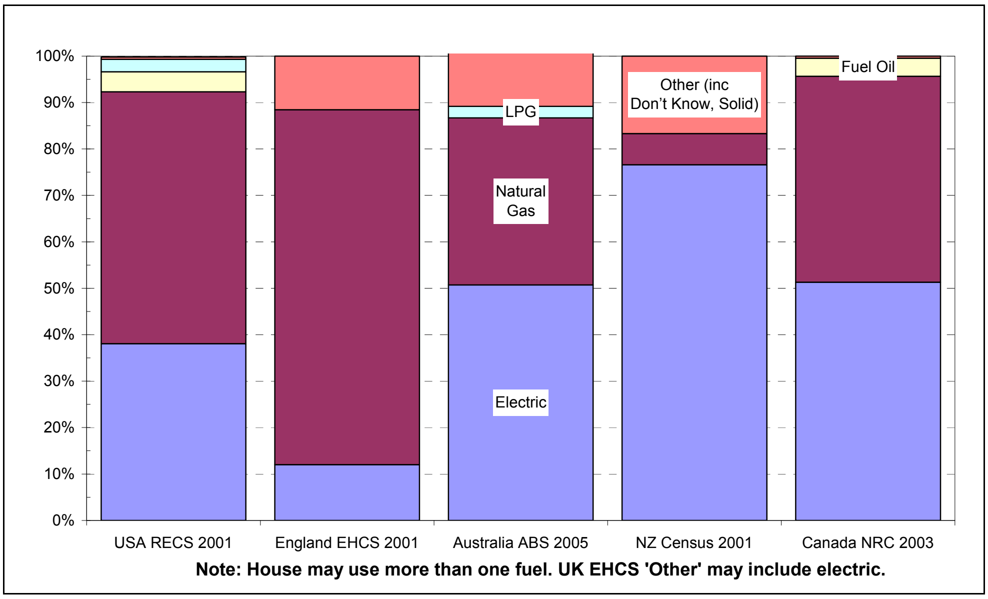


Figure 62: DHW fuels – international comparison

An examination of countries for which regional data is available suggests a link between the use of hydro-electricity and the proportion of houses served by electricity hot water systems.

A state-by-state examination of Australia reveals that Tasmania (90%) has the highest proportion of electric systems, followed by Queensland (68%) and New South Wales (64%) (ABS 2005). Ninety percent of Tasmanian electricity is generated from hydro sources (Hydro Tasmania 2005)

The large majority of Tasmanian hot water systems are mains pressure storage cylinders ranging in size from 160 to 315 litres, depending on household size. There is an element size limit of 16 W/litre cylinder capacity in order to reduce the hot water peak load, as most are on a continuous tariff i.e. a 180 litre tank can have a maximum 2.9 kW element (Pers. Com. Soheil Haee, Aurora Energy, 29 May 2006).

For Canada, the 2003 Survey of Household Energy Use (OEE 2006) shows that Québec (93%) had the highest percent of electric hot water systems followed by the Atlantic region (73%). Ninety-one percent of Quebec electricity is generated from hydro (82%) or nuclear (9%) sources, while it is 90% (87% hydro, 3% nuclear) in the Atlantic region (Statistics Canada 2004). Canadian domestic water heating systems are generally located in the basements of most houses, due to the extremely cold temperatures in winter. Typically these are mains pressure storage (pers. com. David Ryan, Director, Canadian Building Energy End-Use Data and Analysis Centre (CBEEDAC), 1 June 2006). The general tendency is for new Canadian houses to use natural gas rather than electricity for DHW (Aguilar et al 2005).

Figure 62 and Figure 61 taken together would suggest New Zealand has a unique national situation, with a very high level of electric storage water heaters. However, even in countries with a relatively low overall proportion of electric storage hot water systems there are regions with even higher proportions that are found in New Zealand. In addition, New Zealand has a very high proportion of low pressure hot water systems.

14. DISCUSSION AND CONCLUSIONS

This report, the 10th annual HEEP report, continues our practice of releasing information to a wider audience as soon as it becomes available. With the completion of data monitoring in May 2005, the analysis now presents reliable and complete information on energy use and end-uses for New Zealand.

HEEP has demonstrated the benefits of basing analysis on actual data throughout its life. The latest revision of New Zealand's energy statistics to take account of the new HEEP knowledge is yet another example. The completion of the HEEP research in 2007 will provide an opportunity to bring together the wide range of research results.

A highlight of the past year was the Year 10 celebration. HEEP researchers and funders were joined by a range of organisations that have made use of the HEEP results and those that can see opportunities for the future.

Those with any interest in the HEEP results are invited to contact the research team at BRANZ. Full contact details are given in Section 1.3.

14.1 Key results

The following section provides a brief summary of the key results discussed in this report, divided into new knowledge on: energy use and end-uses; social issues; mitigating climate change; energy planning; and electricity efficiency.

14.1.1 Energy use and end-uses

- **Non-normal distribution of household energy use**: The top 20% of households use over 14,450 kWh/yr and account for 36% of total energy use, while the bottom 20% use under 6,940 kWh/yr and account for only 9% of energy use.
- **Consistent regional total energy use**: Total energy and electricity use per household appears to vary little by region, although the end-uses and the per occupant use differ. Regional breakdowns are provided for total, hot water and space heating energy use by fuel, and annual average energy use per house for selected end-uses.
- **Low temperature heat is the main use of household energy**: 63% of household energy is used for space heating (34%) and water heating (29%), at temperatures below 100°C.
- **Solid fuel is the main space heating fuel**: 56% of primary space heating energy is provided by solid fuel, although after taking account of appliance efficiency this reduces to about 45%. Even so, the use of solid fuel in New Zealand houses is the equivalent of a 530 MW power station feeding conventional resistance heaters, or 180 MW feeding heat pumps (COP = 3). Reducing the use of solid fuel heaters will result in a significant growth in the peak demand on the national electricity grid. Houses heated with enclosed solid fuel burners tend to be warmer than the average, regardless of house age. Descriptive statistics on solid fuel use are provided.
- **Other (non-low grade heat) uses are electricity dominated:** Appliances account for 37% of household total energy use or 54% of household

electricity use. The breakdown is: plug-load appliances (13%); refrigeration (10%); range (6%); and lighting (8%).

- **Electricity end-uses have changed proportions since 1971/72:** Hot water electricity use on average has fallen from about 44% of household electricity to about 34%. Appliances (including lighting and refrigeration) have increased in importance from 28% to 47% of household electricity use. The importance of electricity use for cooking ('range') has fallen from 13% to 7% of household electricity use, possibly due to changes in lifestyle.

14.1.2 Social issues

- **Fuel poverty is an issue in New Zealand:** The HEEP data reveals that while low income houses appear to value increased warmth, they are unable to achieve warm indoor temperatures (despite expending proportions of their income on energy which would be considered overseas to place the household in the fuel poverty category).
- **Māori households use less heating energy and are over-represented in the 'colder' temperature category**: The number of Māori households in HEEP is small, so no general New Zealand results can be provided. The Māori households in HEEP use less than the average heating energy and it must be of some concern that Māori households are over-represented in the 'cold' evening living room temperature category.

14.1.3 Mitigating climate change

- **Newer houses tend to be warmer in summer than older houses**: As there is little use of air-conditioning in New Zealand houses, the house age (decade of construction) and the local climate (average external temperature) together explain 69% of the variation in mean summer living room temperatures. The mean summer living room daytime temperatures show a trend of increasing by 0.25^{o}C per decade i.e. houses built at the end of the 20th century are 2.5^{o}C warmer than those built at the beginning. The reasons for this increase are not obvious (e.g. areas of solar glazing, thermal insulation etc), and are being further explored.
- **Newer houses are warmer in winter than older houses:** The heating schedule, climate, heater type and fuel, house age and thermal insulation all play important roles in winter evening temperatures. Winter evening living room temperatures average 17.9°C, although the mean range is from 10°C to 23.8°C. They show an average rise of 0.2°C per decade of house construction i.e. houses built in 2000 are 2°C warmer than houses built in 1900.

14.1.4 Energy planning

- **Appliance ownership models:** A range of model algorithms have been developed from the HEEP data (including the monitored data, occupant surveys and house audit) to help understand some of the factors that influence the type and number of appliances found in households. These factors include variables based on location, income, life stage, occupant numbers, house age and tenure. Not all variables apply to all appliances and the differences can be most revealing.
- **HEERA model software continues in development:** The Household Energy Efficiency Resource Assessment (HEERA) model is undergoing final

preparation of the database and scenario modelling software to develop a powerful analysis tool. This will support a wide range of 'what-if' type questions which, through the use of appropriate scenarios, will be able to be used for a wide range of policy analysis.

14.1.5 Electricity efficiency

- **Definitive standby and baseload power estimates are provided**: Total standby and baseload electricity is estimated at (112±4) W. Standby power consumption is estimated at (57±4) W, heated towel rail use at (21±2) W, and faulty refrigeration appliances at (15±10) W. Minor loads are (4±1) W and lights that are always on are a further (7±3) W, leaving unaccounted only (8±12) W which is not statistically different from zero. This is equivalent to a cost of about $150 per house per year, and over all houses is equivalent to about 10% of total average residential electricity use.
- **1978 insulation requirement has not reduced electricity use**: Since 1978 all new houses have been required to be insulated, yet there has been little research on the effects of this requirement. HEEP is not a longitudinal, retrofit study but it does provide the opportunity to compare the energy use and characteristics of pre-1978 and post-1978 houses. The analysis concludes that although the mandatory insulation has led to warmer houses and less energy use, most of the reductions in energy use have come from non-electric fuels. Based on the HEEP data, a minimum sample size has been calculated for a future retrofit study to explore the actual energy consequences of thermal insulation.
- **Taking faulty refrigeration appliances out of service offers real electricity savings**: Refrigeration appliances (refrigerators, combination fridge freezers and freezers) use, on average, (1,119±72) kWh per household per year, or approximately 15% of household electricity. HEEP identified faulty refrigeration appliances as a significant electricity load in the Year 8 report (Isaacs et al 2004). About 7% of domestic refrigeration appliances are faulty, and 9% operate marginally. An overseas algorithm has been adapted to New Zealand refrigeration appliances, tested and found to identify faulty refrigeration appliances reliably.
- **Low power factors may provide opportunities to reduce electricity system load:** A total of nine houses (three houses per year for three years) were monitored with meters that reported both real and reactive power, providing information on the household power factor over time. The lower the power factor, the greater the load on the electricity system. The mean power factor varied from 0.76 to 0.97, with an overall mean of 0.86, but analysis is also reported for selected time periods.
- **New Zealand has the highest dependence on electric hot water systems in international sample:** Electricity provides three-quarters (75%) of energy used for hot water, with gas (20%) and wetback (5%) providing almost all of the rest. Seventy-seven percent of household hot water cylinders are electric – the highest proportion for any country. Combined with the high proportion of low pressure systems (72%) this creates a unique situation. The shift towards mains pressure gas hot water systems is likely to have a significant impact, not only on energy but also on water use.

14.2 Future

This will be the final HEEP annual report. With the completion of data collection we can now publish final analysis on energy use and end-uses in New Zealand homes. A full summary report will be published later in 2007 that will bring together (and update) all the material covered in the various HEEP annual reports, and provide definitive results for future users.

Funding from the Foundation for Research Science and Technology for the HEEP research will now terminate on 30 September 2007. The Foundation, along with Building Research, have been the major funders of this work from its early days. We would like to thank both organisations for the ongoing support they have given this research.

15. REFERENCES

15.1 HEEP reports

Electronic (PDF) copies of all HEEP executive summaries are available from the BRANZ Ltd website (www.branz.co.nz). Printed copies are available from BRANZ Ltd at the addresses given in Section 1.3 at the current advertised price. The full reference for each report is given below:

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

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

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

Year 4: Camilleri M, Isaacs N, Pollard A, Stoecklein A, Tries J, Jamieson T, Pool F and Rossouw P. 2000. 'Energy Use in New Zealand Households: Report on Aspects of Year 4 of the Household Energy End-use Project (HEEP)'. BRANZ *Study Report 98*. BRANZ Ltd, Judgeford, New Zealand.

Year 5: Stoecklein A, Pollard A, Camilleri M, Amitrano L, Isaacs N, Pool F and Clark S (ed). 2001. 'Energy Use in New Zealand Households: Report on the Year 5 Analysis for the Household Energy End-use Project (HEEP)'. BRANZ *Study Report 11*. BRANZ Ltd, Judgeford, New Zealand.

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

Year 7: Isaacs N, Amitrano L, Camilleri M, Pollard A and Stoecklein A. 2003. 'Energy Use in New Zealand Households: Report on the Year 7 Analysis for the Household Energy End-use Project (HEEP)'. BRANZ *Study Report 122*. BRANZ Ltd, Judgeford, New Zealand.

Year 8: Isaacs N, Amitrano L, Camilleri M, French L, Pollard A, Saville-Smith K, Fraser R and Rossouw P. 2004. 'Energy Use in New Zealand Households: Report on the Year 8 Analysis for the Household Energy End-use Project (HEEP)'. BRANZ Ltd *Study Report 133*. BRANZ Ltd, Judgeford, New Zealand.

Year 9: Isaacs N, Camilleri M, French L, Pollard A, Saville-Smith K, Fraser R and Rossouw P. 2005. 'Energy Use in New Zealand Households: Report on the Year 9 Analysis for the Household Energy End-use Project (HEEP)'. BRANZ *Study Report 141*. BRANZ Ltd, Judgeford, New Zealand.

15.2 HEEP *BUILD* articles

The BRANZ magazine *BUILD* has published results from HEEP on a regular basis. Articles published in the year to 30 June 2006 are:

Isaacs NP. 2005. 'HEEP Delivers National Results'. *BUILD* 90: 98-99 (Oct/Nov).

15.3 HEEP conference papers

A number of the papers presented over the years by the HEEP team are available at no charge in PDF format from the BRANZ website (www.branz.co.nz). Hard copies can also be purchased online from the BRANZ Bookshop on the website. The following list is additional to that in the HEEP Year 9 report, and covers the period 1 July 2005 to 30 June 2006.

Pollard AR, Camilleri MT, French LJ and Isaacs NP. 2005. 'How are Solar Water Heaters used in New Zealand?' In *Proc. Solar 2005 Renewable Energy for a Sustainable Future – A Challenge for a Post-Carbon World Conference,* 28-30 November 2005, University of Otago, Dunedin, New Zealand, ISBN: 0-473-10937-9 (BRANZ *Conference Paper CP 120*).

French LJ, Camilleri MJT and Isaacs NP. 2005. 'Summer Temperatures in New Zealand Houses'. In *Proc. Solar 2005 Renewable Energy for a Sustainable Future – A Challenge for a Post-Carbon World Conference,* 28-30 November 2005, University of Otago, Dunedin, New Zealand, ISBN: 0-473-10937-9 (BRANZ *Conference Paper CP 121*).

Isaacs N. 2006. 'Energy Exploration at Home – Household Energy End-use Project (HEEP)'. In *Presentation Materials of International Symposium on Urban Energy Infrastructure Development for Mitigating Environmental Impact*. Organised and published by Handai Frontier Research Center, Osaka University, held at Awaji Yumebutai International Conference Center, Japan 28-29 March 2006 (invited international speaker).

Saville-Smith K and Fraser R. 2006. 'Local Housing Action, Energy Retrofitting and Sustainable Energy Use for Wellbeing and Sustainable Communities'. In *Proc. 12th Annual International Sustainable Development Research Conference,* 6-8 April 2006, Hong Kong.

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ACEEE Summer Study on Energy Efficiency in Buildings "Less is More: En Route to Zero Energy Buildings", 13-18 August 2006, Asilomar Conference Center, Pacific Grove, California, USA (BRANZ *Conference Paper CP 124*).

Isaacs N, Camilleri M and French L. 2006. 'Why Bother Collecting Data? Experiences of the Household Energy End-use Project'. In *Proc. 2006 ACEEE Summer Study on Energy Efficiency in Buildings "Less is More: En Route to Zero Energy Buildings"*, 13-18 August 2006, Asilomar Conference Center, Pacific Grove, California, USA (BRANZ *Conference Paper CP 125*).

Cogan D and Stoecklein A. 2003. 'Household Energy End-Use Survey as a Basis for Devising Residential Energy Efficiency Strategy'. In Bertoldi B, Conti F and Pagani R (eds). *Energy Efficiency in Domestic Appliances and Lighting – Proceedings of the 3rd International Conference on Energy Efficiency in Domestic Appliances and Lighting,* 1-3 October 2003, Turin, Italy, pp661-666.

15.4 Other HEEP references

HEEP also formed a significant part of the following industry presentations:

Isaacs N and Vale R. 2006. *Sustainable Design – What is Happening Today?* Seminar series for Architectural Designers NZ Inc (ADNZ). Presented at six locations (Tauranga, Palmerston North, Blenheim, Christchurch and Dunedin) July-August 2005.

Isaacs N. 2006 *Understanding Houses: 1 – Temperature and Water, 2 – Energy Research.* Commissioned seminars presented to Hometech Ltd franchisees' annual meeting, 25-26 March 2006, Mooloolaba, Queensland, Australia.

Isaacs N. 2006. *NZ Building Code and Domestic Glazing.* Opening address to the Glass Association of ANZ Industry Day, 16 June 2006, Christchurch, New Zealand.

Isaacs N. 2006. *Energy Use in the Home – Household Energy End-use Project (HEEP).* Presented to Energy Trusts of NZ Annual Conference, 4 May 2006, Wellington, New Zealand.

General presentations on the HEEP research were given to: *Transpower staff* (Wellington, 15 July 2005), *NZIA Otago Public Meeting* (Dunedin, 3 August 2005), six staff visiting New Zealand from the *Municipal Electricity Authority* (MEA), Bangkok, Thailand (Wellington, 12 August 2005), *Parliamentary Commissioner for the Environment staff* (Wellington, 19 August 2005), invited keynote speaker to *Environment Canterbury workshop* (Timaru, 20 October 2005).

Lectures including results of HEEP research were given to students at Victoria University of Wellington, Auckland University, University of Otago, Massey University (Albany Campus).

HEEP results were also included in other articles prepared by the research team:

Isaacs N. 2005. 'Health Energy – Some New Insights'. *PHA News* 3(5): 3,4,10 (Nov).

Isaacs N. 2006. 'Building History – Electric Hot Water Plugs into the Mains' *BUILD* 94: 110 (Jun/Jul).

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16. APPENDIX 1: STANDBY POWER AND ENERGY TABLE

For further discussion see Section 7.3: Standby power and energy.

Group	Appliance	Standby power (W)	Standby energy (W)	Appliances per house (#)	Standby energy per house (W)
Entertainment	Audio component*	3.5	2.2	0.40	0.9
	TV set-top box	13.3	11.8	0.41	4.3
	DVD player*	3.5	1.9	0.10	0.2
	Games console	5.2	3.8	0.21	0.1
	Miscellaneous*	5.1	3.2	0.10	0.3
	Radio*	1.7	0.7	0.43	0.3
	Radio cassette*	1.7	0.7	0.38	0.3
	Stereo	7.1	4.6	1.35	6.2
	Television	5.2	3.1	2.10	6.3
	VCR	9.4	7.5	1.13	9.0
Garage	Door opener*	2.6	1.8	0.18	0.3
	Power tool*	4.7	0.2	0.78	0.2
	Weedeater*	0.8	0.2	0.03	0.0
Kitchen	Bread maker	2.8	2.5	0.24	0.8
	Coffee maker	0.0	0.0	0.30	0.0
	Crockpot	0.0	0.0	0.17	0.0
	Dishwasher	1.6	1.2	0.41	0.5
	Electric grill*	0.0	0.0	0.07	0.0
	Electric oven*	0.0	0.0	0.10	0.0
	Extractor fan*	0.0	0.0	0.07	0.0
	Food processor*	0.6	0.0	0.40	0.0
	Frying pan	0.5	0.4	0.29	0.0
	Jug	1.1	0.8	0.98	0.8
	Microwave	3.6	3.1	0.90	2.8
	Mini-oven*	0.0	0.0	0.13	0.0
	Mixer*	0.1	0.0	0.41	0.0
	Rangehood*	0.4	0.2	0.33	0.1
	Small appliance*	0.1	0.0	0.76	0.0
	Toaster	0.1	0.1	0.84	0.1
	Waste disposal	0.4	0.1	0.10	0.0
	Wastemaster*	0.0	0.0	0.10	0.0
Laundry	Dryer	1.0	0.6	0.64	0.4
	Iron	0.0	0.0	0.71	0.0
	Washing machine	3.1	1.9	0.98	1.8
Miscellaneous	Alarm clock*	1.6	1.1	1.13	1.2
	Burglar alarm*	2.3	1.0	0.12	0.1
	Cell-phone charger*	1.2	0.6	0.26	0.2
	Charger*	1.6	0.5	0.25	0.1
	Cordless phone*	2.0	1.5	0.74	1.1
	Electric blanket	0.0	0.0	0.80	0.0
	Electric organ*	4.1	2.9	0.06	0.2
	Hairdryer*	0.0	0.0	0.34	0.0
	Instant gas water heater*	9.0	11.3	0.03	0.3
	Intercom*	1.5	1.9	0.01	0.0
	Lamp	1.1	0.8	2.52	2.0
	Miscellaneous appliance*	1.3	0.4	0.19	0.1
	Miscellaneous gear*	2.9	1.9	0.06	0.1
	Miscellaneous personal*	0.9	0.3	0.31	0.1
	Sewing machine	0.1	0.0	0.30	0.1
	Shaver*	1.1	0.6	0.06	0.0
	Spa pool	1.1	1.3	0.03	0.0
	Toothbrush*	1.3	0.7	0.08	0.1
	Vacuum	0.5	0.2	0.97	0.2
	Waterbed	2.2	0.9	0.04	0.0
Refrigeration	Freezer	1.8	0.7	0.68	0.5
	Fridge	10.6	4.6	0.66	1.7
	Fridge freezer	15.0	5.3	0.65	4.7
Home office	Answerphone*	3.4	2.7	0.10	0.3
	Computer	7.6	4.1	0.85	4.4
	Monitor*	2.1	1.8	0.12	0.2
	Fax machine*	5.2	3.3	0.25	0.8
	PC peripherals*	3.6	2.8	0.33	0.9
	Printer*	3.3	2.1	0.42	0.9
Space Conditioning	Air-conditioner	0.0	0.0	0.06	0.1
	Dehumidifier	2.1	0.7	0.22	0.2
	Fan	0.1	0.1	0.58	0.1
	Heater	0.4	0.2	1.51	0.3
	LPG heater (fan) *	5.0	6.3	0.01	0.1
	Air fresheners*	1.7	1.2	0.21	0.3

Table 62: Standby power and energy for all measured appliances

Note: appliances marked * were measured with spot measurements.

17. APPENDIX 2: ENERGY CONSUMPTION TABLES

The following tables provide the annual kWh (gross energy) for fuels and end-uses which were monitored in a significant number of houses (see Section 3.3). Note fuel oil is not separately included due to the small HEEP sample size.

Location	All fuels	SE	Electricity	SE	Gas	SE	LPG	SE	Solid fuel	SE
Overall	11,410	420	7,800	210	1,060	140	240	40	2,310	270
Auckland	10,660	520	7,970	360	1,870	370	90	30	720	190
Hamilton/Tauranga	10,750	840	7,270	780	1,780	570	120	60	1,580	580
Wellington	10,860	790	7,840	610	2,380	630	200	110	640	260
Christchurch	11,010	750	8,710	500	220	160	320	190	1,750	530
Dunedin/Invercargill	14,580	1,450	10,610	1,010	170	170	820	320	2,980	940
Clusters	11,740	810	7,300	340	530	160	270	60	3,620	550
Warm clusters	9,960	790	6,740	420	500	210	340	80	2,380	520
Cool clusters	13,780	1,170	7,950	490	560	240	190	80	5,050	790

Table 63. Average annual total energy use per house by fuel

Location	All fuels	SE	Electricity	SE	Gas	SE	Solid fuel	SE
Overall	3,260	100	2,440	80	660	90	150	40
Auckland	3,580	200	2,310	180	1,270	260	-	-
Hamilton/Tauranga	3,390	530	2,590	590	660	320	140	60
Wellington	4,610	420	2,350	300	2,240	550	30	20
Christchurch	2,960	210	2,710	210	140	140	110	40
Dunedin/Invercargill	3,100	280	2,840	310	-	-	250	160
Clusters	2,860	140	2,400	100	190	80	260	90
Warm clusters	2,700	170	2,270	100	280	130	150	110
Cool clusters	3,050	220	2,540	180	100	70	370	130

Table 64. Average annual hot water energy use per house by fuel

Location	All fuels	SE	Electricity	SE	Solid fuel	SE	Gas	SE	LPG	SE
Overall	3,820	350	920	190	2,150	250	520	110	240	40
Auckland	3,190	840	1,630	720	720	190	750	340	80	30
Hamilton/Tauranga	2,830	530	280	80	1,430	530	990	360	120	60
Wellington	2,630	730	780	600	610	250	1,230	400	200	110
Christchurch	3,010	690	950	350	1,640	520	90	90	320	190
Dunedin/Invercargill	6,810	910	3,130	420	2,720	820	140	140	820	320
Clusters	4,370	560	420	110	3,360	510	320	130	270	60
Warm clusters	3,080	480	290	140	2,230	450	220	160	340	80
Cool clusters	5,860	830	550	180	4,680	750	440	230	190	80

Table 65. Average annual space heating energy use per house by fuel

Location	All cooking	SE	Range	SE	Lighting	SE	Refrigeration	SE
Overall	900	60	630	50	910	90	1,120	70
Auckland	1,030	100	650	90	1,460	300	1,030	160
Hamilton/Tauranga	910	210	590	190	620	110	1,100	100
Wellington	1,090	340	800	340	880	250	1,220	260
Christchurch	990	160	700	140	530	130	800	170
Dunedin/Invercargill	970	150	740	110	1,550	150	720	280
Clusters	760	70	570	70	680	90	1,260	110
Warm clusters	840	110	620	110	580	110	1,470	140
Cool clusters	620	70	430	60	800	140	1,000	110

Table 66. Average annual energy use per house for selected end-uses