STUDY REPORT

No. SR 141 (2005)

Energy Use in New Zealand Households

Report on the Year 9 Analysis for the Household Energy End-use Project (HEEP)

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Energy Use in New Zealand Households – HEEP Year 9 Report

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This Executive Summary provides a selection of the results – copies of the full report can be obtained from BRANZ. Note that all **the results, monitoring and analysis methodology reported here are copyright to BRANZ Ltd** and not available for wider use without explicit permission. The results reported are subject to change as data processing proceeds.

This is the ninth annual report on the Household Energy End-use Project (HEEP). After six years of monitoring, the HEEP database now has data on a total of some 400 randomly selected houses, covering New Zealand from Invercargill in the south to Kaikohe in the north. The large majority (300) of these houses have been monitored in the past three years.

The 440 hot water cylinders, 65 wet-backs, 206 solid fuel burners, seven solid fuel ranges, 42 open fires and 175 portable LPG heaters provide a unique snapshot of how New Zealanders heat their hot water and homes. HEEP has collected at least two temperatures in each house's main living room and one in the main bedroom providing high quality data, not only on room temperatures, but also on the importance of room temperature gradients. The record is completed with detailed house occupant surveys, house physical and energy audits as well as over 8,000 photographs of the houses, appliances and monitoring equipment in place.

Nearly 14,000 appliance power measurements, label details from a further 6,000 appliances and detailed house light records provide a comprehensive overview of household electricity uses. This rich database provides an internationally unique resource for New Zealand. The possibilities for its use are wide, limited only by the imagination of potential users.

The report provides an overview of the entire project and the monitored houses; a review of the house selection methodology; an examination of the importance of selected social factors on household energy use and temperatures; a description of the development of the 'Household Energy Efficiency Resource Assessment' (HEERA) model; quantification of the space heating contribution of solid fuel burners; descriptions of the patterns of home heating (including heating season and indoor temperatures); an evaluation of the performance of the ALF computer programme; the first national estimates of residential standby and baseload power demands; and a historic review of hot water provision in New Zealand homes and analysis of current hot water energy use, including 'wet-back' supplementary water heating.

How New Zealanders live

HEEP offers a snapshot of New Zealand homes. Just over half of the HEEP houses had a solid fuel burner (52%), while fewer than one in nine had an open fire (11%). Four out of every nine houses (44%) had an LPG heater. A small number of houses had oil-based heating, and slightly more had a solid fuel range, which was often used for cooking and water heating. Only 28 of the houses had a spa or a swimming pool (7%).

The house floor areas ranged over a factor of six – from 51 m² up to 315 m², while the floor area per person varied by a factor of nearly 18 – although the highest occupancy was a small house with a number of occupants.

The most numerous electricity end-use is lights, ranging from a minimum of seven in a house up to a maximum of 143. All appliances in the house are recorded, with information on their location and power. A minimum of seven and a maximum of 82 appliances were recorded in any house, with an average of 33.

The largest numbers of a single appliance type were the 22 sewing machines in one house, but the most popular appliance is the television (averaging just under two televisions per house). The largest number of televisions in one house was nine.

Monitoring

Early HEEP monitoring was analysed to establish the required sample size. In order to estimate average space heating energy with an error of less than 10% and with 90% confidence, the required sample size was found to be 375 households nationwide. A target sample size of 400 households was set to ensure adequate numbers would be available in case of any problems e.g. any houses withdrawing from the study, or being found not suitable.

Now data collection is complete, this sample size has been found to be reasonable and provide acceptable error limits. Although not planned, it has also been found that it provides a reasonable basis for some regional energy use estimates.

Solid fuel burners and wet-backs

Previous studies of energy use in New Zealand houses have focused on the use of electricity and natural gas for space heating. These fuels are widely used, and easy to monitor and to analyse. As HEEP monitors all fuels, it has been necessary to develop appropriate systems to monitor portable LPG heaters and solid fuel burners. Analysis of space heating energy use has now been completed for all houses and all fuels.

The HEEP data shows that solid fuel burners play a major role in the heating of New Zealand homes. Solid fuel would appear to be at least as important as electricity for space heating. 'Energy Data File' estimates suggest solid fuel accounts for around 5% of domestic energy use, while the HEEP data would suggest it is over 15%.

Solid fuel burners are generally larger heat sources than portable gas or electric heaters. A not unexpected consequence is that houses heated by enclosed solid fuel burners are the warmest. Interestingly, houses heated by open fires are the coolest. The current environmental policies designed to shift away from solid fuel burners may have implications for other heating fuels.

Solid fuel burners are mostly used in the 0.5 to 4kW output range. It is likely that at these lower power outputs the emission levels differ from the full-power test measurements used for air quality certification.

Wet-back, supplementary water heaters, are not uncommon in New Zealand homes. A coil in the back of the burner feeds heat through a thermosyphon into the household hot water tank. On average, houses with wet-back systems get about 20% of the total hot water energy from the wet-back. About 5% of houses with wet-backs get all of their hot water supplied by the wet-back, although most of these systems are dedicated solid fuel water heaters. Overall, roughly 5% of the national total hot water energy is supplied by wet-backs.

There is regional variation in the hot water provided by wet-back systems. Some wet-backs provide only a few percent of the total hot water for a household, while some provide more than two-thirds. This is readily explained, because in colder climates the solid fuel burners are used more often, more intensively, and for more months of the year, so more energy is fed into the wet-back circuit. Wet-back water heating would not appear to be a good option in warm climates with short heating seasons.

Heating season

As part of the house survey, occupants are asked which months they heat and these have been used in previous HEEP reports for analysis of heating months. When the pattern of heating was evaluated based on the monitored energy use, it appeared that heating was occurring on average for one month longer than reported.

Regional Council	Start Temp. °C	End Temp. °C
Northland	15.2	15.2
Auckland	15.1	14.7
Bay of Plenty	14.2	14.2
Waikato	13.1	14.5
Gisborne/Hawkes Bay	13.7	13.8
Taranaki/Manawatu-Wanganui	13.7	13.5
Wellington	13.0	12.4
Tasman/Nelson/Marlborough	12.6	13.2
Canterbury	12.3	11.7
Otago/Southland	11.7	13.5

Table i: Heating season temperatures

The temperatures at which households start and stop their heating season were also explored, and are given by regional council area in Table i. The further south, the cooler the external temperature before heating starts. The Invercargill summer average temperature is cooler than the threshold for heating in Auckland!

All possible HEEP houses have now been modelled in the thermal simulation programme ALF3. the results will be used to develop ALF and in HEERA.

Standby and baseload

Standby and baseload power consumption has been reported in HEEP since 1999. These early estimates of standby (power used while the appliance waits to be used) and baseload (appliances that are on continuously) power consumption have been instrumental in raising awareness throughout Australasia. Now HEEP monitoring is complete, nationally representative estimates of standby and baseload power consumption can be prepared. This is a world first, as no other country in the world has undertaken a study comparable to HEEP.

Data on standby power comes from three sources within HEEP:

1. **End-use data:** 10 minute monitored energy data from individual appliances
2. **Power measurements:** spot measurements made during monitoring installation
3. **Survey:** occupant survey recording appliance numbers and use.

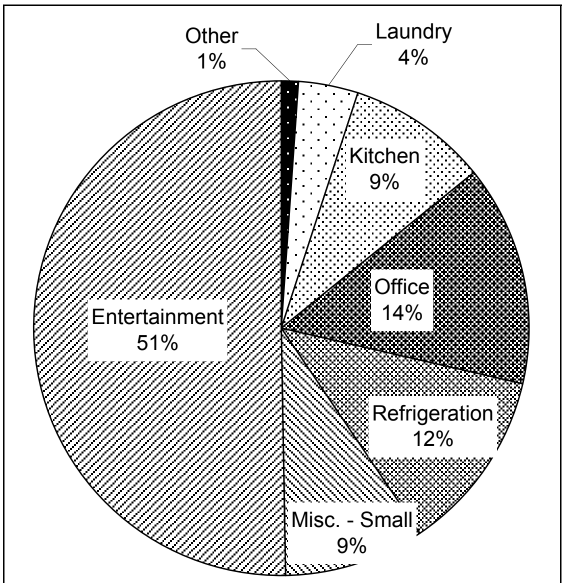

Fig i: Baseload & standby energy

By combining information from these three sources, a complete picture of household standby and baseload power consumption can be made. Figure i provides a breakdown by the main uses.

The average energy use per house for standby is equivalent to 58 W continuous i.e. the average New Zealand house is spending nearly $80 a year (at 15 c/kWh) just keeping these appliances powered-on while they wait to be used.

The top five appliance types in terms of their current standby impact on the electricity system are (in alphabetical order): fridge/freezers; home computer (includes monitor); stereo; television; and video recorders. They account for more than half the total household standby energy consumption. Three out of the top five are in the ‘home entertainment’ grouping.

The average house baseload and standby demand is 112 W ± 4 W continuous, equivalent to an annual cost of about $150 per year. Assuming 1.4 million houses, this is equivalent to about 150 MW of continuous load or an average Waikato hydro-power station.

This comprises standby power of 58 W ± 4 W and heated towel rail power of 21 W ± 2 W, with 33 W ± 6 W remaining. Hard-wired appliances (stove, sensor lights, etc) are 3 – 5 W. As discussed in the Year 8 HEEP report, faulty refrigeration appliances could easily account for 15 W ± 10 W per house, and the remainder of 14 W ± 12 W is not statistically different from zero. We can therefore conclude that it is unlikely that there are any other large components.

Domestic hot water

The energy used for domestic hot water can be split into two parts: a technical component that relates to the performance of the hot water generator, the piping system and the system design; and a social component that relates to patterns of use and the amount of use. HEEP has been concerned with establishing their relative importance.

Our houses represent 'snapshots' of ideas, equipment and facilities of the time they were built. Many, but not all, houses are refurbished (or even rebuilt) to more recent standards. In-house hot water is a relatively new facility in New Zealand homes – the 1945 Census found just over one-quarter lacked a hot water service but this had fallen to about 1% by the 1966 Census. Electric hot water cylinders (a New Zealand invention) were first used in 1915. By 1996, three-quarters (75%) of all homes had only electric hot water, but this reached a maximum of 82% in 1981. The 1996 Census, the most recent to collect hot water data, found 75% of houses had electricity only; 10.5% had electricity and solid fuel; 7% had gas only, and the rest had a range of different system types and combinations.

Since the 1971/72 Household Electricity Survey there have been noticeable changes in the use of showers (as noted earlier) and in the volume of electric hot water cylinders e.g. 56% of houses had 135 litre cylinders in 1971/72, but this has now fallen to 40%, while the use of larger cylinders has increased. Even so, 18% of HEEP households report they 'sometimes' run out of hot water.

Tap >60°C & Thermostat <=60°C 17%	**Tap >60°C & Thermostat >60°C** 43%
Tap <=60°C & Thermostat <=60°C 18%	**Tap <=60°C & Thermostat >60°C** 21%

Table ii: Count of thermostat setting vs tap hot water temperature

The poor performance of electric hot water cylinders identified by HEEP in 2003 has been confirmed by analysis of the full sample. Sixty percent of electric hot water cylinders deliver water at clearly unsafe temperatures (over 60°C). Only one-third of the cylinders have accurate thermostats (delivered temperature within ± 10°C of the thermostat set point), with older thermostats (marked in °F and likely to have been manufactured prior to 1975) performing with less accuracy than newer ones. One-half of the thermostats set at a safe temperature delivered unsafe water – so even if the occupants set the thermostat at a safe temperature there is an almost equal chance the delivered water is too hot.

Figure ii gives revise average total energy use and standing loss estimates for four systems types: electric storage, electric night rate storage, natural gas storage and natural gas instant.

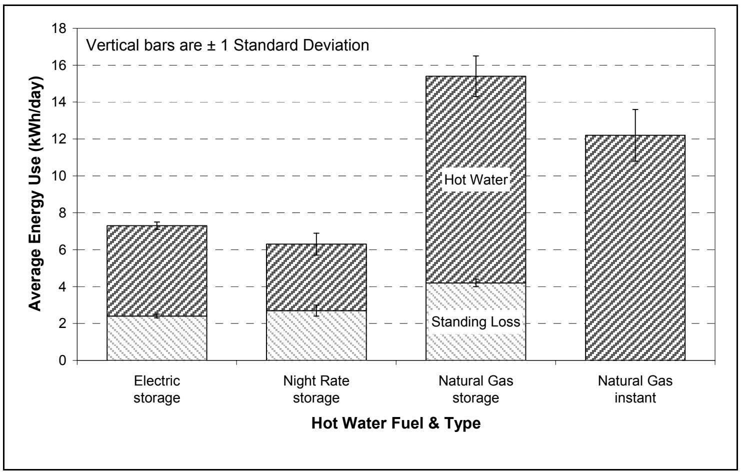

Fig ii: Energy consumption and standing losses by system type

Total energy use ranges from 7.3 (electric night rate storage) to 15.4 kWh/day (natural gas storage). Average standing losses range from 27% (natural gas storage) to 43% (electric night rate storage) of total energy use.

Energy use and standing loss data is now based on the total HEEP sample. For wet-back hot water systems, where possible, standing losses were also estimated. Newer A and B grade cylinders have lower heat losses in comparison to older, less well insulated C and D grade systems.

C or D grade cylinders fitted with an appropriate cylinder wrap have standing losses of 1.0 kWh/day (less than the unwrapped cylinders for 135 litre and 0.6 kWh/day less for the 180 litre cylinders). This would suggest that installing wraps on the approximately 240,000 unwrapped 135 litre and 160,000 180 litre systems could save about 122 GWh per year, with a retail electricity cost of about $20 million per year.

Cylinder wraps and pipe insulation could also give energy savings for A or B grade systems, although the savings would be smaller. Assuming a conservative 0.3 kWh/day saving, the potential savings for the approximately 600,000 A or B grade systems are 66 GWh per year, with a retail electricity cost of about $10 million per year.

Social drivers

The way we use our homes depends on many things – the type of home, the type of appliances, the type of people we are, just to name a few. As well there are changes in the way we behave as a society – for example in 1971/72 only 25% of houses used mainly the shower, nowadays the HEEP sample found 94% mainly use the shower.

The importance of a range of different social drivers for energy use has been explored, not only for total household energy use, but also for hot water and lighting energy use. These drivers need not only to have been collected by HEEP, but also need to be available in a long-term series to permit the scenario model to work. The key social drivers explored thus far relate to a measure of the household income (equivalised income), the life stage of the household (related to the age of the youngest person living in the house), the number of people normally living in the house, and occupancy (a constructed variable calculating crowding as a function of household size and total number of rooms).

Because of the close correlation between occupancy and household size, two sets of multiple regressions were undertaken. As Table iii shows, the explanatory power of these variable sets is not strong.

Predictor variables	Dependent variable	Adjusted R square
Equivalised income, life stage, size of household, occupancy	Log total energy use	0.225
Equivalised income, life stage, size of household	Log total energy use	0.210
Equivalised income, life stage, size of household, occupancy	Log DHW energy use	0.311
Equivalised income, life stage, size of household	Log DHW energy use	0.318

Table iii: Multiple regression analysis

When modelled together, the four selected social dynamic variables account for about 22% of the variance in total energy use, reducing to 21% when the occupancy term is dropped. For domestic hot water (DHW), occupancy accounts for about 32% of variance, but still the occupancy variable has little impact.

These results are now being used to help develop the HEERA model.

HEERA model

The main tool to come from HEEP will be an energy model of the residential sector. It will provide a very much improved understanding of energy use in New Zealand houses. The HEERA model estimates the historic and projected residential energy use, energy supply and greenhouse gas emissions (GHG) based on the economic, demographic and social drivers. The data collected by HEEP, and many other agencies such as Statistics New Zealand, provides baseline information on houses and their appliances, and the use made by different types of households of space heating, water heating, cooking, lighting, refrigeration, electrical appliance and electronic appliances.

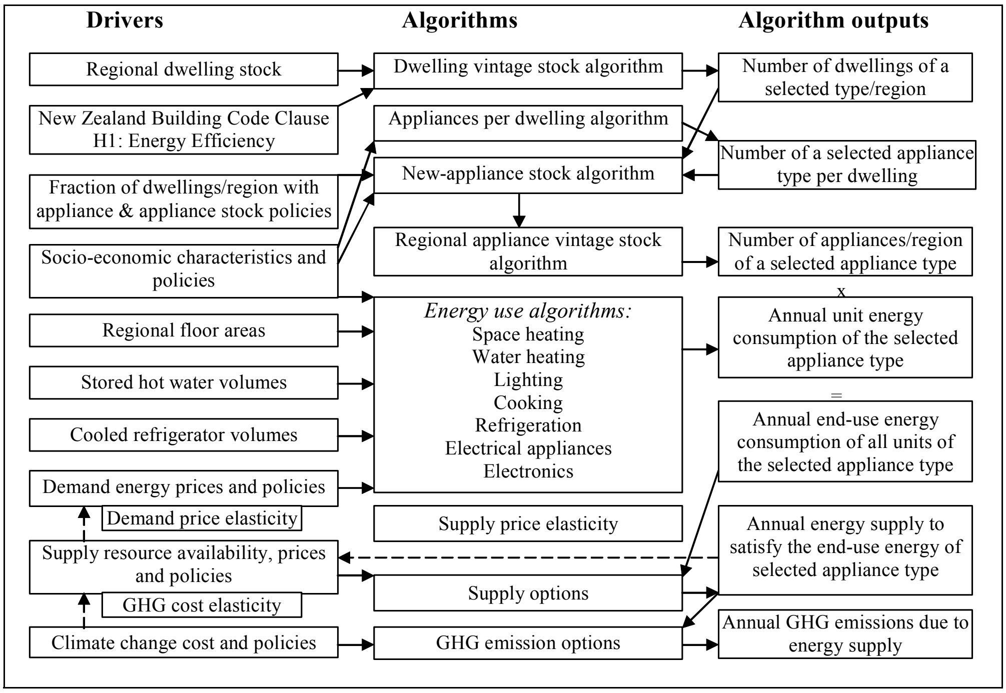

Fig iii: 'Household Energy Efficiency Resource Assessment' (HEERA) flow diagram

Over the past year the HEERA model structure has been developed (Fig iii), and historic data obtained. HEEP data has been analysed to create formulae that link together the many aspects of the model. In turn, the basic model has been tested, and used to construct a set of simple scenarios. HEERA has been implemented as a spreadsheet, and the software is now being developed for a free-standing programme.

Future

Each 1% improvement in the efficiency of energy use in New Zealand homes would result in a benefit of $17 million and reduce CO_2 emissions by 0.1%. HEEP and HEERA will provide clear guidance on the 'best' areas for action and the likely consequences, thereby maximising the potential benefits. The HEEP results will also lead to improvements in the design, construction and utilisation of New Zealand houses to enable them to meet the comfort expectations of all classes of occupants in the most energy efficient way.

Now that HEEP data collection is completed, our focus is on reporting analysis and developing the HEERA model. From its start, HEEP has received its main science funding from the Building Research and the Foundation for Research, Science and Technology. Funding continues until the end of June 2008, and is built around three objectives.

1. **Energy Use in Residential Buildings,** now completed it provided scientific support to the monitoring and data collection.
2. **Energy Demand Model** is supporting the development of HEERA, and will be completed by the end of June 2006.
3. **Promotion of Residential Energy Efficiency** commenced at the start of July 2005, and is focusing on ensuring that the new efficiencies and policy opportunities are taken up in the energy, health, housing, construction and welfare sectors.

Acknowledgements

We would like to acknowledge the support and help of the many households that have taken part in the HEEP research – 24% of the houses contacted have taken part in the project.

We offer our sympathy to those who lost loved ones during our monitoring and our delight in being able to be with those of you who celebrated times of great happiness. In addition to thanking the funding agencies named on the front cover, we would also like to thank the staff and students of the 'BBSC 331 Environmental Science' paper, School of Architecture, Victoria University of Wellington who helped with the final round of installations. Our thanks also to the many BRANZ Ltd staff who helped, including design and construction of data loggers and, of course, the HEEP field staff who have travelled over 126,000 km. Over the life of HEEP close to 1,250 people have been involved – without you, this research would not have happened.

Obtaining HEEP reports

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

Copies of this Executive Summary and the full Year 9 report are available through the HEEP page on the BRANZ website:

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ENERGY USE IN NEW ZEALAND HOUSEHOLDS

Report on Year 9 of the Household Energy End-use Project (HEEP) – June 2005, BRANZ Study Report 141

Authors:

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REFERENCE

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

ABSTRACT

This is the ninth annual report on the Household Energy End-Use Project (HEEP). HEEP is a multi-year, multi-discipline, New Zealand study that is monitoring 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, and the report is the first with full data from 400 randomly selected houses. The report provides an overview of the entire project and the monitored houses; a review of the house selection methodology; an examination of the importance of selected social factors on household energy use and temperatures; a description of the development of the 'Household Energy Efficiency Resource Assessment' (HEERA) model; quantification of the space heating contribution of solid fuel burners; descriptions of the patterns of home heating (including heating season and indoor temperatures); an evaluation of the performance of the ALF computer programme; the first national estimates of residential standby and baseload power demands; and a historic review of hot water provision in New Zealand homes and analysis of current hot water energy use, including 'wet-back' supplementary water heating.

Acknowledgements

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

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

The 2004 installation teams included Bachelor of Building Science (BBSc) students studying for paper 'BBSC 331 Environmental Science' in the School of Architecture, Victoria University of Wellington, who used the experience to learn about issues of research and data collection in the field.

We would like to acknowledge the excellent work of Ruwan Fernando (a BBSc student at Victoria University of Wellington) for his vacation work in taking measurements of plans and entering all the houses into ALF.

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

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1. INTRODUCTION

This is the ninth annual report on the Household Energy End-use Project (HEEP). All monitoring is now completed, so this report provides an overview of the monitoring programme. It also provides analysis from the HEEP database.

Readers with interest in specific use of the HEEP data are invited to contact the HEEP team by any of the methods given in Section 1.2.

Please note that all the results, monitoring and analysis methodology reported is the copyright of BRANZ Ltd and is not available for wider use without explicit permission.

1.1 HEEP in action

HEEP continues to be well received, nationally and internationally. HEEP is now recognised as the pre-eminent source of data on energy use in New Zealand households, including references in such documents as the Parliamentary Commissioner for the Environment's review of the Electricity Commission. The results also assisted in the first stage of redevelopment of the New Zealand Building Code Clause H1: Energy Efficiency.

HEEP material is actively sought from the BRANZ Ltd website, with over 3,100 downloads of the various Executive Summaries in the year to 30 June 2005, including over 940 of the Year 8 report in just five months since its release. A selective Google search found over 40 explicit references to the HEEP work in New Zealand and internationally. Wider use is made of the results, but users neglect to reference HEEP as the origin. For example, the HEEP analysis of household fuels formed a key portion of a sales and marketing presentation for a New Zealand energy supply company. Presentations to a wide range of users, ranging from a peer-reviewed conference to trade training events, are ensuring the results of the research are being made available to stakeholders.

HEEP was the basis for the opening paper to the Royal Society of New Zealand annual conference held in Christchurch on 18 November 2004. The paper *Supply Requires Demand – where does all of New Zealand's energy go?* (also available as a BRANZ Ltd reprint) was then published by the Royal Society.

Ten presentations have been made to a wide range of end-users over the past year: Ministry for the Environment (31 January 2005), EECA staff (4 March 2005), Electricity Complaints Commission (24 March 2005); Energy Centre, University of Auckland (10 May 2005); NZIA Environmental Group (Auckland, 10 May 2005); lecture to students at the Department of Architecture, University of Auckland (11 May 2005); lectures to students at the School of Architecture, Victoria University of Wellington; National Carpentry Tutors Mid-Year Conference (Wellington, 28 June 2004); Senior Building Officials Tour of BRANZ Ltd 12 October 2004 and 27 October 2004).

The research team was invited to give nine international workshops or presentations reporting on the research during the year: American Council for Energy Efficient Economy (ACEEE) 2004 Summer Study on Energy Efficiency in Buildings (ad hoc workshop on residential energy monitoring); Natural Resources Canada (Ottawa 30 September 2004); Building Research Establishment (Garston, England, 3 September 2004); Department for Environment Food & Rural Affairs (London, England) 6 September 2004; Institute of Energy and Sustainable Development, De Monfort University (Leicester, England, 8 September 2004); The Bartlett – Faculty of the Built Environment, University College London (London, England, 9 September 2004); 10th UK Thermal Comfort Interest Group Meeting, Oxford Brookes University (Oxford, England, 14 September 2004); Sustainable Energy Authority of Victoria staff (Melbourne, Australia, 10 March 2005); Solar Cities Consortium (Melbourne, Australia, 11 March 2005).

1.2 Further information

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

Section 14 provides full references for a range of HEEP written material:

- HEEP Reports
- HEEP *BUILD* articles
- HEEP conference papers
- Other references

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

HEEP analysis is also available to other interested groups. Please contact us and we will work with you to define your question and work out how HEEP analysis could best assist you. On request, your name can be included in our 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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1.3 Acknowledgements

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

- *Building Research (BRANZ Inc)*
- *Foundation for Research, Science and Technology, Public Good Science & Technology Fund (PGST)*

The assistance of the following individuals and organisations is also acknowledged:

- Bill Bordass, **William Bordass Associates**
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- Sue Clark, **Consultant**
- David Cogan, **Consultant**
- Michael Donn, **Victoria University of Wellington**
- Frank Pool, **Consultant**
- Lindsey Roke, **Fisher & Paykel Ltd**
- Les Shorrock, Peter Iles, Janet Utley and John Henderson, **BRE Ltd**
- Professor Arthur Williamson, **Thermocell Ltd**
- Andrew Wright, **De Monfort University**

The HEEP team wishes to our expresses sorrow and sympathy to the families and friends of the four people who died during the monitoring of their homes over the full monitoring period.

2. MONITORING SUMMARY

After six years of monitoring, the HEEP database now has data on a total of 397 randomly selected houses covering New Zealand from Invercargill in the south to Kaikohe in the north. This section provides some summary statistics on the programme, while the following selection outlines the selection method.

2.1 What we measured

The HEEP approach to monitoring New Zealand households has been to ensure that all fuels used in the house are monitored or recorded. Table 1 summarises the different aspects of the HEEP monitoring in the randomly selected houses.

The majority (74%) of HEEP houses have the total for each fuel and the domestic hot water (DHW) heater monitored.

	Count
Total load and hot water houses	293
End-use houses (EUM & SAM)	104
Energy Intellect remote reading meters	8
Hot water cylinders monitored	440
• Wet-backs	65
• Solar hot water heaters	5
Solid fuel burners	206
Solid fuel ranges	7
Open fires	42
LPG heaters	175
Diesel (fuel oil) heating	2
Spa pools	26
Heated swimming pools	2
Living room temperatures	774
Bedroom temperatures	380
External temperatures	37
Other room temperatures	30
Litres of each hot, warm and cold water (measure temperature and shower flow)	~1000
Photos of appliances, monitoring equipment and the houses	~8000

Table 1: What did HEEP record and measure?

In about one in four houses (26%), detailed end-use monitoring of significant fuel use was undertaken e.g. gas hobs, as well as significant fixed electricity use e.g. electric stove. Two types of electric end-use monitoring systems were used:

- EUM (68 houses) – a purpose-built, commercial, power line carrier system, that allows monitoring of 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) (36 houses) – a standard Siemens revenue meter with a pulse output that feeds into a BRANZ Ltd data logger.

Both end-use monitoring systems provide high resolution data on appliance electricity use.

Details on each hot water cylinder are recorded, and depending on the fuel supply either each cylinder or the combination of all cylinders are monitored. The relatively small number of solar water heaters means that it is not possible to provide detailed information on their contribution to hot water supply. The measure of shower water flow rates has consumed at least 1,000 litres of water in the HEEP houses.

Table 1 shows that over half of the houses had a solid fuel burner (52%) while less than one in nine had an open fire (11%). Four out of every nine houses (44%) had an LPG heater. A small number of houses had oil-based heating, and slightly more had a solid fuel range which was often used for cooking and water heating.

Spa and swimming pools were present in only 7% of the houses.

Apart from the early houses in Wellington, at least two living room and one bedroom temperature were recorded. Table 1 also documents the number of external temperatures and temperatures measured in other rooms.

Appliance database	Counts
Power measurements made	13,862
Appliances labels read	5,755
Photos of appliances	~2,400
Appliances in the database (excludes lights)	11,839
Appliances recorded in survey (includes lights, excludes washing machines, dryers etc)	17,264

Table 2: Appliance database

Table 2 summarises the data held in the appliance database. Full details are given in section 9.1, but in brief over the entire HEEP project detailed lists have been compiled of the appliances present in each house. In later years data collection was rationalised with all appliances continuing to be listed, but full details were recorded only for selected appliance types e.g. whiteware, entertainment.

All major appliances were photographed, and where reasonable many of the smaller appliances. This photographic record has proved invaluable in allocating ages to refrigeration appliances and matching measurements to the monitored appliances.

2.2 Where we went

Figure 1 places the monitoring locations on a map of New Zealand and Table 3 summarises the locations in which HEEP has monitored the randomly selected houses. Non-randomly selected houses have also been monitored in Wanganui, Christchurch, Wellington and Hamilton. A small additional number of houses have also been monitored to replace those houses which were unable to participate in the monitoring for a full year. Locations circled in Figure 1 are the stratified sample selections in the urban areas, while the other locations are cluster sample selections (see Section 3.2).

The monitoring period has been 12 months from early in the HEEP work. In order to maximise the use of equipment, and skilled labour, installations (and hence removals) have been staggered over a number of months – installations commencing in December and being completed by April. Table 3 provides indicative installation and removal periods.

Monitoring of randomly selected houses commenced in Wellington in 1999, with Hamilton in the following year. The main Auckland urban area (96 houses) was monitored over the two years 2001 and 2002. Waikanae and Christchurch monitoring was completed in 2003, while the following year saw monitoring completed in Northland (Kaikohe, Kamo West and Sherwood Rise), part of the Waikato (Minden and Tauranga), part of the Central North Island (Arapuni), Foxton Beach and Otago/Southland (Oamaru, Dunedin and Invercargill). The final year (completed May

2005) completed coverage with houses outside the main urban areas – Auckland (Orewa and Awhitu), Central North Island (Western Heights, Ngakuru and Rangatira), East Coast (Mangapapa, Wairoa and Tamatea North), and Marlborough (Wai-iti and Seddon).

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 N. Z.	**Total**	**397**	**1999-2005**

Table 3: Location, count and year monitored for HEEP houses

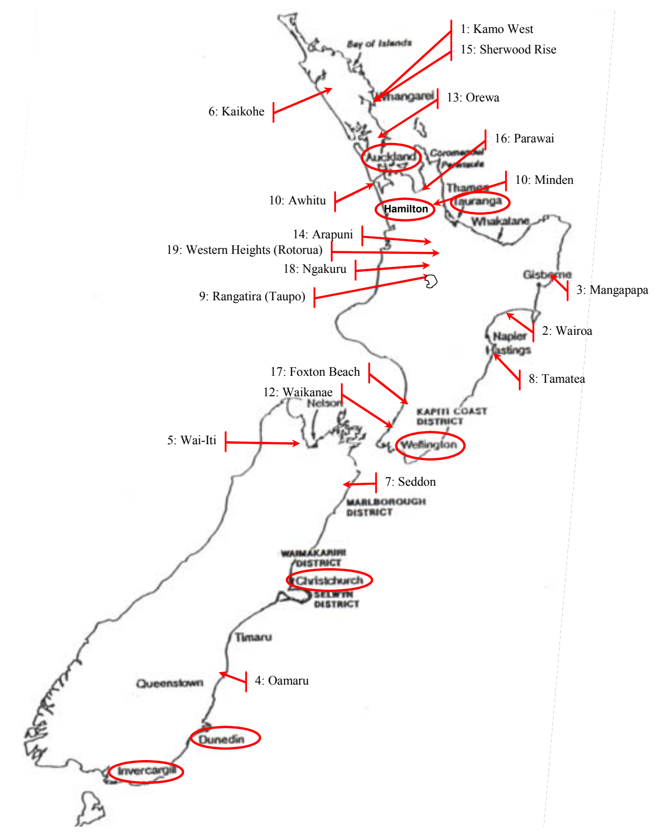


Figure 1: Map of New Zealand showing locations of HEEP monitoring

Letters inviting participation were sent to over 2,600 households and, of these, contact was made by phone or a personal visit to 1,687 houses in order to achieve the final monitoring selections. Approximately 800 person days were spent in installing monitoring equipment over about 40 weeks. The installations were undertaken by BRANZ Ltd staff working with the field download staff and local electricians, gasfitters and plumbers. The installation team consisted of three, four or five people, and took two to four hours to complete an installation. The 2004 installation teams included students studying for paper 'BBSC 331 Environmental Science' in the School of Architecture, Victoria University of Wellington, who used the experience to learn about issues of research and data collection in the field.

Role	Number
BRANZ Ltd HEEP team	9
Contract staff	5
Other BRANZ Ltd staff	5
Download field people	12
Electricians and gasfitters	26
Temporary installation people	47
Total number of people in HEEP team	**104**
House occupants (397 random houses)	1,143
Total number of people involved with HEEP	**1,247**

Table 4: Number of people involved with HEEP

Table 4 tabulates the number of people who have been involved in the HEEP research – including those based at BRANZ Ltd headquarters at Judgeford working either primarily on HEEP or involved in providing ongoing specialist support, download field staff, temporary installation people, and of course the householders. Over 1,200 people have been involved in creating the HEEP data set for analysis.

Table 5 provides an estimate of the distance travelled by the field download staff, who travelled over 126,000 km to collect the data. Early in the monitoring programme it was found that the use of independent data loggers (i.e. not connected to a central house data collection or through telecommunications to a central data storage facility) managed by field staff was not only lower in cost, but also provided a higher level of data quality. The field staff were instructed not to provide any feedback to house occupants, but they did record relevant changes in house occupancy or use during the monitoring period. They also undertook the removal of monitoring equipment at the end of the monitoring period.

Monitoring year	Locations	Approximate distance (km)
1999	Wellington	8,400
2000	Hamilton	5,500
2001	Auckland, Manukau, North Shore, Waitakere	17,500
2002	Auckland, Christchurch, Manukau, North Shore, Waikanae, Waitakere	22,670
2003-04	Arapuni, Dunedin, Invercargill, Kaikohe, Kamo West, Minden, Oamaru, Tauranga, Sherwood Rise, Foxton Beach	29,230
2004-05	Awhitu, Mangapapa, Ngakuru, Orewa, Rangatira Seddon, Tamatea Nth, Thames, Wai-iti, Wairoa Western Heights	43,060
Total mileage for all areas and download staff		***126,360***

Table 5: Estimated distance travelled by HEEP download staff

2.3 Equipment

A range of specialist monitoring equipment was either purchased or designed and built by BRANZ Ltd staff. Early in the project it was found that commercially available data logging equipment with acceptable accuracy, resolution and storage was too costly to permit the desired coverage to be achieved within a limited budget. A basic data logger design was prepared and modified to enabled it to be used for temperatures, pulse counting and thermocouples. Seven hundred and fifty BRANZ Ltd data loggers have been built for use in the HEEP work. These dataloggers have proved to work extremely well. Now HEEP is completed the equipment is available for other research projects or for hire.

Monitoring equipment	Number
BRANZ Ltd Temperature loggers† Tiny Tag Internal Temperature loggers Tiny Tag External Temperature loggers	313 65 15
BRANZ Ltd Pulse loggers†	245
BRANZ Ltd Microvolt loggers† • Thermocouples†	190 ~1500
Siemens Electricity Meters	275
EUM power line carrier electricity meters • EUM Appliance Transponders	12 30
Siemens Appliance Meters (SAM)	30
Energy Intellect remote reading meters	3

Table 6: Monitoring equipment

† Designed and made at BRANZ Ltd

HEEP also made early use of the remote-reading electric 'smart metering' developed by Energy Intellect Ltd (formerly Total Metering Ltd)[1]. Since 2002, three sets of meters have been placed on three houses for one year[2]. They replace other HEEP metering, and provide both real and reactive power every minute. The data is provided directly to the HEEP team through a web-based interface.

Over the life of HEEP, a large number of 9 V and 3.6 V batteries have been used to power the data loggers. The spent 150 kg (approximately) of batteries have been recycled through Tredi New Zealand Ltd.

2.3.1 Logger calibrations

All HEEP monitoring equipment was subject to regular maintenance and calibration. All BRANZ Ltd temperature loggers were calibrated annually before they went out into the field.

From September 1998 to July 2004, 1,021 BRANZ Ltd temperature loggers were calibrated. This was carried out in 49 batches, averaging 21 loggers per batch. Each calibration involved at least three temperature set-points (3,230 set-points in total).

2.3.2 Equipment destroyed or damaged

During the HEEP installations and monitoring, two cars and one van were damaged. One toolbox was driven over, seven laptops died in service (but not in vain …) and one set of monitoring equipment was taken over by a cockroach infestation. Most installation equipment remained in use throughout the project, although a number of small whiteboards (used for house identification in photographs) have shifted to other parts of the universe.

Given the size and complexity of the monitoring work, remarkably few households were damaged or otherwise affected. In all cases, the HEEP team arranged for repairs to be made, and suitable compensation was paid for any damage:

- Five fridges/freezers were accidentally defrosted
- Five other appliances were damaged sufficiently to require repair or replacement
- One temperature logger fell from its wall mounted location, and destroyed a porcelain ornament
- In one early house, the monitoring of the wet-back hot water heater resulting in a water leak damaging the contents of a linen cupboard – after this, the flow rate monitoring of wet-back water heaters was discontinued

[1] Website: www.energyintellect.com

[2] One house-year of data was lost due to monitoring issues.

- Two houses damaged when removing meters
- Two LPG cabinet heater incidents occurred – although neither appeared to be directly caused by monitoring equipment
- One large bottle LPG connection valve was repaired.

2.4 Largest and smallest

The HEEP data provides a snapshot of New Zealand houses and appliances, as shown in Table 7. The floor areas range over a factor of six – from 51 m² up to 315 m², while the floor area per person varies by a factor of nearly 18 – although the highest occupancy is from a small house with a number of occupants.

The most numerous electricity end-use in New Zealand houses are 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, while another house had the largest refrigeration appliance – a walk in 3,000 litre chiller (which did not appear to be in commercial use). The most popular appliance is a television, with a total of 786 in all the HEEP houses – average of just under two televisions per house. The largest number of televisions in one house was nine. The next most popular appliance types were also in the entertainment category – video recorders and stereo systems.

Per house	Minimum	Maximum
Floor area	51m^2	315m^2
Number of people	1	10
Occupancy	1 person / 178m^2	1 person / 10m^2
Number of lights	7	143
Appliance power measurements	7	82
Sewing machines		22
Largest freezer		approx 3,000L
Televisions		9

Table 7: Largest and smallest

3. HOUSEHOLD SELECTION

This section provides a background to the HEEP house selection methodology, an analysis of the participation rate and a comparison with other similar research projects.

3.1 Sample size

The necessary sample size for a representative national sample was set out in the HEEP Year 2 (Bishop et al, 1998) report, and the reasons summarised in the HEEP Year 5 report (Stoecklein et al, 2001).

Based on the statistical analysis reported in Bishop et al, (1998), it was necessary to monitor approximately 400 households. This was based on the recognition that space heating and hot water heating each use approximately one-third of the total household energy consumption, and that the data quality of these two end-uses coupled with the total load should determine the sample size. The largest number of houses required is for space heating. Even treating the night store heated households separately, in order to estimate space heating energy with an error of less than 10% and with 90% confidence, the required sample size was 375 households nationwide. A target sample size of 400 households nationwide was chosen to ensure that should any houses pull out from the study, or be found not suitable e.g. due to inadequate data collection, the results would be statistically representative of the country.

Now data collection is complete, a review of the data has found that 400 houses form a reasonable sample size with acceptable error limits. Although not planned, it has also been found that the data set designed for national estimates provides a reasonable basis for some regional energy use estimates.

The HEEP sample size can be usefully compared to that used for television audience measurement in New Zealand. The Nielsen Media Research Ratings on which television commercial sales and programming are based are built on a 'PeopleMeter' panel of 500 permanent, private households. The panel make-up is determined by an establishment survey and the quinquennial national census. Homes remain on the panel for a maximum of 36 months.[3]

3.2 Methodology

The method of selecting households was outlined in the HEEP Year 5 (Stoecklein et al, 2001) and HEEP Year 3 (Camilleri et al, 2000) reports. In brief, Statistics New Zealand provided a set of randomly selected (on a population weighted basis) area units, and the HEEP team carried out a further random sampling of the meshblocks and then random sampling of households within these meshblocks.

A meshblock is the smallest area used to collect and present statistics by Statistics New Zealand. The size of a meshblock depends primarily on the number of people and type of area covered. Generally meshblocks in rural areas have a population of

[3] See further information see 'Nielsen Media Research – TV Ratings' on www.acnielson.co.nz

around 60 people, while in urban areas the meshblock is roughly the size of a city block and contains approximately 110 people.

Area units combine a number of meshblocks. An area unit must be a single geographic entity with a unique name referring to a geographical feature. Area units of main or secondary urban areas generally coincide with suburbs or parts thereof. Area units within urban areas normally contain 3,000-5,000 population, although this can vary, while in rural areas they can be as low as two or three meshblocks and a very low population count.

There were 1,860 area units and 38,350 meshblocks in the 2001 Census Area Unit classification.[4]

The HEEP random house selection approach includes the following steps:

a) Select locations. Define locations by matching them to area unit boundaries.
b) Determine household populations in selected locations, with proportions of national total.
c) Draw a proportional random sample of meshblocks from selected location.
d) Select a random household in each selected meshblock and obtain consent from residents. If no consent is given, repeat procedure within the meshblock until a house is found. If no additional house is available in a given meshblock (e.g. due to very small numbers of households), then randomly select another meshblock in that area unit and repeat the process.

A total of 399 households were selected for inclusion in the HEEP database. This population weighted sample included 221 households from the major population regions of 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 from those New Zealand households not covered by the major population regions. From the HEEP Year 5 report it was anticipated that the size of the clusters be fixed at 10 households. However, equipment restraints in the final year of monitoring required that the size of each of the remaining 11 clusters be reduced to nine households. The Orewa cluster was further reduced to eight houses following a last minute withdrawal by the occupants of one house.

The description Statistics New Zealand provides for a specific meshblock is the geographical features forming the boundary of that meshblock, such as the area bounded by streets w, x, y and river z. Statistics New Zealand do not provide lists of the street numbers of the houses within the meshblock.

Initially for the selections in Wellington, Porirua, Lower and Upper Hutt, lists of the houses within each meshblock were obtained from each of the councils. The aerial photographs provided by Porirua City Council also proved to be helpful to identify those street addresses which did not have a dwelling on them.

[4] For further information see www.statistics.govt.nz under 'Statistical methods' then 'Classifications'.

For the following years, rather than dealing with a range of individual councils (whose assistance in providing information varied dramatically) Quotable Value New Zealand was contracted to provide the household names (owners) and addresses for the selected meshblocks. Until the last year of monitoring (2004) the following information was available for each property in the meshblock: the owner of the property, the physical address, the postal address and the meshblock number.

The Local Government (Rating) Act 2002, which came into force on 30 April 2003, placed a greater restriction on access to owner/occupiers' names and addresses. As a consequence, for the 2004 selections Quotable Value were unable to provide the physical address of the households, but were limited to providing the name of the house owner and a postal address. This made it more difficult to undertake a follow-up contact of householders who did not reply to the initial letter, particularly in rural areas where the postal addresses were often either a Post Office box number or rural delivery number.

The HEEP sampling framework required a response – **yes** for the house to participate, or **no** for the next house in the selection to be able to be used. If the house occupants failed to reply, either a phone call or house visit was required. This change in address availability increased the difficulty of obtaining not only rural, but also rental, houses regardless of location. This was because the postal address for a rental property was for the owner, who sometimes was based outside the sampling area. This meant that we relied on the owner contacting HEEP to provide the house contact details, or passing the posted material to their tenants. If it appeared that this had not occurred, the HEEP team attempted to find the telephone number of the owner, asked them for the house physical address and tenant name, and then send another information pack to the tenants. If the response at any of these steps was negative, then another house was selected.

The standard method of approaching households to take part in the study was to initially send them an information pack which included background information on the study, a freepost reply envelope, as well as an 0800 number for them to call if they had additional questions or wished to reply via the phone. If we did not receive a reply from a household, local field staff would phone or visit the household in person during the day or evening. If no-one was home, a further letter was left inviting their participation.

The incentives remained the same throughout the monitoring. At the installation of the monitoring equipment, the house occupants received a gift of $50 to cover any cost associated with the installation and a copy of the BRANZ Ltd book *Maintaining Your Home*. Shortly after the end of the monitoring period, the occupants received a report of how energy is being used in their own house (e.g. energy consumption by different appliance, peak energy use, time etc.). No information was provided to the house occupants on the results of the monitoring (specifically room temperatures and energy use) during the monitoring period.

Some households proved extremely difficult to contact, so after three unsuccessful approaches (at different times of the day and each time a letter was left asking the occupants to contact us), were made to the household, the house was deemed as not wishing to participate. For Northland, with the higher frequency of surveying undertaken by other agencies in that area, it was felt that a greater response rate would be achieved by making first contact through a personal visit. A local experienced person was employed for this task.

It was anticipated that some households would not participate so four (or five after 2001) households were initially selected from each meshblock to be approached. To prevent additional bias, these households were then accepted in the order in which they were selected e.g. if House 2 replied 'yes', it was not accepted for monitoring until House 1 had replied 'no' or had been excluded due to unsuccessful contact attempts.

For the selections up to 2001 (Wellington, Hamilton and the first year from Auckland, Manukau, North Shore and Waitakere), if none of the initial four households wished to participate in the survey then a replacement meshblock was selected and another four households were approached and so on. A total of 164 meshblocks were approached to find the 106 households.

After 2001, the selection procedures were changed so that if a household was not found amongst the first five houses selected from a meshblock, then additional households to approach were randomly selected from the same meshblock. Only where the meshblock contained a small number of houses and a majority of the households in the meshblock had been approached was a replacement meshblock selected. A total of 13 replacement meshblocks were required to select the 293 households after 2001.

3.3 Participation rate

A total of 1,687 households were approached in order to select the 399 houses in the survey, giving an overall participation rate of 24%.

The participation rate for both selecting a new meshblock after four 'no's' were encountered (24%) and continuing to select houses from the same meshblock (23%) were similar. The following discussion considers the two replacement methods together.

Figure 2 graphs the frequency of the number of households that had to be approached before encountering a household that was willing to participate in the study. The higher frequencies around 10-13 households could possibly be explained by the use of replacement meshblocks. The first replacement method would replace meshblocks once eight or 12 households had declined to take part. Under the second replacement method, replacement of the meshblock was much less common but the most frequent number of houses contacted before the meshblock was replaced was 10. The case which required 30 households to be contacted before one agreed to participate (on the far right of Figure 2), resulted from 25 'no' responses before a second meshblock was selected.

The 'expected' curve shown in Figure 2 is what distribution would be expected if each household approached had the same probability (taken as the observed participation rate) of agreeing to take part in the study, and shows a good agreement with experimental results.

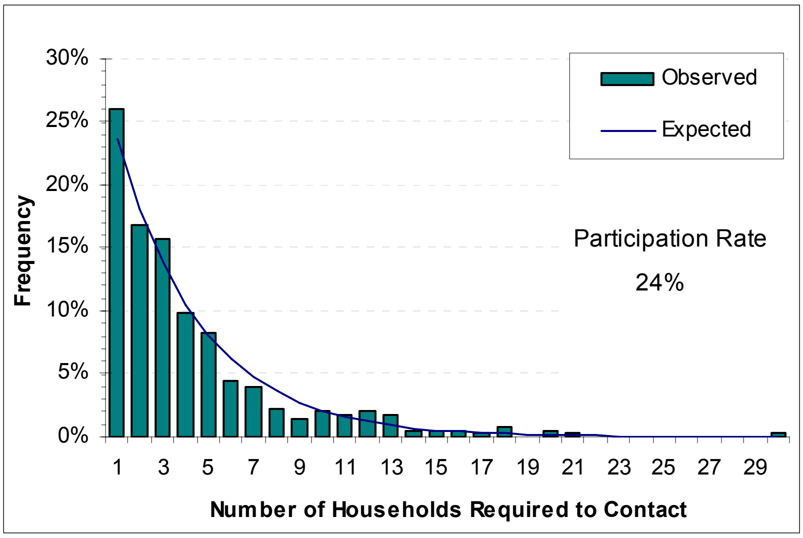


Figure 2: Participation rate of households taking part in HEEP

Households Approached	Cumulative Participation Rate
1	24%
2	42%
3	55%
4	66%
5	74%
6	80%
7	85%
8	88%
9	91%
10	93%

Table 8: Participation rate

Table 8 gives a cumulative total from the expected curve and shows that theoretically it could be expected that 74% of households would be found from the initial selection of 5 households, with 93% of households being selected once 10 houses had been contacted.

Figure 3: Regional participation rate by urban level

Table 9 provides a breakdown of the participation rate for each region/cluster ordered by those most willing to take part in the study. Figure 3 graphs this data by urban level (Statistics New Zealand classification of the region or cluster).

The small numbers of regions in each group make it difficult to make any inference on the mean participation rate for each of the classes of urban level. Grouping the Major Urban and Secondary Urban together into an 'Urban' group and the Minor Urban and Rural areas together into a 'Small Town/Rural' group gives a significant (p 0.03) difference between the mean participation rate in for the Urban regions (25%) and the mean participation rate for the Small Town/Rural regions (33%).

There are many factors that influence whether a particular household participates in a survey. One of the HEEP regional data collection co-ordinators has noted that 'only nice people' decided to take part, and that they could commonly be grouped into a number of categories: those who wanted the gift; those interested in understanding their energy use (often 'why are my energy bills so high?'); and those who were community-minded and generally took part in surveys.

Region / Cluster	Urban Level	# Households Required	# Households Contacted	Participation Rate
Wairoa	Minor Urban	9	15	60%
Arapuni	Rural etc	10	25	40%
Foxton Beach	Minor Urban	10	26	38%
Minden	Rural etc	10	26	38%
Kaikohe	Minor Urban	10	27	37%
Kamo West (Whangarei)	Major Urban	10	29	34%
Sherwood Rise (Whangarei)	Major Urban	10	31	32%
Seddon	Rural etc	9	28	32%
Invercargill	Major Urban	6	19	32%
Hamilton	Major Urban	17	54	31%
Oamaru	Secondary Urban	10	32	31%
Wellington	Major Urban	41	134	31%
Dunedin	Major Urban	14	47	30%
Tauranga	Major Urban	9	32	28%
Wai-iti	Rural etc	9	33	27%
Western Heights (Rotorua)	Major Urban	9	34	26%
Waikanae	Secondary Urban	10	39	26%
Manukau	Major Urban	24	99	24%
Mangapapa (Gisborne)	Major Urban	9	39	23%
Ngakuru	Rural etc	9	40	23%
Christchurch	Major Urban	37	180	21%
Orewa	Major Urban	8[†]	40	20%
Parawai (Thames)	Minor Urban	9	47	19%
Rangatira (Taupo)	Secondary Urban	9	48	19%
Tamatea North (Napier)	Major Urban	9	49	18%
Waitakere	Major Urban	16	96	17%
North Shore	Major Urban	19	119	16%
Auckland	Major Urban	38	240	16%
Awhitu	Rural etc	9	59	15%
Overall		399	1687	24%

Table 9: Participation rate of households asked to participate in the HEEP study

Note: [†] The Orewa cluster was originally intended to be nine houses in size; however a last withdrawal by the occupants from one of the households selected reduced the number by one. The households contacted for this non-participating household have been excluded from the count.

An important factor for households to participate in a study is the quality (clarity, authority, completeness) of the material sent to them and the impression made by the interviewer. With the HEEP selections involving a number of different contact people taking place throughout the country over a number of years, the importance of this factor is difficult to estimate. A particular example is the high participation rate in the Wairoa cluster which could, in part, be due to many of the householders already knowing the Wairoa HEEP data collection co-ordinator. Conversely the low participation rates in Awhitu may be due to the many holiday houses in the area.

During the HEEP one year monitoring, 20 houses (5%) of the houses had a change of occupants. This compares to the 2001 Census results which reported that half of the people in New Zealand on Census night 2001 (Statistics NZ, 2002a) had changed their usual address at least once since 1996 – about 10% movement a year, or twice that of HEEP. It is possible that people expecting to move decided not to take part in the HEEP monitoring, and thus self-select themselves out of the sample. Section 4.3 provides further information on the HEEP sample.

3.4 Other measurement studies

There have been few residential measurement programmes of the scale of HEEP undertaken worldwide. Three programmes which have reported on their success rate in terms of household participation are the 1971-72 Survey of Household Electricity Consumption undertaken by the New Zealand Electricity Department, the End-use Load and Consumer Assessment Program (ELCAP) undertaken in the Pacific Northwest of the United States of America in the late 1980s and early 1990s and the Residential End-use Study (RES) undertaken in New South Wales.

The sample size for the New Zealand 1971-72 Survey of Household Electricity Consumption (Department of Statistics, 1973) was set at 2,000 households. Prospective households were sent two letters, one under the signature of the Government Statistician and the other under the signature of the chair of the local electricity supply authority requesting their participation in the survey. A total of 3,194 households were contacted to select the 2,000 households required giving a participation rate of 63%.

The USA Pacific Northwest ELCAP study (Sandusky et al, 1993) reported that of the 757 residents contacted, 463 (61%) agreed to participate. Key differences are:

- ELCAP data was collected remotely, not requiring a visit to the house. Each of the monthly visits to the HEEP houses also requires access to the inside of the house to allow data from the stand-alone loggers (including electricity, indoor temperatures, solid fuel burners, LPG heaters) to be retrieved as well as swapping equipment monitoring individual appliances (in the detailed monitored sub-set of houses).
- The ELCAP nuisance payment ($US 75 – 125) was higher than the HEEP gift.
- The regional power authority (Bonneville Power Authority) had a high profile in the ELCAP study.

The New South Wales RES study had 370 (19%) households agree (who had meter boards suitable for the mounting of the data logging equipment) from the 2,000 households (400 initial and 1,600 reserve) contacted. These households were then approached by a market research company to undertake a survey, of which 302 were completed. Of these 302 households, 248 were instrumented with data logging equipment. The *Book of Australian Facts 1993*, was given to those households taking part. Mackintosh et al (1993) commented that lower participation rates were observed in metropolitan areas and amongst those households with low electricity consumption (Mackintosh et al, 1993).

4. SOCIAL FACTORS IN ENERGY USE AND TEMPERATURE OUTCOME

Energy use is a social act. Effort has been directed over the past year to establishing the extent to which prevailing patterns of energy use and indoor temperatures are correlated with socio-economic characteristics. The particular focus in Year 9 has been for the ongoing development of the HEERA model. In this section we:

- Review the socio-demographic characteristics of the HEEP households in relation to indoor temperatures and energy use.
- Explore the correlations between social variables, energy and temperature variables.

4.1 The HEERA model

The HEERA model (Section 5) is a scenario model that allows energy consumption to be calculated under a range of different conditions. The social interactions and mediating factors that may give rise to particular energy use patterns and household temperature outcomes are complex. To assist development of HEERA, the social analysis has focused on those social and economic characteristics of households collected in HEEP for which there are also significant and accessible time series of national data. The major sources of social and economic data relating to households and household members that have an extended time series are:

- Dwelling and population census
- Household Economic Survey, and the
- Household Labour Force Survey.

The main variables for which we tested correlations of energy use and indoor temperatures respectively were, consequently:

- household characteristics such as:
  - size,
  - type, and
  - life stage
- household economic status such as:
  - income sources,
  - income, and
  - employment status.

The specification and operationalisation of social variables which appeared to hold promise for HEERA are discussed in the relevant sections.

4.2 The preliminary social analysis in Year 8

Preliminary analysis was reported in the HEEP Year 8 report (Isaacs et al, 2004) based on the socio-demographic data available for 399 households and energy use/temperature data for 296 households. In brief, the following points were noted:

1. There was some difference between the HEEP and the Census household profiles. In particular, among HEEP households there is a slight over-representation of ‘Couple Only’, ‘Couple only with Other Persons’, and ‘Couple with Children’ households. ‘One Parent’ and ‘One Person’ households are under-represented.

2. There appeared to be some association between equivalised household income quintiles and indoor temperatures.
3. When fuel use is categorised into quintiles, with Quintile 1 being the lowest 20% of fuel users and Quintile 5 being the highest 20% of fuel users, there was some suggestion of a relationship with:
   - life stage, and
   - equivalised household income.

It was noted in the Year 8 report that those preliminary analyses provided some tantalising insights into energy use and temperature outcomes. Identifying the key social variables correlated with energy use and temperature outcomes for use in the HEERA model has been the focus of Year 9 analysis.

4.3 Socio-demographic characteristics of the HEEP households

Cleaning and stabilising of the data set in Year 9 has resulted in a reduction from 399 to 394 households for which full data is available, although the socio-demographic characteristics do not vary materially.

4.3.1 Household type

The predominant household compositional type in the 394 dwellings is the 'Couple-with-Children' household. Those households make up 35.7% of the households, followed by 'Couple-Only' households (31.1%), with 'One Person' households at 13.3%. Figure 4 compares the household composition profile of the 394 HEEP households with New Zealand households as recorded in the 2001 Census.

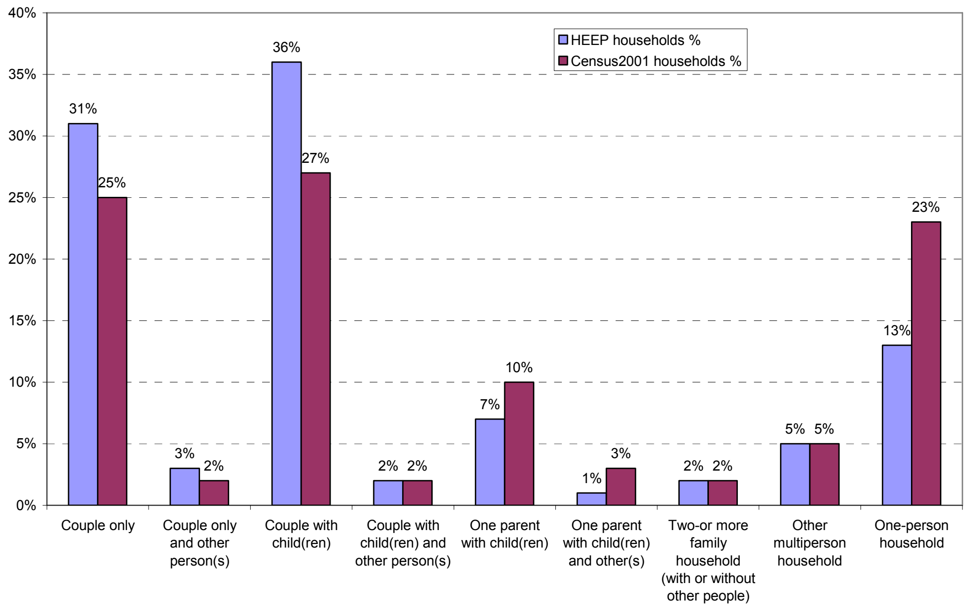


Figure 4: HEEP and 2001 Census household compositions

Similar proportions of HEEP households can be described as being in 'dependency' life stages either because they have members who are under five years of age (15.2%) or because all members are 65 years or older (16.1%).

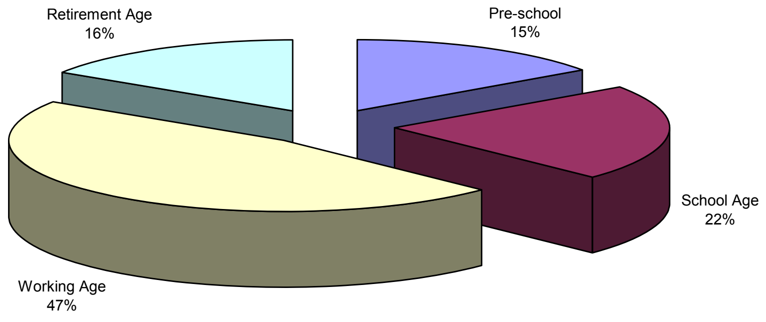


Figure 5: Age of youngest HEEP household member

Figure 5 sets out the profile of households in relation to critical life stages associated with the youngest household member.

Just over a quarter of the households had no adult member in employment (25.5%), while 17.3% were households in which all the adult members were in full-time employment. The other largest category of households was households in which there was a mix of adults in full-time employment and adults not-in-employment.

4.3.2 Household income

Household income is calculated by combining the annual personal income for all household members. For analytic purposes, equivalised household income is a more robust measure because it takes into account household size. The most sensitive and complex equivalence scale used in New Zealand is the Revised Jensen Scale (RJS) (Jensen and Vasantha, 2001). Its data requirements exceed those provided through HEEP. Instead we have used the 'Luxembourg Income Study (0.5) Scale' (LIS) (Atkinson et al, 1995). The LIS Scale is increasingly being used overseas and shows similar results to those generated by the RJS. The LIS scale adjusts equivalised household income by dividing annual household income by the square root of the number of persons in the household.

The Luxemburg method gives equivalised income quintile boundaries for the HEEP households of:

- Quintile 1 – less than or equal to $15,653
- Quintile 2 – $15,654 to $24,749
- Quintile 3 – $24,750 to $35,000
- Quintile 4 – $35,001 to $49,498
- Quintile 5 – over $49,499.

If household types were randomly distributed, then there would be equal numbers of each in each quintile, but this is not the case. The following HEEP household types are over-represented among the lowest household income quintiles if a normal distribution is assumed:

- one-person households
- other multi-person households
- one-parent with child(ren) households
- multiple family with children households
- couple-with-children plus others households
- couples with others households.

The latter are also over-represented in the highest income Quintile 5. Couple-with-children households tend to be over-represented in Quintiles 2, 3 and 4.

In relation to life stages, the situation in relation to income quintiles is somewhat more mixed. Figure 6 shows the quintiles for equivalised household income for households in each life stage calibrated by youngest household member. Retired person households tend to be over-represented among income Quintiles 1, 2 and 3. Households with pre-school and school aged children tend to be over-represented in income Quintiles 1 and 2. Households entirely made up of working age members tend to be over-represented in income Quintile 5.

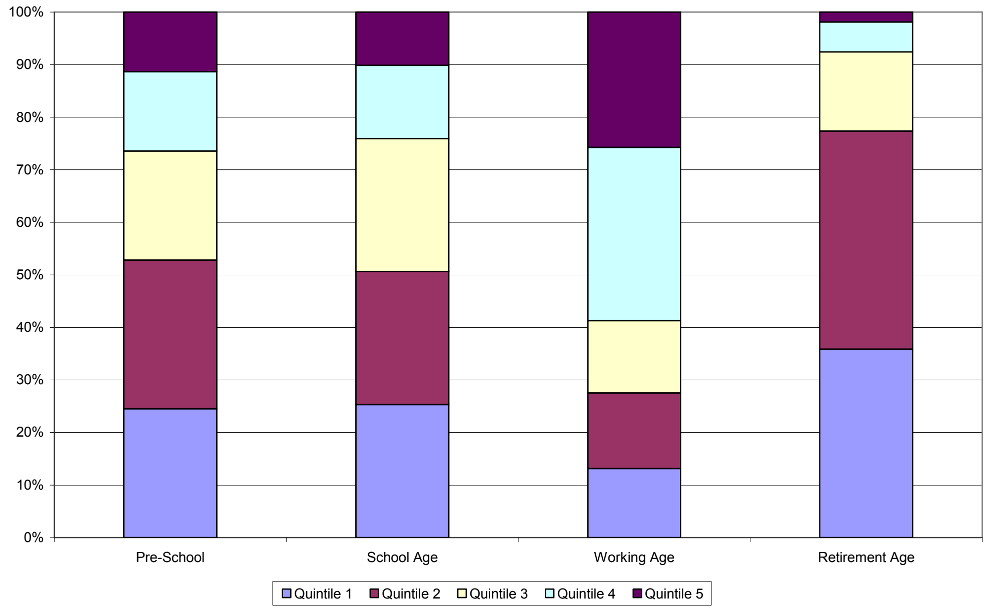


Figure 6: Equivalised HEEP household income by youngest household member

4.4 Income, living room temperatures and energy use

Energy pricing and expenditure are critical energy and social sector issues. It is an energy sector issue because of the potential impact of different pricing regimes on the maintenance of energy supply and the distribution infrastructure. It is also a critical issue in relation to consumption management. Economic assumptions about demand and the impact of price would suggest that a major tool in reducing energy consumption might be the management of price, with the impact of pricing being dependent on the demand curve and elasticities. Of course, the use of price as a management tool and/or price increases reflecting reduced supply raise issues of affordability and anxieties around the potential for low income groups to be exposed to fuel poverty.

In the HEEP Year 8 report (Isaacs et al, 2004) we noted that the connection between energy policy and social policy has been largely ignored. We suggested that there are four critical questions around energy that can be illuminated by the HEEP data to connect energy policy to social policy. They are:

1. To what extent are well-being outcomes associated with differentials in access to and the efficient use of energy?
2. What are the determinants of differential household energy use and energy efficiencies?

3. To what extent can the nation's 'energy efficiency' be increased and energy consumption minimised through the targeting of households with different socio-economic and demographic characteristics?
4. To what extent can the optimisation of low income households' incomes be pursued through energy efficiency?

The HEEP Year 8 report noted that while preliminary analysis of household income and temperature did not reveal a significant relationship between the two, initial data analysis did not equivalise household incomes in any way. Consequently, income effects tend to be masked by household size effects. We then showed that when using equivalised incomes and income quintiles, there did appear to be an over-representation of low income quintiles among colder dwellings.

In Year 9 we have furthered that analysis by exploring more rigorously the relationships between the following variables:

- Equivalised income (see Section 4.3.2 above)
- Temperature – supplied from the direct monitoring of house temperatures in HEEP dwellings (units °C). The temperature variable is the calculated mean winter evening living room temperature (5pm to 11pm, June to August).
- Energy use – a variety of energy use variables were constructed based on monitoring use data[5] (units kWh per year):
  - Total Energy Use: total annualised gross energy for all fuels
  - Heating Energy Use: estimated annualised gross energy used for heating
  - DHW Energy Use: estimated annualised gross energy used for hot water
  - Residual Energy Use: estimated annualised gross energy used for non-heating and non-domestic hot water purposes, e.g. lighting and cooking.

All those variables are scale variables. Statistical descriptive measures of the six variables are set out in Table 10.

Variable		Equivalised Income Using LIS scale	Mean Winter Evening Living Room Temperature	LOG Total Energy Use	LOG Heating Energy Use	LOG DHW Energy Use	LOG Residual Energy Use
N	Valid	353	386	330	320	369	339
	Missing	41	8	64	74	25	55
Mean		$31,394	17.8	3.98	3.33	3.45	3.52
Std. error of mean		$908	0.121	0.012	0.031	0.012	0.016
Median		$27,500	17.75	3.99	3.41	3.45	3.56
Mode		$49,498	17.2	3(a)	1(a)	3(a)	1(a)
Std. deviation		$17,060	2.37	0.22	0.56	0.23	0.29
Skewness		0.545	-0.017	-0.26	-1.39	0.09	-1.89
Kurtosis		-0.440	0.2	0.48	3.55	0.06	13.17
Range		$88,883	13.8	1	4	1	3
Minimum		$1,118	10.0	3	1	3	1
Maximum		$90,001	23.8	5	4	4	4

Table 10: Income, living room temperature and energy use descriptive statistics

Note: (a) Multiple modes exist. The smallest value is shown.

[5] The energy use data was based on annualised figures available at the time of analysis. This may change once final monitoring data has been incorporated.

Three sets of analysis were undertaken in relation to the equivalised income, temperature and energy variables. Subsequent to descriptive analysis, a correlation test was performed to identify any statistically significant relationship between each pair of variables. Where a statistically significant correlation was found, regression analysis was used to model the relationship between the variables. The latter was directed to assessing the strength of the relationship and the potential for that relationship to contribute to the HEERA as a forecasting model.

4.4.1 Equivalised income and mean living room temperature

There was no statistically significant correlation found between equivalised income and mean living room winter temperatures.

4.4.2 Equivalised income and energy use

The extent to which equivalised income had a statistically significant correlation with energy use varied, and are set out in Table 11. For total energy use, DHW and residual energy use statistically significant correlations emerged. In relation to heating energy use, no statistically significant relationship was found.

Correlation Variables	Pearson Correlation Statistic
Equivalised income and total energy use	0.147*
Equivalised income and energy use for heating	0.116
Equivalised income and energy use for DHW	0.142*
Equivalised income and residual energy use	0.121*

Table 11: Correlations equivalised income and energy use variables

Note: * Correlation is significant at the 0.05 level (2-tailed)

Although there are statistically significant relationships between equivalised income and some energy use variables, the explanatory strength of those relationships are not particularly strong.

Table 12 sets out the regression analysis results for:

- equivalised income and total energy use
- equivalised income and hot water energy use
- equivalised income and residual energy use.

It shows that equivalised income explains only 2% of the variation in total energy use. Equivalised income explained less than 2% of the variance for both hot water energy use (1.7%) and residual energy use (1.8%).

Model	Predictor Variable	Dependent Variable	R-square	Adjusted R-square
1	Equivalised income	Log total energy use	0.022	0.018
2	Equivalised income	Log hot water energy use	0.020	0.017
3	Equivalised income	Log residual energy use	0.021	0.018

Table 12: Paired model summaries equivalised income and energy variables

The adjusted R-square value indicates the loss of predictive power or shrinkage and is generated by the SPSS computer programme. The R-square indicates the amount of the variance that is accounted for by the regression model from our sample; the adjusted values tells how much variance would be accounted for if the model had been derived from the population from which the sample was taken (Field, 2000).

4.5 Size of household, living room temperatures and energy use

The HEEP Year 8 report (Isaacs et al, 2004) noted that preliminary analysis of the social data did appear to confirm the widely-held belief that the size of household is related to household energy use. We were interested in exploring whether household size also impacted on indoor temperatures. The variables used for this analysis are:

- Size of household – two variables were constructed to address size of household impacts:
  - Household size: The number of usually resident household members.
  - Occupancy: A constructed variable calculating crowding as a function of household size and total number of rooms. It is highly correlated to household size and initial testing shows that in most analysis household size appears to be the stronger variable. Occupancy has been calculated using the American Crowding Index – defined as the number of usual residents in a dwelling divided by the number of rooms in that dwelling (Statistics NZ, 2003). This index does not take into account the type of rooms in the dwelling or the age and sex of the usual residents.
- Temperature – as described in Section 4.4 above (units °C).
- Energy use – as described in Section 4.4 above (units kWh per year).

All those variables are scale variables. The descriptive measures of those six variables are set out in Table 13.

		Household Size	Occupancy	Mean Winter Evening Living Room Temperature	LOG Total Energy Use	LOG Heating Energy Use	LOG DHW Energy Use	LOG Residual Energy Use
N	Valid	394	393	386	330	320	369	339
	Missing	0	1	8	64	74	25	55
Mean		2.90	0.33	17.8	3.98	3.33	3.45	3.52
Std. error of mean		0.08	0.01	0.12	0.012	0.03	0.01	0.02
Median		3.00	0.29	17.8	3.99	3.41	3.45	3.56
Mode		2	0.22	17.2	3(a)	1(a)	3(a)	1(a)
Std. deviation		1.5	0.19	2.4	0.22	0.56	0.23	0.29
Skewness		1.32	2.71	-0.02	-0.26	-1.39	0.09	-1.89
Kurtosis		3.23	16.92	0.2	0.48	3.55	0.06	13.17
Range		10	1.92	13.8	1	4	1	3
Minimum		1	0.08	10.0	3	1	3	1
Maximum		11	2.00	23.8	5	4	4	4

Table 13: Household size, living room temperatures and energy use statistics

Note: (a) Multiple modes exist. The smallest value is shown.

4.5.1 Household size and mean living room temperature

There was no statistically significant correlation found between household size and mean living room winter temperatures.

4.5.2 Household size, occupancy and energy use

The extent to which household size and occupancy respectively had a statistically significant correlation with energy use varied. For total energy use, DHW and residual energy use statistically significant correlations emerged. Household size showed the highest correlation. In relation to heating energy use, Table 14 shows that no statistically significant relationship was found.

Correlation Variables	Pearson Correlation Statistic
Household size and total energy use	0.357**
Household size and energy use for heating	0.092
Household size and energy use for DHW	0.513**
Household size and residual energy use	0.307**
Occupancy and total energy use	0.205**
Occupancy income and energy use for heating	0.058
Occupancy income and energy use for DHW	0.339**
Occupancy income and residual energy use	0.121*

Table 14: Correlations equivalised income and energy use variables

Note: Correlation is significant at the: * 0.05 level (2-tailed). ** 0.001 level (2-tailed)

Table 15 sets out the results from the regression analysis for:

- household size and total energy use
- household size and heating energy use
- household size and residual energy use
- occupancy and total energy use
- occupancy and heating energy use
- occupancy and residual energy use.

Table 15 shows that household size explains around 17% of the variance in total energy use. In relation to hot water energy use, household size explains 26% of the variance. Household size explains only 9% of residual energy use.

Model	Predictor Variable	Dependent Variable	R-square	Adjusted R-square
1	Household size	Log total energy use	0.173	0.170
2	Household size	Log hot water energy use	0.264	0.261
3	Household size	Log residual energy use	0.094	0.091
4	Occupancy	Log total energy use	0.060	0.057
5	Occupancy	Log hot water energy use	0.108	0.106
6	Occupancy	Log residual energy use	0.014	0.011

Table 15: Paired model summaries household size, occupancy and energy variables

Occupancy has a lower explanatory power, explaining 11% of DHW energy use variance but only 1% of the residual energy use. It should be noted that both occupancy rate and household size are also highly correlated to each other (Pearson test, r = 0.810, p<001). Testing also shows a strong correlation between life stage (a factor variable) and household size (Spearman test, r^2 = -0.738, p<0.001).

4.6 Household life stage, temperatures and energy use

The impacts of life stage or life cycle on consumption, activity patterns and ways of life have been well-documented (e.g. Davey and Mills 1989, Davey 1993, Davey

1998, Pool 1995, Silva et al, 1994). To capture the impact of life stages in the context of domestic energy use in HEEP, we have constructed a life stage variable around the age of the youngest individual usually resident in the household.

In the HEEP Year 8 report we noted that there appeared to be some relationship between energy use and life stage. First, households whose youngest member is aged five to 14 years tended to be over-represented among the higher total fuel users while, by way of contrast, households whose members are all in excess of retirement years were over-represented among the lowest quintile of total fuel users. Figure 7 shows that pattern still prevails.

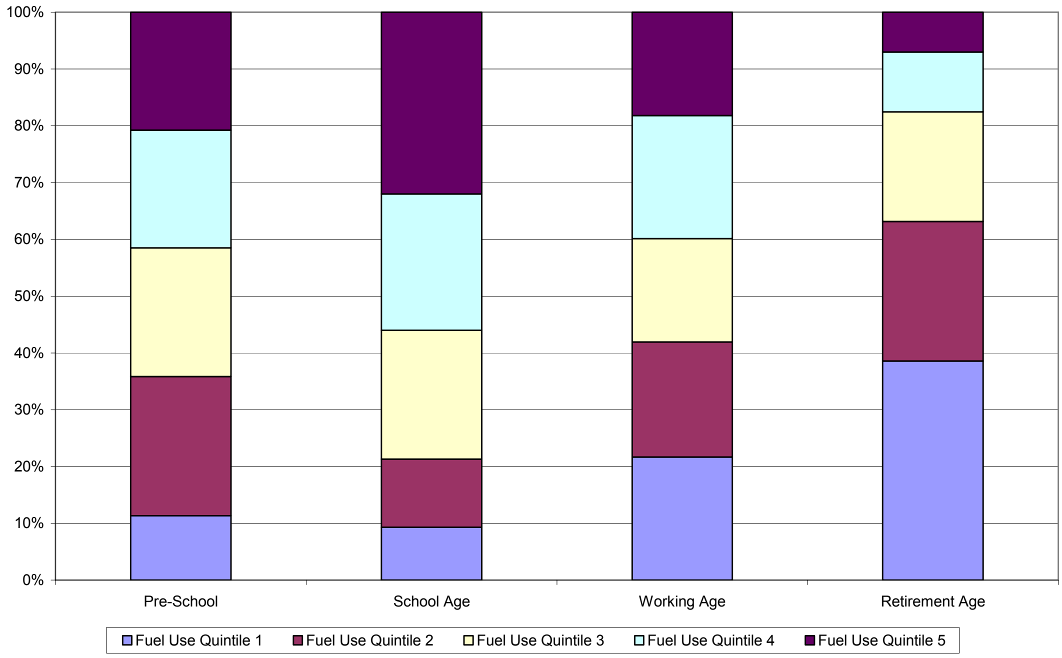


Figure 7: Total fuel use by age of youngest household member HEEP households

The variables used for this analysis are:

- Life stage – this is a constructed variable based on the age of the youngest member in the household: pre-school age (0-4 years); school age (5-14 years); working age (15-64 years); and retired (65+ years)
- Temperature – as described in Section 4.4 above (units °C)
- Energy use – as described in Section 4.4 above (units kWh per year).

The majority of those variables are scale variables. The descriptive measures of the temperature and energy variables are set out in Table 10 and Table 13 above. Life stage is an ordinal variable. A frequency table for life stage is set out in Table 16.

Value		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	pre-school (0-4 years)	60	15.2	15.3	15.3
	school age (5-14 years)	86	21.8	21.9	37.2
	working age (15-64 years)	183	46.4	46.7	83.9
	retired (65+ years)	63	16.0	16.1	100.0
	Total	392	99.5	100.0	
Missing	missing (i.e. missing age data)	2	0.5		
Total		394	100.0		

Table 16: Frequency table of the life stage variable

4.6.1 Life stage and mean living room temperature

There was no statistically significant correlation found between life stage and mean living room winter temperatures.

4.6.2 Life stage and energy use

The extent to which life stage had a statistically significant correlation with energy use varied. For total energy use, DHW and residual energy use life stage has a statistically significant correlation. Table 17 shows that in relation to heating energy use, no such statistically significant relationship was found.

Correlation Variables	Spearman Correlation Statistic
Life stage and total energy use	-0.271*
Life stage and energy use for heating	-0.053
Life stage and energy use for DHW	-0.346*
Life stage and residual energy use	-0.239*

Table 17: Correlations life stage and energy use variables

Note: * Correlation is significant at the 0.05 level (2-tailed)

Table 18 sets out the results from the regression analysis for:

- life stage and total energy use
- life stage and DHW energy use
- life stage and residual energy use.

The life stage variable explains around 10% of the variance in total energy use. In relation to hot water energy use, household size explains 17% of the variance. Life stage explains around 8% of residual energy use.

Model	Predictor Variable	Dependent Variable	R-square	Adjusted R-square
1	Life stage	Log total energy use	0.103	0.095
2	Life stage	Log hot water energy use	0.174	0.167
3	Life stage	Log residual energy use	0.088	0.080

Table 18: Paired model summaries for life stage and energy variables

4.7 The impact of social variables

Further analysis was undertaken through multiple regression to test energy use in relation to all four social variables:

- equivalised income
- household size
- occupancy, and
- life stage.

Because of the close correlation between occupancy and household size, two multiple regressions were undertaken. One included occupancy and one excluded the occupancy variable. Table 19 sets out the results for the multiple regression analysis.

Model	Predictor Variables	Dependent Variable	R-square	Adjusted R-square
1	Equivalised income, life stage, size of household, occupancy	Log total energy use	0.241	0.225
2	Equivalised income, life stage, size of household	Log total energy use	0.223	0.210
3	Equivalised income, life stage, size of household, occupancy	Log DHW energy use	0.324	0.311
4	Equivalised income, life stage, size of household	Log DHW energy use	0.328	0.318
5	Equivalised income, life stage, size of household, occupancy	Log lighting etc energy use	0.167	0.151
6	Equivalised income, life stage, size of household	Log lighting etc energy use	0.153	0.139

Table 19: Multiple regression analysis for social dynamics variables and energy use

As Table 19 shows, the explanatory power of these variable sets is not strong. When modelled together, the four selected social dynamic variables account for around 22-24% of the variance in total energy use. When the occupancy term is dropped from the analysis, the explanatory power of the model is reduced only slightly.

For DHW, the variable set including occupancy accounts for 31-32% of variance. The dropping of the occupancy variable from the set has little impact.

Similarly with residual energy use, when the occupancy variable drops out of the model the explanatory power is reduced, but only slightly. The four variable set explains 15-17% of the variance in residual energy use, while the three variable set (excluding occupancy) accounts for around 14-15% of the variance.

This simply confirms the strong correlation between household size and occupancy. The use of household size for HEERA purposes would thus provide a simple and reliable method of capturing the size effects of the population living within a single dwelling.

5. DEVELOPMENT OF HEERA

The development of a residential scenario model based on monitored data and to enable the stakeholders to utilise it to their best advantage is a primary goal of HEEP. This residential scenario model has been named the 'Household Energy Efficiency Resource Assessment' (HEERA) model.

5.1 Background to HEERA

HEERA is a scenario model designed to allow the investigation of trends in energy consumption and the impact of energy efficiency options on energy consumption and greenhouse gas emissions. The HEERA energy-use scenarios are capable of being analysed, and the impact of policy measures determined, from a range of viewpoints. This in turn is based on the database disaggregation at the regional, dwelling type, end-use and appliance levels. Information on household socio-economic characteristics is incorporated at the regional level.

At this stage, no macro-economic equilibrium mechanism to provide an energy-price feedback to the demand-side has been included in the model. However, when the effects of policy options which change the price of fuels need to be taken into account, and if end-use fuel-price elasticities justify it, such a feed-back loop could be developed.

HEERA estimates the historic and projected residential energy use, energy supply and greenhouse gas emissions through a set of algorithms based on economic, demographic and socio-economic drivers. These algorithms calculate the dwelling and appliance stocks, and the space heating, water heating, cooking, lighting, refrigeration, electrical appliance and electronic appliance energy use per appliance.

The dwelling and appliance vintage stock algorithms simulate dwelling and appliance stock changes through a dynamic balance between the annual addition of new stock and removal of stock by retirement. This enables the calculation of the national and regional energy demands that are required for energy-use scenarios.

The space heating algorithm simulates a dwelling's space heating requirements by taking into account the physical features (construction, heating systems, location) of a dwelling and uses external inputs about the household operations (temperatures and heating regimes). Water heating, lighting, cooking, refrigeration, electrical and electronic appliances contribute to the space heating internal heat gains through their algorithms.

The energy used by water heating, lighting, cooking, refrigeration, electrical and electronic appliances are calculated by taking into account:

- household socio-economic variables such as household size, life stage, equivalised income and tenure
- physical appliance variables such as water use, floor area, stored hot water volume, refrigerated volume, space temperature and usage regime.

The background and theoretical basis of the HEERA model and database have been described in the HEEP Year 8 report (Isaacs et al, 2004). This report summarises the work undertaken in the past year and addresses the following aspects:

- development of the HEERA model structure
- collection and processing of time-series household socio-economic, dwelling and appliance data
- development of energy demand algorithms for the main end-uses
- demonstration of the HEERA model to construct a set of simple scenarios.

5.2 HEERA model

The HEERA model is based on information about the number and turnover of energy-using appliances in a dwelling e.g. fridges and freezers, towel rails, dehumidifiers and washing machines. Changes in appliances are also important, particularly where this also results in efficiency changes e.g. high-efficiency wood burners replacing open fires etc. The frequency, and changes in the frequency, of the use of appliances is also important e.g. an oven may be only used occasionally, but this pattern may alter with changing lifestyles.

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 et al, 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. How these algorithms are related to drivers and outputs is shown in the HEERA flow diagram of Figure 8.

In the flow diagram, solid arrows indicate existing linkages. Multiplication and equal signs indicate mathematical relationships between outputs. The broken arrows indicate feedback linkages in the form of price elasticities that could be included in the model in future. These price elasticities are defined for HEERA as:

- **Demand price elasticity**: percentage change in the demand energy price for a 1% change in the supply energy price
- **Supply price elasticity**: percentage change in the supply energy price for a 1% change in supply energy
- **GHG price elasticity**: percentage change in the supply energy price for a 1% change in the GHG energy price.

Figure 8 shows the energy consumption per dwelling of an appliance is the product of the appliance stock and the unit energy consumption (UEC) per appliance as calculated by the energy-use algorithms.

The background behind the algorithms in Figure 8, except the supply and GHG emission algorithms, their drivers and outputs are described in Sections 5.2.1 to 5.2.3.

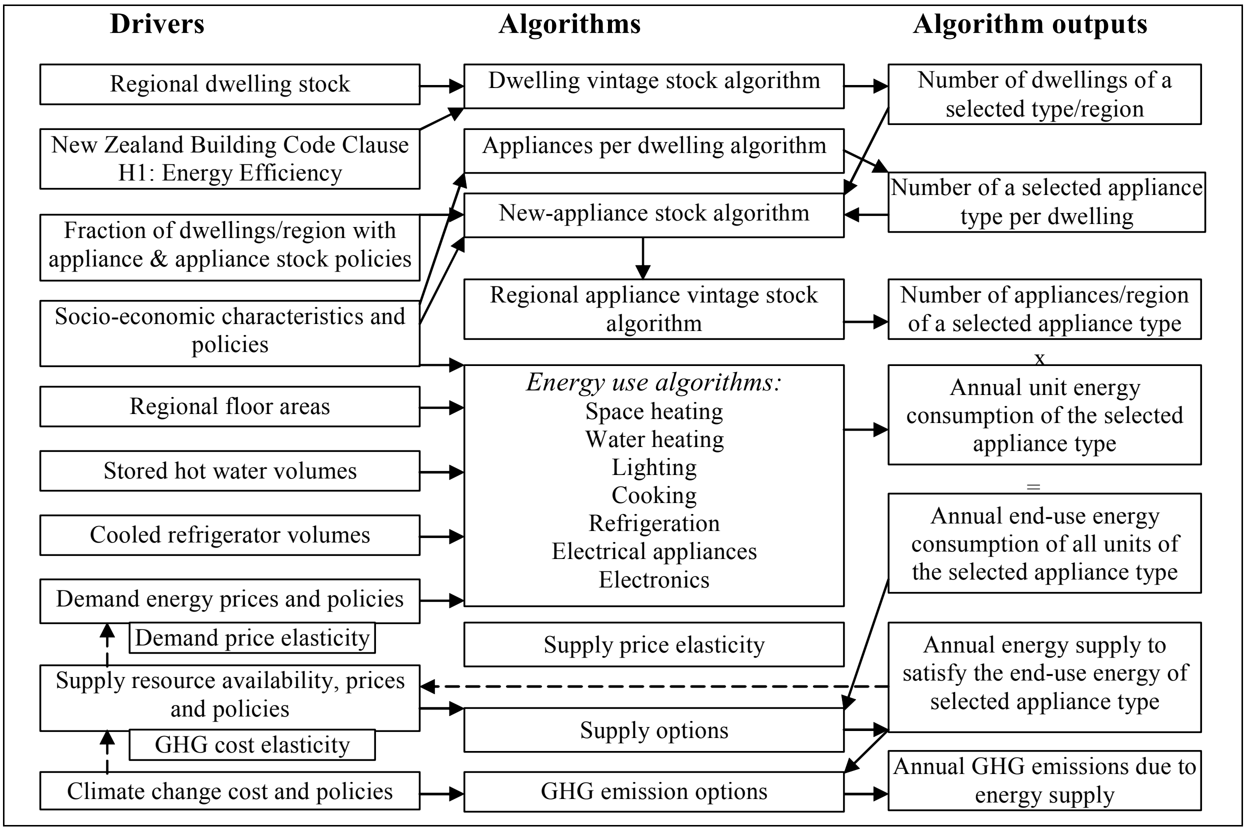


Figure 8: HEERA flow diagram

5.2.1 Dwelling vintage stock algorithm

The dwelling vintage stock algorithm provides the number of dwellings of a specific type by region. This is important as the number of dwellings per region directly influences the annual number of new appliances per region, which is the main scenario driver for the regional appliance energy use.

The term 'vintage' refers to the fact that the total dwelling stock per region for a given year is the sum of the remaining stock from all years prior to and including that year. The new dwelling stock entering the dwelling stock retires at a rate described by the dwelling stock algorithm below.

Census statistics over the historic period covered by HEERA (1980 to 2001) are available for the occupied permanent private dwelling stock at the Regional Council and Territorial Authority levels from the quinquennial censuses (NZ Department of Statistics, 1982a, 1987a, 1992; Statistics NZ, 1997, 2002). Statistics New Zealand also provides household stock projections at the Regional Council and Territorial Authority levels up to 2021 (Statistics NZ, 2004). For HEERA, the term dwelling has been adopted to include permanent private dwellings and households.

The Statistics New Zealand dwelling totals are used with an iterative procedure to calculate the number of new dwellings per region per year for the period 1980 to 2020 with the help of the dwelling stock algorithm. The number of new dwellings per region is used in conjunction with Table 21 to estimate the numbers of different dwelling types per region for a given year.

The geographic regions in HEERA are based on the boundaries of 16 Regional Councils, and are given in Table 20 in terms of their Territorial Authority combinations (Source: Local Government NZ, 2004):

Region ID	Region Name	Territorial Authority Coverage
1	All Regions	All regions
2	Northland	Far North DC, Whangarei DC, Kaipara DC
3	Auckland	Rodney DC, North Shore CC, Waitakere CC, Auckland CC, Manukau CC, Papakura DC, Franklin DC (North)
4	Waikato	Franklin DC (South), Waikato DC, Hamilton CC, Waipa DC, Otorohanga DC, Waitomo DC (North West), Thames-Coromandel DC, Hauraki DC, Matamata-Piako DC, South Waikato DC, Taupo DC (West), Rotorua DC (South West)
5	Bay of Plenty	Taupo DC (North East), Tauranga DC, Whakatane DC, Kawerau DC, Western Bay of Plenty DC, Opotiki DC, Rotorua DC (North East)
6	Gisborne	Gisborne DC
7	Hawkes Bay	Taupo DC (South East), Wairoa DC, Hastings DC, Napier CC, Central Hawkes Bay DC, Rangitikei DC (North East)
8	Taranaki	New Plymouth City DC, Stratford DC (West), South Taranaki DC
9	Manawatu-Wanganui	Stratford DC (East), Ruapehu DC, Wanganui DC, Rangitikei DC (South West), Manawatu DC, Tararua DC (North), Palmerston North CC, Horowhenua DC, Waitomo DC (South-East), Taupo DC (South)
10	Wellington	Kapiti Coast DC, Masterton DC, Carterton DC, South Wairarapa DC, Upper Hutt CC, Lower Hutt CC, Wellington CC, Porirua City CC, Tararua DC (South)
11	Marlborough	Marlborough DC
12	Nelson	Nelson CC
13	Tasman	Tasman DC
14	West Coast	Buller DC, Grey DC, Westland DC
15	Canterbury	Kaikoura DC, Hurunui DC, Waimakariri DC, Christchurch CC, Banks Peninsula DC, Selwyn DC, Ashburton DC, Timaru DC, Mackenzie DC, Waimate DC, Waitaki DC (North West)
16	Otago	Waitaki DC (South East), Central Otago DC, Queenstown-Lakes DC, Dunedin CC, Clutha DC
17	Southland	Southland DC, Gore DC, Invercargill CC

Table 20: HEERA regions

The stock of dwellings per region is given by the dwelling vintage stock algorithm:

$$DwellingStock(k) = \sum_{k=Start}^{End} \sum_{j=Start}^{End} New(j) \times Remain(j,k) - Removed(j) \qquad \textbf{Equation 1}$$

where:

DwellingStock(k) = Estimated number of dwellings in year *k*
New(j) = Number of new dwellings built in year *j*
Remain(j,k) = Fraction of dwellings built in year *j* remaining by year *k*
Removed(j) = Number of dwellings removed by policy measures in year *j*
Start = First year of period over which the algorithm operates
End = Last year of period over which the algorithm operates

In Equation 1 it is assumed that dwellings are retired according to the *Remain(j,k)* factor, unless removed by some policy mechanism through the *Removed(j)* term. Dwellings that are removed by the *Remain(j,k)* factor could be replaced with the same type of dwelling, but this replacement is treated as a new dwelling as it will be of a different construction and thermal performance.

The dwelling stock expressed by Equation 1 is presented in Figure 9 as the sum of the remaining stock from all years prior to and including a given year.

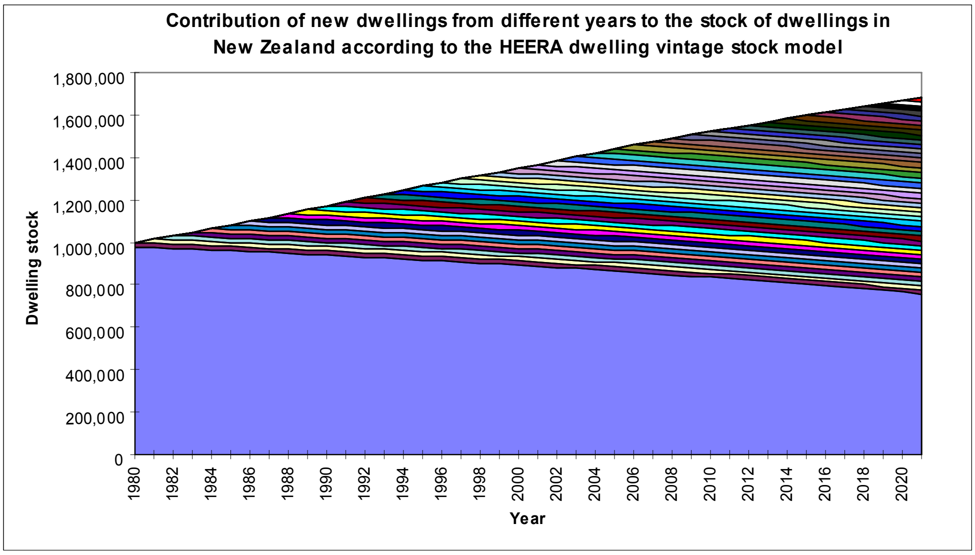


Figure 9: Stock of New Zealand dwellings

The retirement factor *Remain(j,k)* is based on a smallest extreme value distribution and probability density functions with an average mean lifetime and standard deviation of 95 years and 25 years respectively (Figure 10).

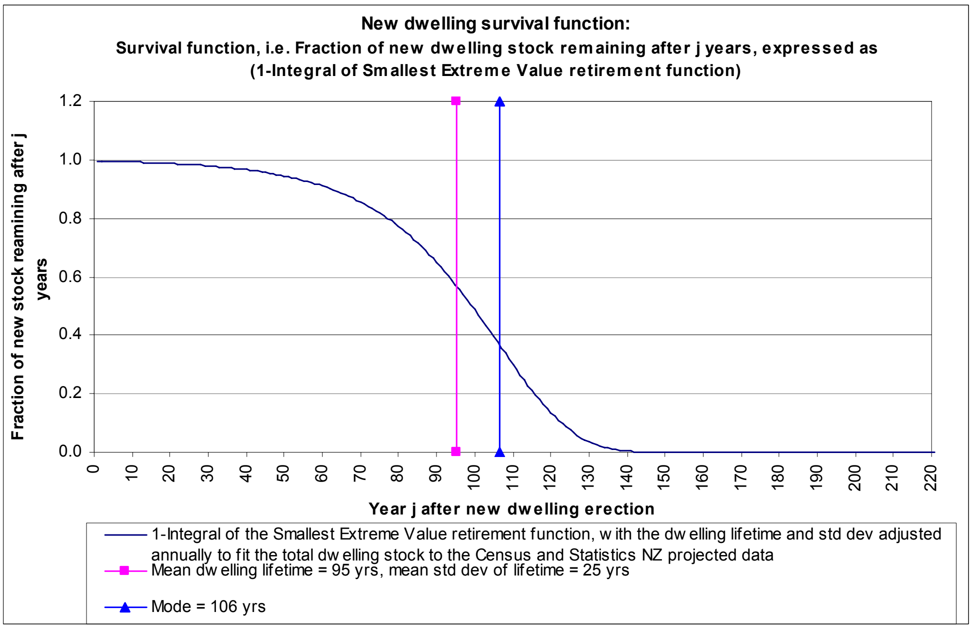


Figure 10: Survival function used in the dwelling vintage stock algorithm

The regional dwelling stock is grouped into a number of basic types that represent different levels of thermal insulation for each region and therefore different levels of energy consumption. The dwelling types of Table 21 represent the minimum thermal insulation levels required by the New Zealand Building Code (NZBC) Clause H1:

Energy Efficiency for each NZBC climate zone and construction method. Revisions in the NZBC may add further dwelling types to those in Table 21.

Dwelling Construction Type *	Roof m² °C/W	Wall m² °C/W	Floor m² °C/W	Window m² °C/W	Infiltration Air Changes/hr
Uninsulated	0.5	0.5	0.5	Single	0.75
Roof insulated	1.9	0.5	0.5	Single	0.75
NZBC 1977 Suspended	1.9	1.5	1.3	Single	0.5
NZBC 1977 Slab	1.9	1.5	2.0	Single	0.5
NZBC 2000 Zone 1 Suspended	1.9	1.5	1.3	Single	0.5
NZBC 2000 Zone 1 Slab	1.9	1.5	2.0	Single	0.5
NZBC 2000 Zone 2 Suspended	1.9	1.5	1.3	Single	0.5
NZBC 2000 Zone 2 Slab	1.9	1.5	2.0	Single	0.5
NZBC 2000 Zone 3 Suspended	2.5	1.9	1.3	Single / Double	0.5
NZBC 2000 Zone 3 Slab	2.5	1.9	2.0	Single / Double	0.5
Super Insulated	3.5	2.5	2.0	Double	0.5

Table 21: HEERA dwelling types for categorising the New Zealand dwelling stock

* Assume all walls are timber frame.

The national dwelling stock is shown in Figure 11 in terms of the basic dwelling types of Table 21, as derived with the dwelling vintage stock algorithm.

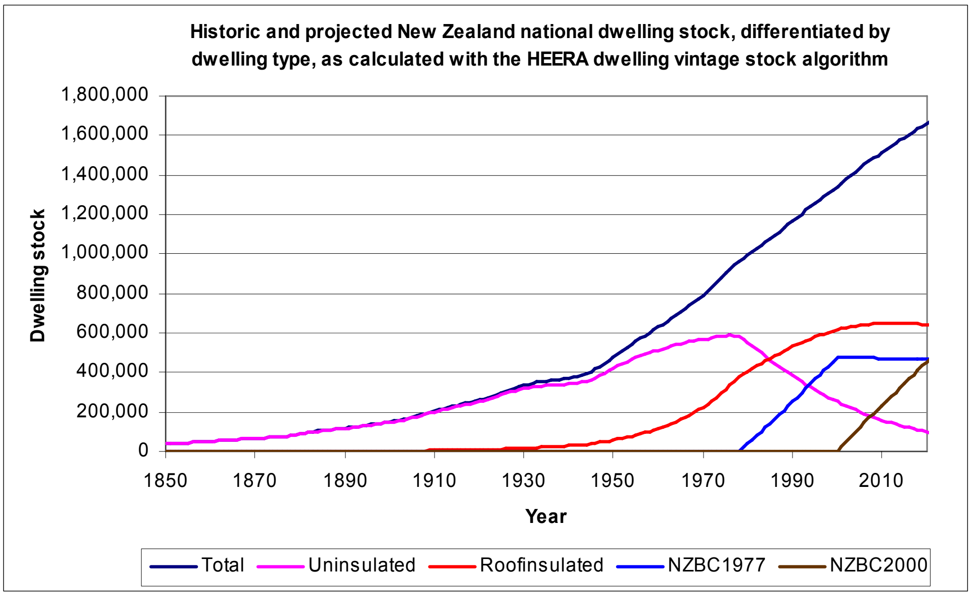


Figure 11: New Zealand national dwelling stock

5.2.2 Appliance vintage stock algorithm

The purpose of this algorithm is to provide details of the stock turnover of a particular appliance type in a given year and region i.e. the:

- total number (stock) of appliances
- number of new appliances entering service that year
- fraction of the previous years' new appliances remaining in that year, after taking into account the effect of retirement.

The total stock of a particular appliance type/region in year *k* can be expressed in two ways. The first is by Equation 2, which gives the historic and projected total appliance stock without providing details about stock turnover. This equation is used in conjunction with Equation 3 to estimate the stock turnover, as described below.

The reason for using Equation 2 is due to the fact that the sales volume data, *Sales(j)* in Equation 3, are normally unavailable or have missing years. In contrast, the *ApplianceFraction(k)* data in Equation 2 is usually collected by a number of organisations on a regular basis. The total stock from Equation 2 is then used to derive the sales data via Equation 3.

$$ApplianceStock(k) = DwellingStock(k) \times ApplianceFraction(k) \times AppliancesPerDwelling(k)$$

Equation 2

where:

DwellingStock(k)	=	Stock of dwellings/region as from Equation 1
ApplianceFraction(k)	=	Fraction of dwellings/region owning the appliance
AppliancesPerDwelling(k)	=	Number of the appliances/dwelling.

The *ApplianceFraction(k)* in Equation 2 has been estimated annually by Statistics New Zealand through their Household Economic Survey (HES) from 1988 to 1998 (Statistics NZ, 1988h, 1989h, 1990h, 1991h, 1992h, 1993h, 1994h, 1995h, 1996h, 1997h, 1998h) and triennially since 2001 (Statistics NZ, 2001h, 2004h). Other agencies such as the Ministry for the Environment, EECA, Environment Canterbury, Christchurch City Council and the New Zealand Television Broadcaster's Council also undertake surveys of appliance ownership. It is assumed that these surveys include appliances that are removed or added by policy measures from years prior to, and including year *k*, unless the exclusion is explicitly stated.

Since ownership data is usually derived from a variety of sources based on surveys with sampling errors, ownership data can show inter-annual fluctuations which may be due to sampling noise rather than real changes in ownership. The ownership data, therefore, has to be smoothed and extrapolated with a low pass filter function to provide a smooth and continuous time series. Logistic growth and exponential decay smoothing functions have been employed in HEERA, but consideration will be given to the use of the IRWSMOOTH algorithm (Young et al, 1991) for this purpose.

As an example, in Figure 12 a logistic growth function is used to smooth and extrapolate the ownership data of dishwashers in New Zealand. The HES survey ownership data is obtained from Statistics New Zealand and ranges over a period from 1988 to 2004. The extrapolated ownership data covers the period 1980 to 2020.

The HES sampling frame for 2004 comprised 2,854 private households, sampled on a statistically representative basis from rural and urban areas throughout New Zealand. It is designed to produce national estimates with a percentage sampling error at the 95% confidence interval of plus or minus 3%. For any expenditure category, this means that there is a 95% probability that the true national expenditure on that category lies within 3% of the average weekly expenditure per eligible household (Statistics NZ, 2004a). Where estimates are made for regions or other sub-populations, sampling errors may seriously limit the use of that information. Given the level of uncertainty in the regional HES ownership data, the use of regression smoothing functions for interpolation and extrapolation is regarded as necessary for HEERA.

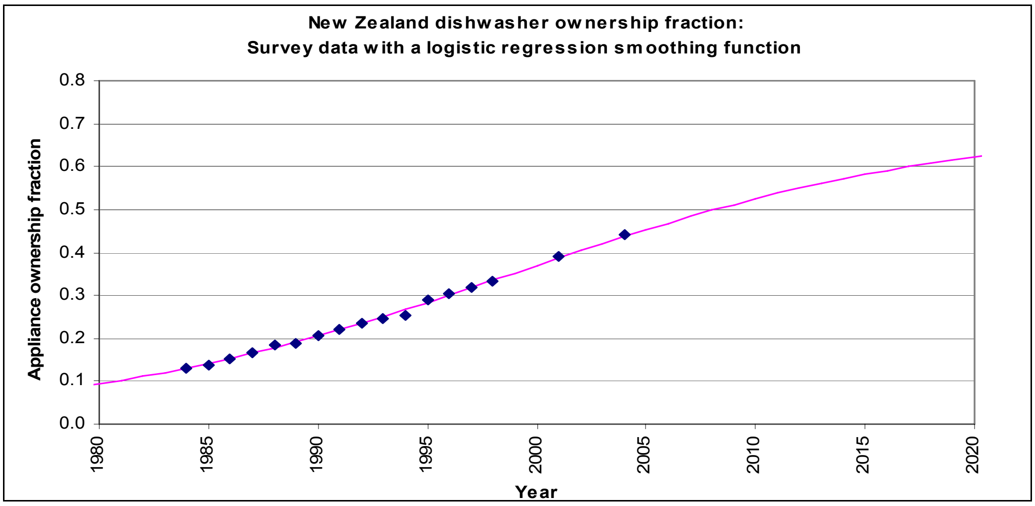


Figure 12: New Zealand survey and smoothed dishwasher ownership data

Refrigerator, freezer and television appliances show time-series trends in the *AppliancesPerDwelling(k)* fraction. This required the development of algorithms based on the evidence of HEEP surveys. For all other appliances, the *AppliancesPerDwelling(k)* is assumed to be unity.

The second method to express the stock of appliances of a particular type per region in year k is by Equation 3. The form of this equation is similar to Equation 1 and also follows the methodology of Boardman et al (1995). The equation provides a breakdown of stock turnover of the total appliance stock estimated with Equation 2. The form of Equation 3 makes it possible to estimate the impact of policy measures on the stock turnover through the *AppRemoved(j)* and *AppAdded(j)* terms.

$$ApplianceStock(k) = \sum_{k=Start}^{End} \sum_{j=Start}^{End} Sales(j) \times AppRemain(j,k) - AppRemoved(j) + AppAdded(j)$$

Equation 3

Where:

ApplianceStock(k)	=	Estimated number of appliances in year *k*
Sales(j)	=	Number of new appliances entering service in year *j*
AppRemain(j,k)	=	Fraction of *NewAppliances(j)* remaining by year *k*
AppRemoved(j)	=	Number of appliances removed by policy measures in year *j*
AppAdded(j)	=	Number of appliances added by policy measures in year *j*
Start	=	First year of period over which the algorithm operates
End	=	Last year of period over which the algorithm operates.

Equation 3 can also be expressed in terms of the annual *Sales(k)* as Equation 4:

$$Sales(k) = ApplianceStock(k) - \sum_{k=Start}^{End} \sum_{j=Start}^{k-1} Sales(j) \times AppRemain(j,k)$$

Equation 4

In Equation 3 it is assumed that appliances are retired according to the *AppRemain(j,k)* factor, unless removed by some policy mechanism through the *AppRemoved(j)* term. Appliances that are removed by the *AppRemain(j,k)* factor could be replaced with the same type of appliance, but such replacement is treated as a new appliance.

The retirement factor *AppRemain(j,k)* for all appliances is based on the normal distribution and probability density functions as described in the HEEP Year 8 report (Isaacs et al, 2004). The average lifetime, or half-life, is defined as the time taken for 50% of each appliance type sold in a given year to retire from the stock of appliances. An example is shown in Figure 13 for dishwashers with a lifetime of 15 years and a standard deviation of 1.7 years, for a period measured in terms of subsequent years after the sale of the dishwashers.

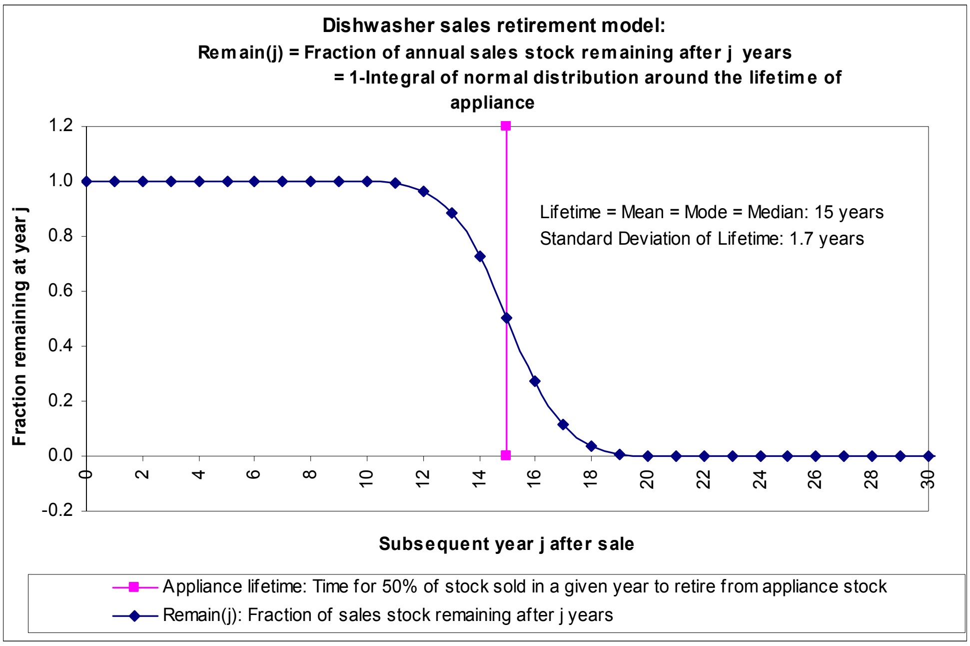


Figure 13: Example – dishwasher sales retirement function

Where the appliance lifetimes and standard deviations are not available they can be calculated from survey *Sales(j)* data with the following iterative procedure:

1. Starting from zero sales and assuming an appliance lifetime and standard deviation from literature, the *ApplianceStock(k)* survey values derived by Equation 2 are used with Equation 4 to calculate *Sales(j)* values over the period covered by the survey *ApplianceStock(k)* data.
2. The lifetime and standard deviation are subsequently optimised by iteratively minimising the sum of the squares of the differences between the survey and calculated *Sales(j)* values.

Appliance	From Literature Average Lifetime * (Years)	Range of Economic Lifetimes ** (Years)	Standard Deviation of Average Economic Lifetime ** (Years)	HEERA Algorithm Average Lifetime (Years)
Bread maker	5+	3-7	0.66	5
Clothes dryer	15+	8-20	2.00	15
Clothes washer	10+	8-20	2.00	10
Computer	5	4-7	0.50	5
Dehumidifier	10+	2-15	2.16	10
Dishwasher	15+	10-20	1.66	15
Combo fridge/freezer	15+	10-20	1.66	15
Fridge	15+	10-20	1.66	15
Freezer	15+	10-20	1.66	15
Heater, fan	5+	1-15	2.33	5
Heater, oil-filled and radiant	10+	2-15	2.16	10
Jug and kettle	5+	1-20	3.16	5
Microwave oven	8+	5-15	1.66	8
Printer	5	3-8	0.83	5
Stereo and CD player	10	3-12	1.50	10
Stove	15+	10-15	0.83	15
Television set	10+	7-10	0.50	10
Vacuum cleaner	12+	5-50	7.50	12
Video recorder	10+	5-10	0.83	10

* Appliance life expectancy. Consumers Institute of New Zealand. Report dated 6 February 2001.
** It is assumed that the range of economic lifetimes according to the manufacturers includes 99.7% of all the lifetimes of an appliance, i.e. 99.7% of the lifetimes fall within ±3 standard deviations about the mean. The Standard Deviation is then (range of manufacturers' economic lifetimes)/6

Table 22: Appliance lifetimes and standard deviation and HEERA lifetimes

The appliance lifetimes and standard deviations used with the HEERA model are given in Table 22. These preliminary values will be updated with this procedure as *Sales(j)* data become available. As an example, the contributions of new dishwashers from different years to the stock of dishwashers as calculated with the HEERA appliance vintage stock algorithm are shown in Figure 14.

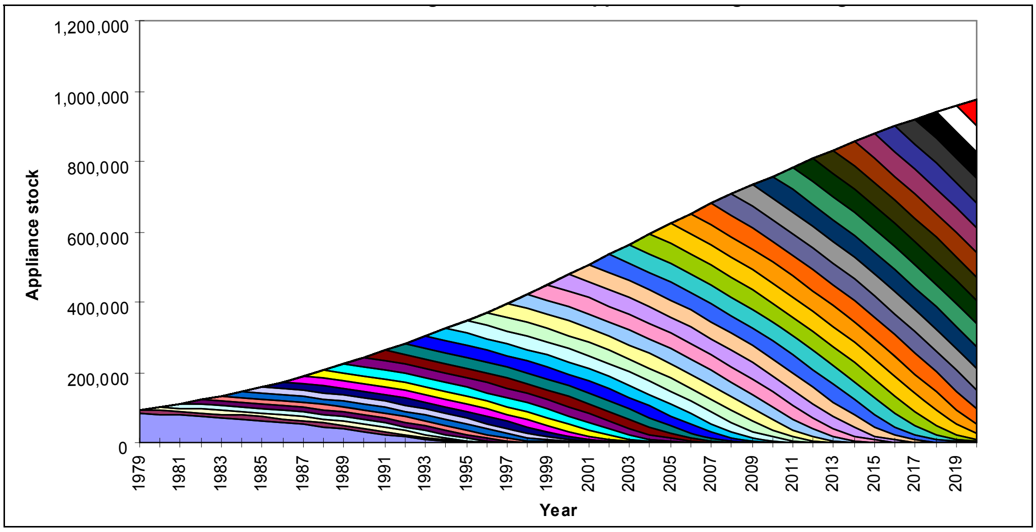


Figure 14: Contribution of new dishwashers to the stock of dishwashers

5.2.3 Energy demand algorithms

In the HEERA model, the effects of physical appliance properties and socio-economic and demographic characteristics and behaviour are reflected in the appliance energy consumption per unit (UEC). The purpose of the space heating, water heating, lighting, cooking, refrigeration and electrical electronic appliance energy demand algorithms, developed from the HEEP data, is to estimate the UEC for each appliance type.

5.2.3.1 Space heating energy demand

The latest version of the single-zone ALF procedure (ALF3) (Stoecklein and Bassett, 2003) is used to estimate the space heating requirement of dwellings in the HEERA regions. The space heating requirement is based on the dwelling's energy balance to maintain the inside temperature of a dwelling at a temperature set by a specified heating schedule. The energy balance is derived from transmission and ventilation losses, internal temperatures, heating patterns, external climate, internal heat gains, solar gains, appliance efficiency and the interaction between these factors. Internal heat gains from water heating, cooking, lighting, refrigeration, electrical and electronic appliances are obtained from their energy demand algorithms.

The construction of the Excel version of ALF3 involved setting up the supporting spreadsheet tables for Regional Council boundaries. Relationships from the ALF3 manual were subsequently established between the spreadsheet tables to determine the heat load required to maintain the dwelling at the temperature set point by the specified heating schedule from the dwelling configuration, thermal characteristics, occupation and operation.

Algorithms were created based on Regional Council areas to establish living room space heating schedules and temperature set points from various socio-economic variables. The temperature set point algorithm incorporates climate, tenure, heater type, household size and life stage as variables. The heating schedule algorithm employs the variables: heater type, equivalised income quintile and NZBC climate zone.

5.2.3.2 Water heating energy demand

Two separate algorithms have been developed from HEEP data, one for instant gas and one for gas, electric, and wet-back water heaters, employing the nominal standing loss, heated volume, household size, equivalised income and life stage as variables.

5.2.3.3 Lighting energy demand

The HEEP algorithm is applicable for fixed wired lighting circuits, with floor area and household size as variables. This excludes portable lights.

5.2.3.4 Cooking energy demand

The HEEP algorithms for ranges and microwaves employ household size and cooker type as variables.

5.2.3.5 Refrigeration energy demand

The HEEP algorithms for freezers and refrigerators have the cooled volume, degree days and year of manufacture as variables.

5.2.3.6 Electrical appliances energy demand

The HEEP algorithms for dishwashers, clothes washers, clothes dryers, electric blankets, toasters and jugs employ various combinations of household size, life stage, equivalised income, number of adults, floor area and degree days as variables.

5.2.3.7 Electronic appliances energy demand

The HEEP algorithms for computers, stereos, televisions and video recorders employ various combinations of household size, equivalised income, floor area, television size, standby power and location.

5.2.4 Demonstrating the HEERA model

An Excel spreadsheet version of the HEERA model was developed and demonstrated by constructing and comparing four scenarios. These scenarios are not intended to be realistic, but rather to start to explore the opportunities such a model could offer.

For example, what would be the effect on electricity use by dishwashers if all households in Auckland changed their life stage? Assume that at the start point in 2004 all households are in the 'Working' life stage, but over the next 16 years (to 2020) all change to 'Pre-school', 'School' or 'Retired' life stages. For all scenarios, the household size (four people) and appliance stock remain the same over the whole period. These scenarios (Figure 15) are caricatures since a region will have a mixture of households from all life stages, whereas it is assumed that all the households in each scenario start in the 'Working' stage and end in on one of other stages. They demonstrate the successful integration and use of the HEERA algorithms.

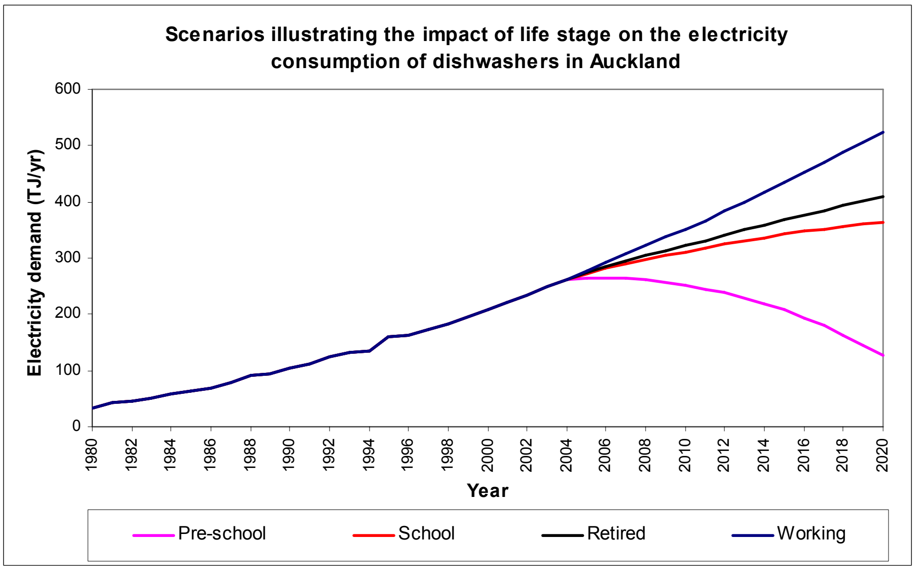


Figure 15: Four scenarios to explore HEERA algorithms

5.3 Discussion

An essential part of the HEEP project is the development of the HEERA model and database, and the 2003/4 and 2004/5 measurements and survey results provided a solid foundation for the successful development and completion of HEERA in 2004/5 and 2005/6. This conclusion is based on the following 2004/5 achievements:

1. A survey of possible sources of HEERA data was undertaken. Regional dwelling stock and appliance ownership data, and the projected number of households were acquired from Statistics New Zealand. National residential sector energy demands were obtained from MED. Together with the HEEP energy-use measurements, this information forms the core of the HEERA scenario driver database.

2. Regional dwelling and appliance vintage stock algorithms were developed for the residential sector, based on the appliance vintage stock algorithm used by the DECADE model in the United Kingdom and on a research study of the New Zealand housing and appliance stock.

3. Household energy demand algorithms for space heating, water heating, lighting, cooking, refrigeration, electrical and electronic appliances were developed, based on the measurements on all randomly selected HEEP houses.

4. An Excel spreadsheet version of the HEERA model was developed and demonstrated by constructing and comparing four scenarios. The scenarios demonstrated the successful integration and use of the HEERA algorithms to achieve the HEEP Year 9 objectives.

5. The importance of socio-economic and demographic characteristics and behaviour on household appliance energy consumption was demonstrated. This justified the incorporation of these variables in the HEERA model and indicated how this could be done.

This modelling foundation will be used during the 2005/6 HEEP project year to revise the HEERA algorithms and to build them into a HEERA Access structure. During the 2006/7 HEEP project year the HEERA model will be beta tested and the results reported in the next HEEP report.

6. SOLID FUEL CALIBRATION

The HEEP monitoring method for solid fuel burners is to attach a high temperature thermocouple to the appliance (typically in contact with the flue) and measure the temperature at five or 10 minute intervals. When the burner is in use, the flue gets hot (typically a maximum thermocouple temperature of 250-400°C). The amount of delivered energy should increase with the thermocouple temperature. Figure 16 illustrates some common types of solid fuel burners.

Figure 16: Examples of solid fuel burners

In addition to the thermocouple monitoring, the house occupants are given a log book to fill in with the amount of wood used each time the solid fuel burner is used. Unfortunately, not everyone is an accurate and motivated record keeper, and for many houses these records are patchy, and sometimes inaccurate, or non-existent.

This section outlines the calculation methodology used to estimate the energy used by solid fuel burners, and provides summary information on the results of this analysis.

6.1 Estimation of missing heat loads

It has proven impractical to estimate the heater output by considering the detailed physics of the heat transfer from the wood burner to the room. There is such a large variety of types of solid fuel burners, and the differences between the flue temperature and the fire-box walls are unknown. This is more than enough to make this calculation impracticable from the measured solid fuel temperatures and other collected data.

One solution was to attempt to use the room or house that the appliance is located in as a calorimeter. If the U-value and thermal mass of the room are known, and the internal and external temperatures are measured, then the net energy input to the room or house can be estimated. By taking out the known energy from direct heating and appliances as measured by HEEP, and making allowances for internal gains such as hot water standing losses and metabolic gains, the difference can then be allocated as coming from solar gains (either directly during the day or through storage in thermal mass) or from the solid fuel burner (at night).

In early attempts at solid fuel burner calibration, the U-value and thermal mass parameters were estimated from an analysis of HEEP data for periods when the solid fuel burner was not being used. Unfortunately, for houses that are normally heated by a solid fuel burner the periods when it is not being used are generally when it is already warm, or when the house is not being heated, or only heated marginally. This effectively reduces the amount of data available for analysis, and as the difference between internal and external temperatures is relatively small it also reduces the range of temperatures for which the analysis can be carried out. The result was that for many solid fuel houses a satisfactory estimate of the U-value and thermal mass was impossible.

To overcome this limitation, the U-value and thermal mass were calculated by using the ALF3 (Stoecklein and Bassett, 2000). Plan details, construction type, climate, window and wall areas, and insulation levels were input. The parameters extracted from ALF3 were the Specific Heat Loss Density, including air leakage losses (per m^2 total floor area), and the Total Thermal Mass. These parameters were found to be comparable to the parameters calculated from the HEEP data for a number of houses.

These parameters were then used to make estimates of the missing heat load calculated using STEM (Short Term Energy Monitoring) modelling (Shorrock et al, 1991), which treats the house as a thermal circuit with one heat loss element and one heat storage element. This approach was first described for HEEP in the Year 2 report (Bishop et al, 1998) and applied in HEEP Year 5 (Stoecklein et al, 2001).

The STEM modelling equation is given in Equation 5:

$$q_{heat} = UA \cdot (T_{in} - T_{Out}) + mC_p \left(\frac{\partial T_{in}}{\partial t} \right) \quad \textbf{Equation 5}$$

where:

q_{heat} = Instantaneous delivered heat to house interior by internal gains and heating (W)
UA = Whole house heat coefficient (W/°C)
T_{in} = Interior air temperature (°C)
T_{out} = External air temperature (°C)
mC_p = Thermal mass of the house (Wh/°C)
$\frac{\partial T_{\mathrm{in}}}{\partial t}$ = Rate of change of interior air temperature (°C/hr).

6.2 Calibration of solid fuel burners

The ALF model depends on the layout and heating pattern of the house. Generally, the whole house is used, as the heat loads cannot normally be localised to particular rooms. Sometimes a smaller zone is used for calibration e.g. the top storey only, or the living areas only. The internal temperature used is a simple average of the internal temperatures measured by the two living room and one bedroom temperature loggers. These are not weighted by the floor area that each sensor represents. Where appropriate, a crude weighting was applied where the bedroom areas are much larger than the living room areas, but this is decided on a case-by-case basis and documented in the house analysis.

The internal loads are usually calculated from the overall total load for the houses (including gas and electricity) minus the hot water load. The internal loads then have metabolic loads added (based on the occupants' age and sex, time spent in the house, and bedtimes), and hot water standing losses (where the cylinder is located within the thermal envelope). In some cases, other particular loads may be removed, for example, especially monitored garage circuits or spa pools. Again, this is carried out on a case-by-case basis.

The calculated missing loads are used as the basis for the solid fuel burner calibrations. Heat loads during daylight hours may include some solar gains, so only time periods during night-time were used for the calibration.

Several houses were tested on this system. These houses had a gas heater or gas central heating system, and the energy for this system was removed from the data for calculation. The missing loads were calculated to compare with the monitored load that had been deliberately excluded.

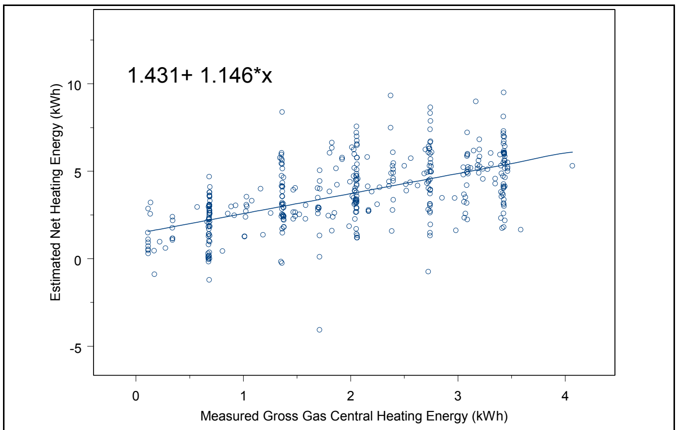


Figure 17: Monitored gas heating energy vs STEM calculated heating energy

For example, the calculated missing loads were in fairly good agreement with the loads measured for the central heating system for House 1 (Figure 17). The slope indicates an efficiency of 87% – a typical gas burner has 80-90% efficiency. The method appears to work for the monitored heating fuels, so it is reasonable to assume that it will work for unmonitored loads, such as solid fuel .

The calibration data for the solid fuel burner from House 2 is presented as an example (Figure 18). A plot of the 10 minute solid fuel temperature shows the correlation with the missing load. Interestingly, it is very close to linear, despite the theoretical fourth order dependence of radiant heat output on temperature. This may be due to the relatively small range of absolute temperature (from about 350K to 600K), and the fact that the thermocouple measures flue temperature which may not be in a direct relationship to the firebox temperature, or to the convective heat output of the burner. A few solid fuel burners do show some curvature, and for these a second order polynomial was fitted.

The solid fuel calibration slope was taken from a weighted linear regression fit of the data grouped according to the solid fuel temperatures in 10°C bins, using only data from 50°C and above. The intercept was then adjusted so that the output of the solid fuel burner is 0 W at 17.5°C – a reasonable average indoor ambient temperature. For the example in Figure 18 the parameters were –192.1+11.0×Solid Fuel Temperature. For this burner, the maximum heat output was about 3.5 kW.

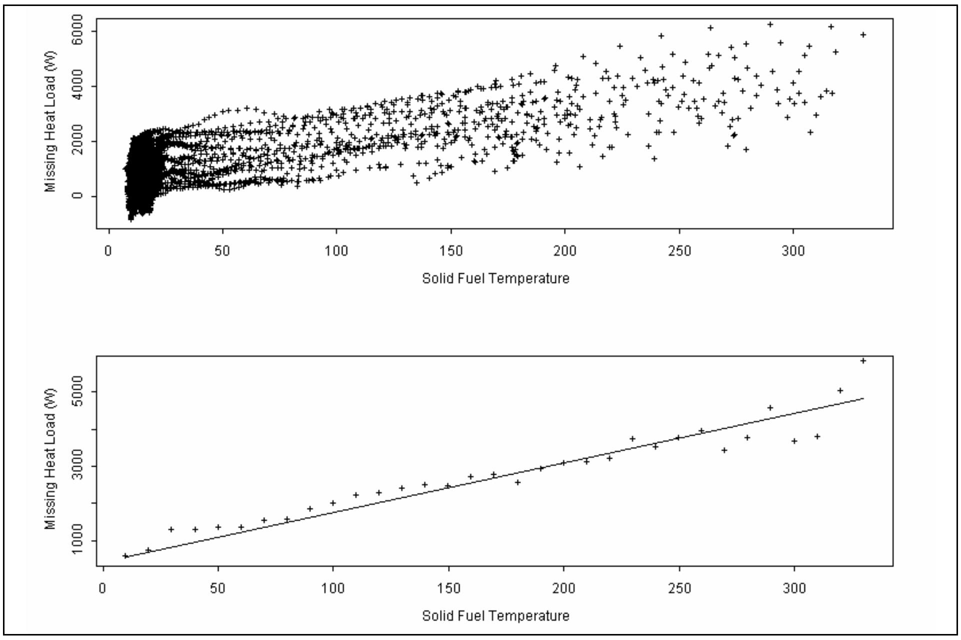


Figure 18: Solid fuel calibration graphs for House 2

6.3 Relative importance of accurate insulation values

Most New Zealand houses built before 1978 have no wall or roof insulation, as it was not a Building Code requirement that they be insulated. About 75% of these houses now have some roof insulation, mostly due to retrofits. The actual R-value of this insulation is not calculable from the HEEP physical audit data.

Fortunately for the calibration process, the whole house R-value of an otherwise uninsulated house is not very sensitive to the actual R-value of the insulation material in the roof. The variation caused by going from an assumed R-value of (approximately) R-1 to (approximately) R-2 is generally less than 20%. This is due mainly to the comparatively large losses of the other uninsulated building elements.

For insulated houses, the window losses are generally high, as most windows are single glazed with aluminium or wooden joinery, and air leakage losses are also comparatively high. This means that variations in assumed R-values of insulation materials have a relatively small effect on the whole house R-value.

6.4 Accuracy of solid fuel burner heat output estimates

Since the accuracy of the log book estimates is poor due to unknown uncertainties in the accuracy of the weight or volume estimates and of the calorific value of the wood, this cannot be used to estimate the accuracy of the solid fuel calibration process. In addition, the efficiencies of each burner in operation are not known accurately.

To estimate the accuracy of the solid fuel calibrations, another approach has been taken. Other HEEP houses with large heaters (e.g. natural gas heaters or fixed wired electric heaters) were put through the same processing as a solid fuel burner. The difference is that when the monitored gas usage of the heater is subtracted from the total house energy use, and the same comparison method carried out the missing load should be equal to the gas heater load. A slope of 1 of the missing load versus the measured load would indicate perfect accuracy.

A number of houses were used for this process, starting with House 1. The ALF estimates of the whole house R-value and thermal mass levels were used. Monitored energy and temperature records were used, with the monitored gas heating and any water heating subtracted from the total electricity and gas.

The results for one house are shown in Figure 19. The top plot of the figure is from the 10 minute data. It has a lot of scatter, as the heater is controlled by switching on and off a large burner, and the house also has a gas instant water heater, which when subtracted from the total gas load also creates further scatter. To estimate the slope of missing heat load to measured heat load, the data are aggregated in bins of width 100 W. The lower plot displays this. The fitted line is from a least squares linear regression, with each point weighted by the number of points in each bin, carried out on all the data points. The slope of this line is 0.85, so the missing heat load is 85% of the monitored heat load. The monitored heat load is a gross energy, and the net heat output of a gas heater would be 80-90% of that figure, so a slope of 0.85 is good.

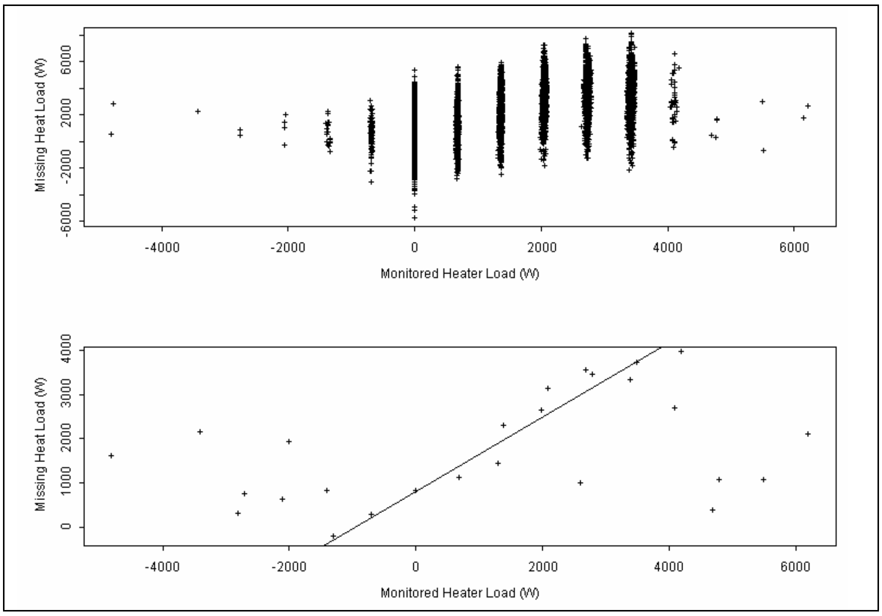


Figure 19: Test calibration of gas heated house – House 1

This process was repeated for a number of other houses, and the results compared to estimate the accuracy of this process (Table 23). If the calibration is accurate, and the fuel has a 100% conversion efficiency into heat in the house, the slope will be equal to 1. There are major differences between the types of heating systems.

House	Slope	Heating Type
House 1	0.85	Gas unit
House 7	0.49	Gas central
House 8	0.31	Gas central
House 9	0.25	Gas central
House 10	0.67	Gas unit
House 11	0.64	Gas unit
House 12	0.72	Gas unit
House 13	0.81	Gas unit
House 14	0.43	Gas unit
House 15	0.54	Gas central
House 16	0.32	Gas central
House 17	0.52	Gas unit
House 18	0.38	Gas under-floor heating
House 19	1.13	Gas unit
House 20	0.21	Gas central (note: very poor fit)
House 21	0.25	Gas central

Table 23: Solid fuel calibration for gas heaters

The average slope of the gas unit heaters is 0.72 ± 0.22, using the sample standard deviation. The precise efficiency of these gas unit heaters is unknown, but likely to be around 80%. Assuming it is 80%, the average of the calibration slopes is 0.9 ± 0.1 (SD of the mean), which is not significantly different from 1. This demonstrates that there is not a large systematic bias caused by the calibration process. The standard error in the calibration for a single heater is ± 0.18 (sample SD), or ± 20%.

The average for the various central heating types is 0.36±0.16. The conversion and distribution efficiency of some gas central heating systems appears to be very low.

6.5 Difficult houses

As is usual with field experiments, some difficulties were encountered. Some houses simply give a very poor correlation between the solid fuel temperature and the missing load. This can be due to the other loads in the house being large compared to the solid fuel output. By restricting the calibration to the family room only, and sometimes by ignoring all the measured energy loads, a good correlation can be established. Generally when solid fuel burners are in use, the other loads in the room are relatively small.

Open fires can be a problem, as their heat output is very low. Using the above method generally gives an acceptable result.

In some houses, there were no HEEP temperature loggers in the same room as the solid fuel burner. This can be a problem if the solid fuel burner is only used to heat this room. In these cases, the temperature of the solid fuel burner data logger can be used instead, as it has a built in temperature chip for establishing the thermocouple reference temperature. This is uncalibrated, so has an uncertainty of about ±1°C, instead of the ±0.2°C of the calibrated temperature loggers. Variations of a ±1°C are too small to adversely affect the calibration process.

6.6 Comparison of estimated heat output with log book records

Several houses with log books were chosen at random to compare their estimated heat outputs from the solid fuel monitoring to the log book records. The comparison was made on daily average kWh energy consumption. The log books recorded the weight of the wood (e.g. kilograms), or the volume of wood used (e.g. number of logs, or number of baskets). The log size and basket weight had been measured at the time of installation. The log books usually give the quantity of wood consumed each day, so they are compared to the daily average consumption on a 7am – 7am basis (wood loaded the previous night can burn into the early morning hours).

6.6.1 Net calorific value of wood

Dry wood (0% moisture content) has a net calorific value of about 19.2 MJ/kg for softwoods and 18.2 MJ/kg for hardwoods, a difference of about 5%. On a weight for weight basis, there is very little difference between species, or between softwoods and hardwoods. Therefore a net calorific value of 18.7 MJ/kg dry has been used for all woods, with no distinction between species or hardwood and softwood. The net calorific value per kg is lower for wet wood. Air dry wood has a moisture content of around 25% (oven dry basis), which gives an average net calorific value of 14.5 MJ/kg, or about 4.0 kWh/kg (moisture content and net calorific data from Baines, 1993).

The actual moisture content of the wood used in the monitored houses is unknown. A few occupants recorded if the wood was (apparently) wet or dry, but most did not. Well seasoned firewood has a moisture content of about 25%, but poorly seasoned or freshly cut wood has higher moisture content and hence lower net calorific value. This source of variation cannot be accounted for with the monitoring from the log books. Fresh harvested wood has a net calorific value about half that of well seasoned wood.

The average net calorific value of wood used in solid fuel burners is assumed to be between 2 and 4 kWh/kg. If 75% of the wood was well seasoned, and 25% freshly cut, the average net calorific value would be 3.5 kWh/kg. This is the figure adopted for all calculations, unless the house is known to have well seasoned wood.

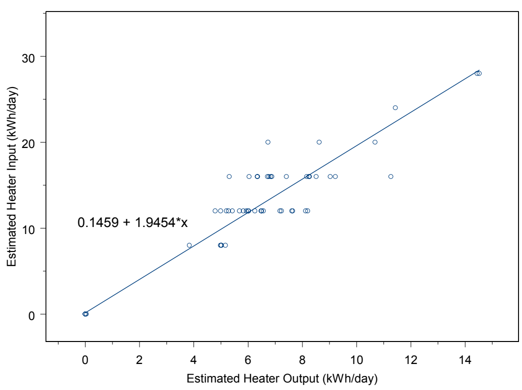


Figure 20: Log book vs STEM heater energy – pot belly

6.6.2 House 3 – pot belly stove

House 3 uses a pot belly stove for heating. It recorded wood usage in units of logs. A large log was measured at 1.6 kg, and an average log is assumed to weigh 1 kg. Figure 20 shows the comparison between the estimated energy input and the estimated energy output. The slope of the line is 1.95 (least squares fit), which is an efficiency of 51%, which is higher than the typical 35% efficiency for a pot-belly stove.

6.6.3 House 4 – free-standing

The next example does not show such a good correlation (Figure 21), and the slope of the line is not very convincing. The robust line fit (least trimmed squared regression) gave a slope of 1.849 – an efficiency of 54%, which is low for a free-standing enclosed wood burner, The maximum output of this wood burner did not exceed 3 kW, so it is possible that it was working below its rated minimum heat output at which efficiencies are tested. The efficiency at these low heat outputs might be lower than 60-70%.

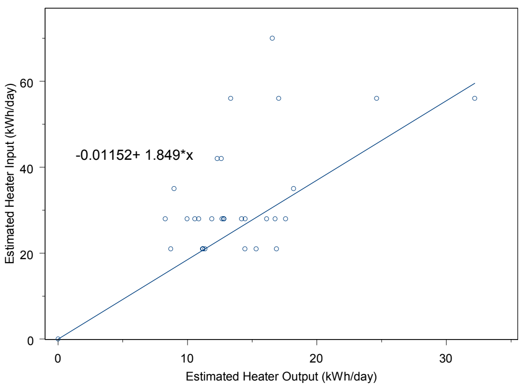


Figure 21: Log book vs STEM heater energy – enclosed wood burner

6.6.4 House 5 – open fire

The open fire in House 5 has a very poor fit, as the amount of wood recorded going into it was almost always recorded as between 11 and 13 kg per day. The occupants appeared to use the open fire for an almost constant number of hours per day (3.5 – 5 hours per day), and fed wood at a constant rate into the fire. This lack of variation makes a good line fit problematic. The slope of the line of 7.7 corresponds to an overall efficiency of about 13%.

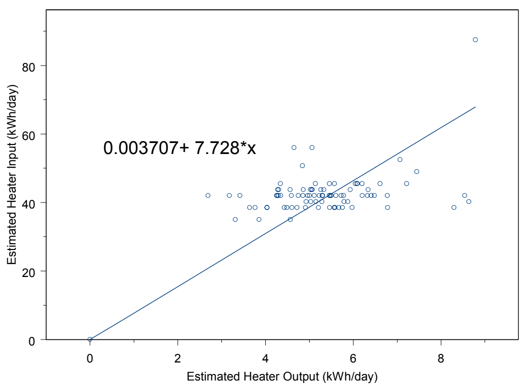


Figure 22: Log book vs STEM heater energy – open fire

House 5 burnt 1,100 kg of wood to deliver 460 kWh for the entire heating season. They bought this wood, at a cost of nearly $200, for a cost per kWh of delivered heat of about 43 cents per kWh, which is 2-3 times the cost of electricity.

6.6.5 Comments about comparison with log books

The comparison of energy use with the log books seems to be a hit or miss affair. For some log books, the correlation between patterns of recorded log usage and calculated solid fuel energy are good. For some they are not.

The overall estimated efficiencies calculated from the comparison with log books are fairly typical of the various types of wood burners examined – around 13% for an open fire, 51% for a pot belly, and 54% for an enclosed wood burner.

Given the large possible variation in the net energy content of the wood with the moisture content, it did not seem reasonable to attempt to use the log books for calibration purposes.

6.6.6 Log books in hindsight

Monitoring solid fuel usage by log book for HEEP was not very successful. Only about 30% of the occupants maintained reasonable quality log books. The weight of wood was estimated either by weighing individual logs that the occupants themselves described as ‘small’, ‘medium’, or ‘large’, or by weighing the wood basket. Both of these types of estimates may not reflect occupants use for the entire winter. The moisture content of the wood is also unknown, and could vary from kiln dried wood (e.g. building site waste wood), to freshly cut wood – a huge variation in energy content.

Log books are good for establishing the frequency of use of the burner, and for getting a good estimate of the quantity of wood used in terms of logs or baskets. However, trying to use log books to estimate energy was unsuccessful due to variations in net energy content with wood moisture content, variable efficiencies of the solid fuel burners, and variations in the way people use their wood burners. Log books that were better laid out for ease of data entry, and backed up by more effort to encourage the occupants to regularly complete them, might have improved the quality of log book records.

6.7 How are solid fuel burners used?

An enclosed wood burner can put out huge amounts of heat – typical test rated outputs of modern woodburners range from 10-20 kW, with a typically mid-sized burner putting out around 15 kW.

However, the HEEP monitored maximum average 10 minute heat outputs are relatively low – in the 0.5 to 4 kW range. Two thirds of enclosed solid fuel burners never exceed 6 kW output.

These values are far lower than the rated maximum output of most solid fuel burners, and often lower than the rated minimum heat output. It appears that most solid fuel burners are not being used for extended periods at high heat outputs, which is reasonable given that the maximum output would seriously overheat most houses.

How efficient these solid fuel burners are in this lower heat output range is debatable. Older solid fuel burners had a damper that could close fully to restrict air-flow and enable the control of low heat output. At this low heat output level many burners may not burn cleanly or efficiently, so in response, modern requirements for clean air have effectively meant for some burners that these dampers no longer close fully. To achieve a low heat output that is sufficiently low to not overheat the room or house, the logs must be loaded and left to burn out. Perhaps solid fuel burners are being routinely oversized, possibly leading to lower efficiency, dirtier smoke and higher running costs than is necessary?

6.7.1 How much heating does a house require?

How can these differences be explained? The HEEP method of calibration is most likely not sensitive to short periods of very high heat output. The averaging on the solid fuel temperature and room temperature measurements is 10 minutes, but due to the fairly slow response time of the room air temperature and the temperature logger temperatures, short periods (<20 minutes) of very high heat output are likely not to be detected as a separate 'event' but averaged over a longer period.

The lower heat outputs during extended use need a different explanation. From the ALF calculations for the houses with calibrated solid fuel burners, the whole house or living space heat loss coefficient (including air leakage losses) is typically 400 – 500 W/°C. The highest heat loss coefficient calculated from 372 (random and non-random) houses was 1,265 W/°C for an insulated, but very large, house.

Assuming a heat loss coefficient of 500 W/°C, to maintain a house at 18°C (the average that solid fuel heaters are heated to in winter evenings) assuming an outside temperature of 5°C (a difference of 13°C), 6.5 kW of heat is needed.

Internal gains in a house with 4-5 occupants would be approximately 500 W for the people, and roughly 1-2 kW of heat from lights, appliances, hot water standing losses, cooking etc. Assuming the internal gains are 1.5 kW, the amount of heat from the solid fuel burner needed to maintain 18°C would be 5 kW, which is comparable to the minimum rated heat output of a modern, high efficiency burner.

For many houses, the difference between internal and external temperatures was typically a lot less than 13°C, or the house heat loss coefficient was lower, and less heat was required. For these houses, the actual heat output required to maintain 18°C in winter evenings is more like 1-3 kW, and this is the average heat output that many of the solid fuel burners are supplying over an evening of heating. In addition, most houses appear to only be heating the main living area, further reducing the heat load.

The high maximum heat output of a modern solid fuel burner is far more than is needed for most houses, especially those in the warmer parts of New Zealand. Even the rated *minimum* heat output is also more than is needed by many houses to maintain warm temperatures once the house is up to temperature.

6.8 Net to gross conversion efficiencies

HEEP uses gross energy data, and the net energy output estimates of the solid fuel burners need to be converted. The conversion efficiencies are given in Table 24:

Type	Efficiency (%)
Open fire	15
Pot belly	35
Enclosed burner	60

Table 24: Assumed efficiencies of solid fuel burners[6]

Efficiencies of modern enclosed burners are often tested at 60-70% or higher. The average label efficiency of the HEEP monitored wood burners was 63% on low, 68% on medium, and 64% on high. The average space heating efficiency of solid fuel burners approved by Nelson City Council is 71% (setting unknown but assumed to be medium).[7]

[6] The efficiencies for open fires and pot belly stoves are from Rossouw, P. A. 1997. *New Zealand residential sector base case: End-use energy consumption*. EERA. Wellington.

[7] See: www.nelsoncitycouncil.co.nz/environment/air_quality/burners_approved_table.htm

Rossouw (1997) reported an efficiency of 65% for a basic closed double burner. The low setting for these tests is typically 4-5 kW, but from the HEEP monitoring it appears that for much of the time enclosed wood burners are being operated at a heat output lower than this, at which the efficiency would be expected to be lower. Also, the actual operating conditions of wood burners would not be expected in general to be as good as on the test of a new appliance under ideal conditions e.g. flue condition, ash build-up, poorly seasoned wood etc. Since most solid fuel burners in HEEP are not the new, clean air-approved types, the low efficiency setting of the basic type is used, and de-rated slightly to 60% to reflect lower efficiency in actual use.

6.9 Energy consumption of solid fuel burners

All the estimates in this section are preliminary. They have not been weighted to give nationally representative values, and additional statistical analysis is required to produce final results.

Type	Estimated Annual Average Gross Energy input (kWh)	SD	Count
Open fire	1000	300	34
Pot belly	1600	600	9
Enclosed burner	4600	400	164
Average all types	*3900*	*400*	*207*

Table 25: Annual gross energy input by appliance type

The average energy consumption of houses that use solid fuel is approximately 3800 kWh ± 400 kWh per year. Some houses have more than one solid fuel burner, and generally the second one (often an open fire) is used infrequently. Open fires have very large gross energy consumption as their efficiency is very low (see Table 24).

There are major differences by region, both in the amount of energy consumed and in the type of appliances. In the five major cities and Northland, open fires are common (in some areas almost as common as enclosed burners), whereas outside of these areas, open fires are rare. Energy consumption of solid fuel is much higher in colder climates, both per burner and per household, as solid fuel burners are in general much more common, and much more intensively used in colder climates.

The simple average solid fuel energy consumption per house is approximately 2000kWh ± 200kWh per year – note that this is averaged over all houses including those without a solid fuel burner.

All of these figures are preliminary, but they do give a rough estimate of the scale and importance of solid fuel use in New Zealand, which appears to be much higher than previously thought.

The Energy Data File ‘Energy Supply and Demand Balance June Year 2004’ (MED 2005) file puts solid fuel use (coal + wood = 2.9 PJ) at 5% of energy consumption in domestic buildings.

HEEP (so far) puts solid fuel use at about 15-20% of domestic building energy consumption. This may change as the full national energy use analysis is completed.

Roughly 5% of the total amount of solid fuel consumed is used in open fires, which are very inefficient and much more polluting than enclosed wood burners. Given the high proportion of open fires that are not used, or used only a few times per year, only a very few houses actually use open fires intensively, and unless the fuel is free, the running cost is likely to greatly exceed the cost of heating using electricity.

7. HEATING SEASONS

The months of heating are reported by occupants in the occupant survey, although (as would be expected) some are unsure, reporting that it depends on the weather. This section looks at data from each individual house to determine when they start heating and how this relates to the outside temperature.

Accurate heating months could be determined for 302 houses, but these houses are spread around the country, averaging 80% of the houses in each monitored area. This sample is thus considered to be representative.

Heating times during the day are also reported by occupants in the initial survey, and this is the data that has been used for analysis in previous reports. However, closer examination of the temperature profiles and recorded heater use revealed that some houses use their heating appliances quite differently to manner they reported.

7.1 Determining when heating starts and concludes

Where the heater is monitored separately, heating times can be determined by examining the fuel usage data. Two hundred and sixty-one houses have separately monitored solid fuel, gas, LPG or fixed electric heating, although many of these houses will also have portable electric heaters.

Portable electric heaters are monitored on a month-by-month basis in one-quarter of the houses. In all houses they are included in the total electricity consumption, but other large electricity uses have to be taken into consideration, and careful comparisons made between winter and summer use to determine the heater use. There is the potential for errors in this method, with some houses expected to have slightly longer or shorter heating season than that reported here.

7.1.1 Solid fuel, gas, LPG and fixed electric heating

For the 261 houses with solid fuel, LPG, gas or fixed electric heaters which are recorded separately, determining the start and stop of the heating season can be determined from an examination of the fuel use patterns.

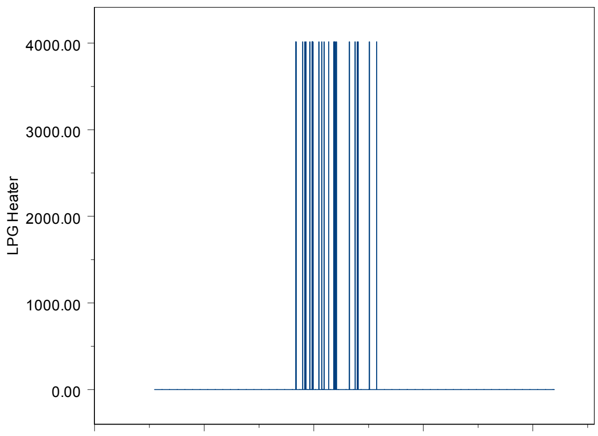


Figure 23: Example – LPG heater use

Figure 23 shows the usage of an LPG heater over a year (January to December). Zero use of the heater can be easily seen, as there is no energy consumed by the heater. The heating season determined from the LPG usage can then be compared with the season determined for the electric heater (see 7.1.2), as the occupants may have been using electric heating for a longer period than the LPG heater.

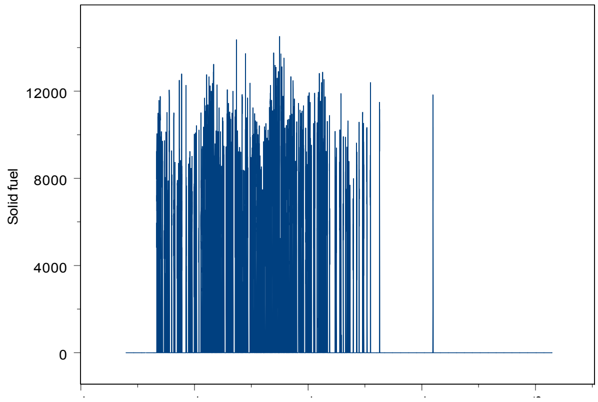


Figure 24: Example – solid fuel use

In the majority of houses there is a distinctive start and stop to the heating (e.g. Figure 23), although in some houses, there will be a period of heating followed by another period of no heating, as shown in Figure 24. Where the start and stop of heating is not clear, a decision was made based on the data for each house.

Thus for Figure 24, the end of the heating season was taken to be the end of the main heating period.

7.1.2 Electric heating

Electric and gas portable heaters are included in the total electricity and gas use of the house i.e. all electricity and gas use excluding water heating. This can cause problems when examining only the space heating energy use.

One method developed to determine heating use is to remove the hot water use from the total energy use, and then take an average of the electricity use for the warmer, immediately before winter, months of January, February and March. Examination of the daily energy use over the entire monitoring period highlights the increases. Most of this increase can be attributed to space heating, although in the majority of houses there is also an increase in lighting and cooking use in winter. The application of a confidence interval of 99% removes the effects of increased lighting and cooking, and in a small percentage of cases it may slightly reduce the apparent length of the heating season. Care has to be taken that houses that heat all year are recognised.

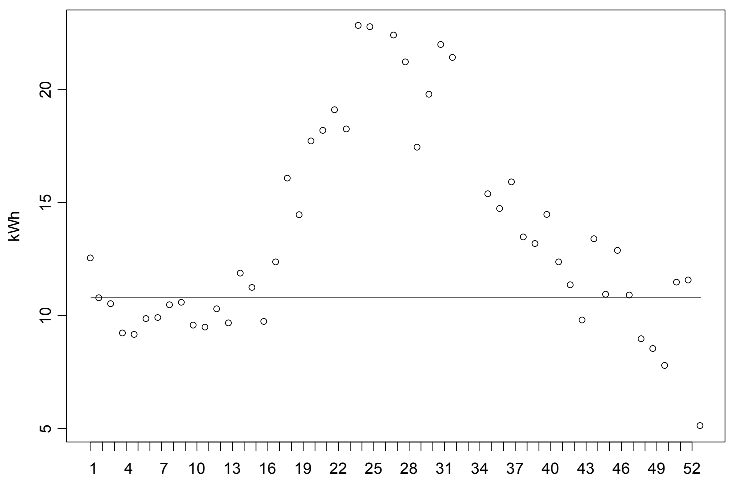


Figure 25: Non-hot water electricity use for one house

Figure 25 plots for a house the weekly total less DHW electricity. Energy use above the line (with a 99% confidence interval) is allocated as space heating.

7.2 Length of heating season

The houses are heated longer on average than the occupants reported. This may be due to occupants not realising how much they heat, or the monitored period could have been a more extreme winter than the occupants were expecting – the real reasons may differ from house to house, and are unknown.

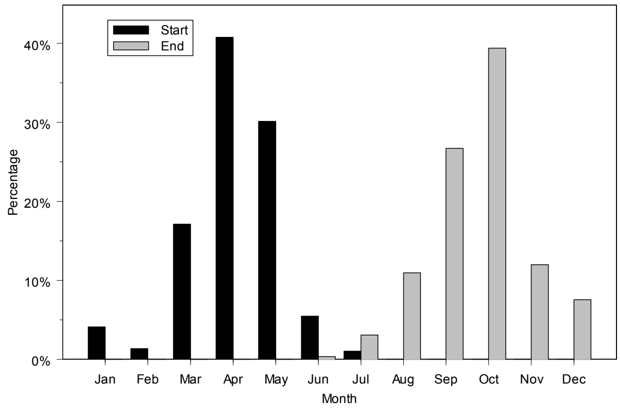


Figure 26: Months of heating – start and finish

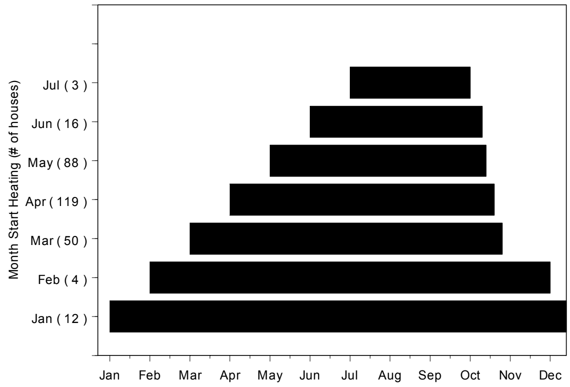


Figure 27: Length of heating season

There are 10 houses that apparently do not heat. These houses are not included in the above graphs or following tables.

Region	Start		Finish		Length	SD	Count
Northland	April	4.9	September	9.4	5.5	0.3	19
Auckland	April	4.5	September	9.2	5.7	0.2	79
Bay of Plenty	April	4.2	September	9.6	6.4	0.2	23
Waikato	March	3.8	October	10.2	7.4	0.3	41
Gisborne/Hawkes Bay	March	3.9	September	9.7	6.8	0.3	26
Taranaki/Manawatu-Wanganui	April	4.2	September	9.8	6.6	0.8	9
Wellington	April	4.2	September	9.4	6.1	0.2	28
Tasman/Nelson/Marlborough	March	3.6	September	9.9	7.3	0.6	13
Canterbury	March	3.9	September	9.5	6.6	0.3	27
Otago/Southland	March	3.3	October	10.8	8.6	0.5	27

Table 26: Heating start and end month by region

Twelve houses in the sample heat for the whole year – approximately 4% of the total number of houses. In general these tend to be in the cooler parts of the country (Central North Island and South Island).

Conversely, 10 houses in the sample do not appear to heat at all – just over 3% of the total number of houses. In general these tend to be in the warmer parts of the country (Auckland and north).

7.3 What temperature do people heat at?

The average monthly external temperature was calculated from NIWA National; Climate Database and then used to determine the temperature at which each house starts heating. Figure 28 shows the external temperature and the energy use for an example house. The time of the year when heating is occurring is outlined in red – which is also when the external temperature is coldest. This graph is smoothed by a seven day rolling average. Note the graph commences in October (month 10).

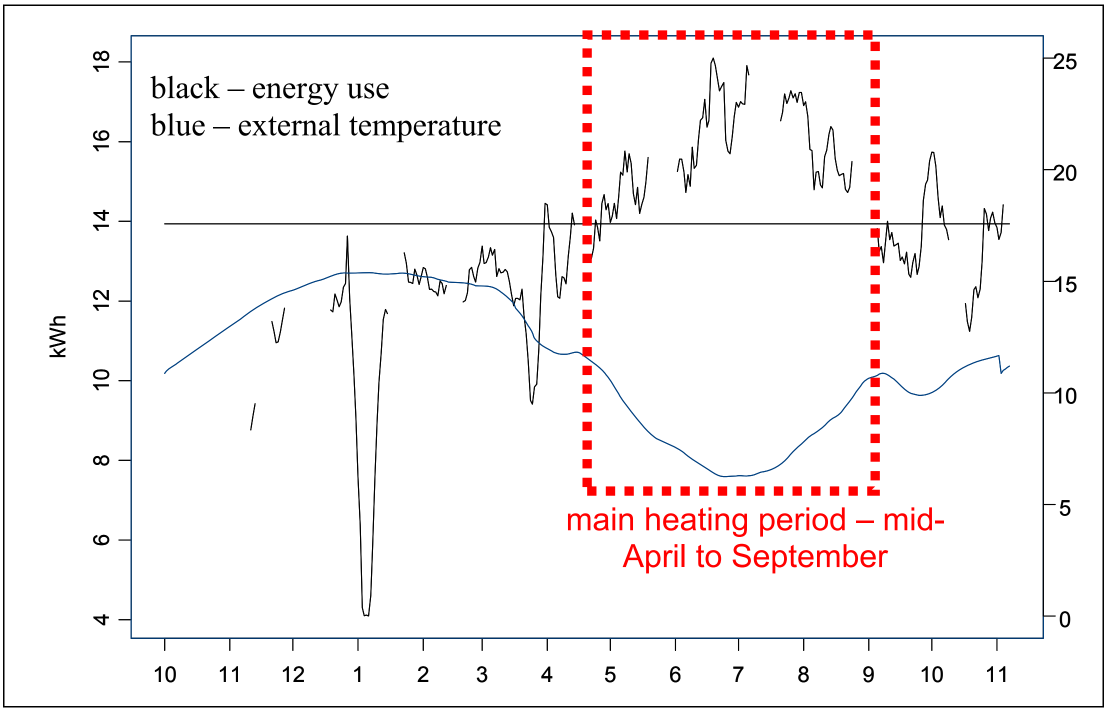


Figure 28: External temperature and energy use during heating season

As the external temperature drops, the heating energy use increases in most houses – although there are still some that manage the winter without heating. There is no doubt that the further south you live, the cooler is the external temperatures before you start to heat. The average external temperature in summer for Invercargill is below the threshold for heating in Auckland! The solar gains in Invercargill would help increase the indoor temperatures. The temperature ranges are given in Figure 29 and Table 27 by region.

Regional Council	Average Temperature °C	Average Temperature SD	Start Temp. °C	End Temp. °C	Count
Northland	13.8	0.5	15.2	15.2	25
Auckland	12.7	0.2	15.1	14.7	81
Bay of Plenty	11.5	0.3	14.2	14.2	23
Waikato	10.6	0.2	13.1	14.5	39
Gisborne/Hawkes Bay	10.8	0.3	13.7	13.8	23
Taranaki/Manawatu-Wanganui	11.3	0.3	13.7	13.5	9
Wellington	9.9	0.2	13	12.4	29
Tasman/Nelson/Marlborough	9.6	0.3	12.6	13.2	11
Canterbury	9.1	0.2	12.3	11.7	27
Otago/Southland	9.0	0.2	11.7	13.5	27

Table 27: External temperatures over heating season

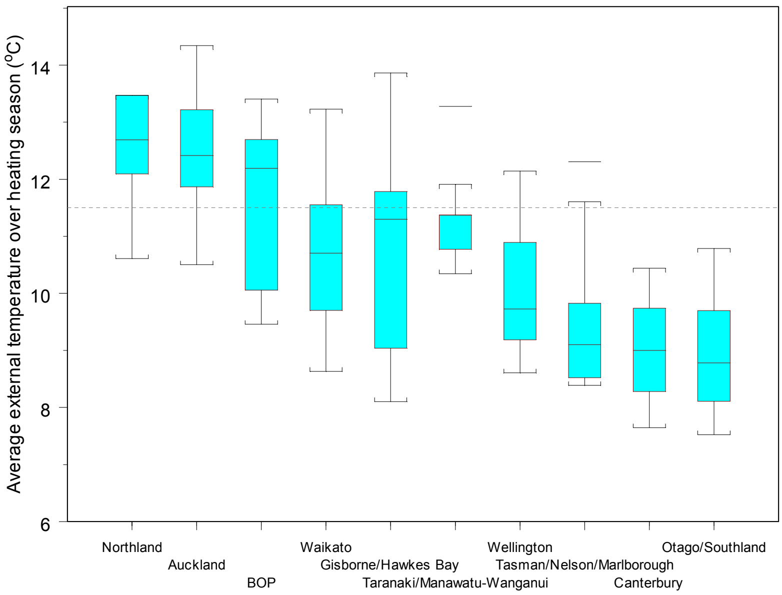


Figure 29: Average external temperature for heating season

There is a significant relationship between the region and the temperature houses start to heat or finish heating.

Heating does not necessarily occur during the coldest months. Figure 30 shows the heating-start external temperature is not necessarily the same as the heating-stop temperature. From the Waikato south, on average the last month of heating is warmer than the first month of heating.

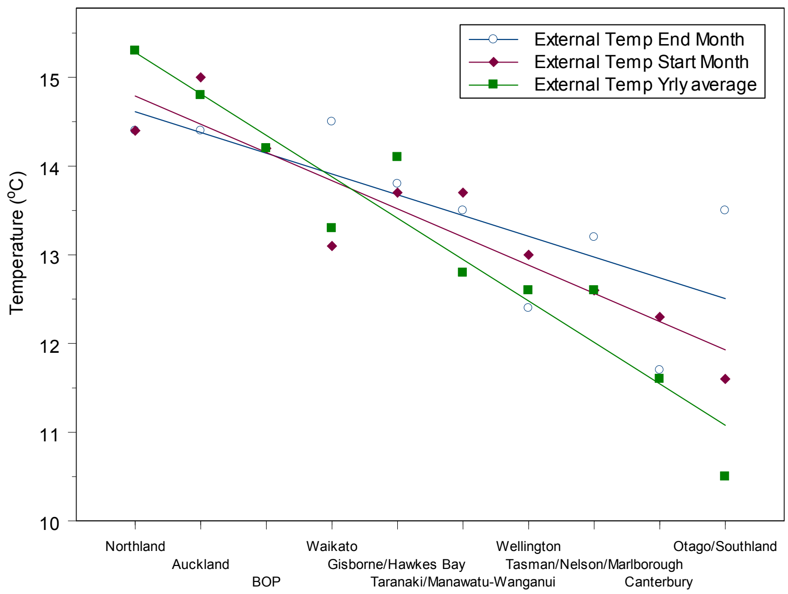


Figure 30: External temperatures of heating start and finish months

The yearly average external temperature used in Figure 30 is the average temperature compiled over a number of years. External temperatures for both the start and finish months are for the year that that house was monitored.

7.4 Discussion

As part of the house survey, occupants are asked which months they heat their home. These reported months have been used in previous HEEP reports for analysis of heating months.

When the pattern of heating is evaluated based on the monitored energy use, it appears that overall occupants heated for a longer period than the one they reported. The reasons for this difference are not obvious – maybe the monitored year was a colder year than they were predicting, or possibly they heat more than they realised.

The difference between the reported and the measured months is statistically significant at a national level, although not significant on a regional basis.

The main differences occurred in houses that heat claim to heat only for a short period of the year. Occupants who reported heating around five months upwards, were found to heat for a period close to the months they reported. On average the occupants heated for just over one (1.1) month longer than they reported.

8. MODELLING VS REALITY – ALF3 VS HEEP

This Section is an update of Section 6 in the Year 8 report (Isaacs et al, 2004). In that report we examined 89 houses heated by electricity or natural gas, but now all possible HEEP houses have been modelled in ALF3, including those houses that heat by solid fuel and oil. All houses held in the HEEP database (including non-random houses) that are able to be modelled in ALF3 have been modelled – giving a total of 375 houses. Some of the houses in the HEEP pilot study were lacking enough information to model, principally in Wanganui and Wellington.

Work is still being undertaken to better understand the differences between reality and modelling. As more analysis is completed, this work will be extended.

8.1 Update to method

The same method was used as for the Year 8 report. Modelling of the houses in ALF3 was undertaken by Ruwan Fernando, a BBSc student at the School of Architecture, Victoria University of Wellington.

One issue of concern from the previous work was the use of self-reported heating, rather than measured seasons and schedules. For the current report, monitored heating schedules were able to be used (see Section 7). This also enabled the heating season to be personalised for each house, rather than as previously for the region.

8.1.1 Modelling

All houses that had sufficient information to permit the creation of an ALF3 model were modelled, although some houses had more data available than others. In some cases, elements had to be estimated using other information available e.g. window sizes taken from photos rather than house plans.

Modelling issues were discussed in detail in the HEEP Year 8 report, including the allocation of a thermal resistance to different construction types based on the limited data available from the HEEP house physical and energy audit. In particular, as it is often not possible to measure the thermal insulation, it is necessary to estimate the roof, wall and/or floor R-values. It is now believed that this can result in R-values that are too generous for older houses and not generous enough for new houses, but in the absence of other information this is the best available approach.

Three of the more complex houses were modelled as two separate ALF3 models. Two of these houses have sleep-outs, while the other had an extensive addition in a different construction to the original house.

8.1.2 Heating months

Previously the heating months were taken from the occupants reported heating season. This year these reported heating months were able to be compared with monitored data to determine the months that heating was done. It was decided the measured heating season was more appropriate to use in this analysis. Based on these heating schedules, the ALF3 climate file was updated to better reflect the monitored houses. Table 28 compares the heating season and standard ALF3 heating season.

Location	Length of Heating Season	
	HEEP	ALF3
Kaikohe	5	1
Whangarei	6	1
Auckland	6	3
Parawai	5	3
Tauranga	5	3
Hamilton	7	4
Arapuni	8	5
Rotorua	7	5
Mangapapa	7	3
Rangatira	8	5
Wairoa	7	3
Tamatea North	6	3
Foxton Beach	6	5
Waikanae	6	5
Wellington	6	5
Wai-iti	7	5
Seddon	8	5
Christchurch	7	5
Oamaru	9	6
Dunedin	8	6
Invercargill	8	8

Table 28: Heating season

The HEEP values are averages for the area. Within each area, the heating seasons do vary significantly from house to house, especially in the warmer areas with the lower average heating months.

Not all HEEP locations have their own ALF3 climate file, so these have been assigned to the closest ALF3 climate. The following ALF3 areas include more than one HEEP location:

- Auckland includes: Orewa, Auckland City, Manukau, North Shore, Waitakere and Awhitu
- Tauranga includes Minden
- Whangarei is the suburbs of Kamo West and Sherwood Rise
- Rotorua includes Ngakuru and the suburb Western Heights.

Not all heating months could be determined due to missing data. At this stage 293 houses have had heating months determined, although this may be able to be improved in future work.

8.1.3 Heating schedules

Heating times during the day and night were determined by looking at daily temperature and energy profiles over the winter months. Where houses are heated by solid fuel or LPG, separate profiles for each of these fuels were also examined. The energy use shown in Figure 31 and Figure 32 is the total electricity and gas use, with the energy for the heating the hot water removed (i.e. non-hot water energy use).

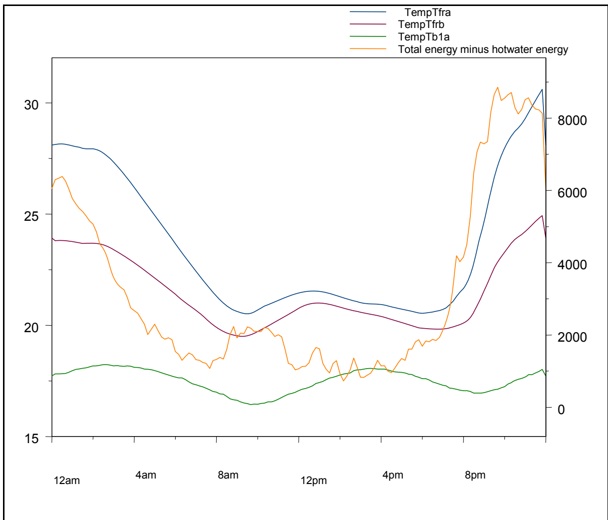


Figure 31: Daily profile of inside temperatures and energy use – weekend

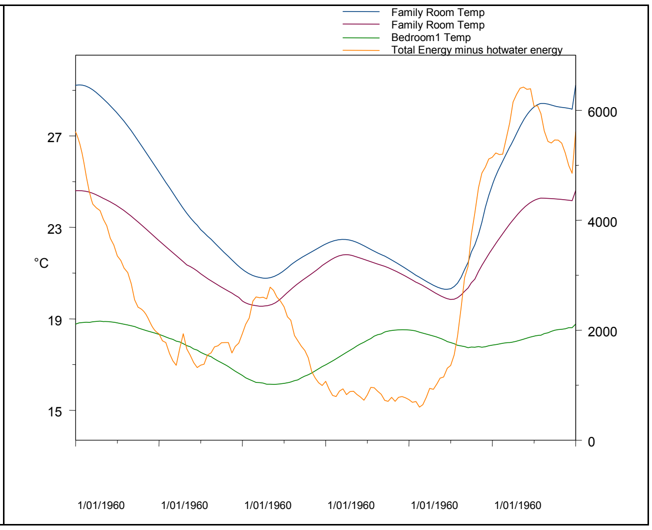


Figure 32: Daily profile of inside temperatures and energy use – weekday

The hours of heating were recorded and the total number of hours heated calculated for the average day. Then the best matched ALF3 heating schedule (Table 29) was chosen, mainly based on the number of hours heated rather than the time of day.

Hours of Heating	Schedule Name	No. of Hours
5–11pm	Evening only	6
7–9am and 5–11pm	Morning and evening	8
7am–11pm	All day	16
24 hr	24 hr	24

Table 29: ALF3 heating schedules

Not all houses could have their heating schedules determined due to missing data. If there was any doubt in determining the heating schedule, they were not included for this analysis. Often, the heating schedules of houses were found to be slightly shorter than the options given in Table 29. If morning heating was used, then one hour of heating would be more common than two, while evening heating would often be less than six hours, especially in the warmer areas of the country.

8.2 Zoning of houses

As ALF3 is a one zone model (i.e. treats the entire house as one single heating zone) and as few New Zealand houses are heated uniformly, adaptations had to be made to correct for this. Two methods were trialled – the 'heating levels for a zoned model' is similar to the method used for the 89 houses in HEEP Year 8 (Isaacs et al, 2004), while the second method establishing a 'whole house average temperature' is new. Neither method can be considered more or less correct than the other.

8.2.1 Heating levels for a zoned model

The average family room temperature during the actual heating period was calculated for each house, as were heating periods during the day and the year. Figure 33 shows spread of the measured average living room temperatures by Regional Council. The dotted black line is at 16°C, the lowest set-point option in ALF3 as well as the lowest recommended temperature by the World Health Organisation (WHO, 1987). The median temperature for each area is above 16°C.

The closest temperature level to the average living room temperature was entered into ALF3, which gives temperature set-point options of 16°C, 18°C and 20°C.

To adjust for the different house temperatures and heating schedules compared with the ALF3 options, the following method was used for each individual house. All houses in the selected sample have been included in this process. According to the author of ALF3, Albrecht Stoecklein, ALF3 reliability will decrease with internal temperatures below 14°C (red dotted line in Figure 33) as the temperature difference between inside and outside is too small and above 22°C as the supporting modelling did not explore this temperature. There are six houses with heating period average temperatures below 14°C and five above 22°C.

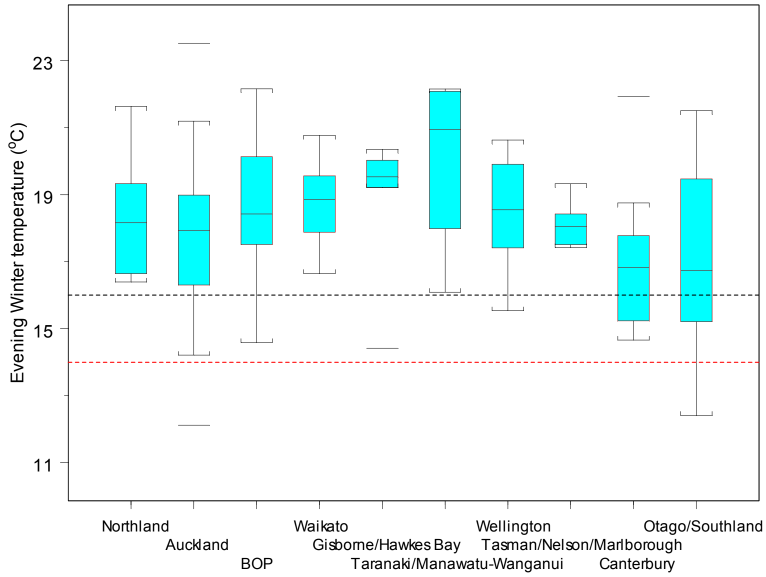


Figure 33: Average living room temperatures during heating times

The method first calculates a ratio using the difference between the actual heating hours and the closest ALF3 option, which for most houses is six heating hours. It then calculates the heating degree hours for both average external and average internal temperatures over the selected heating period.

Heating degree hours are the number of hours heating would have been required at the base temperature (16°C, 18°C or 20°C depending on the house), multiplied by the difference between average inside and average outside temperatures over the heating period. This ratio was then used to adjust the difference in heating degree hours between the two heating schedules (actual and ALF3).

8.2.2 Zones heated

With most New Zealand houses only being partially heated, and ALF3 being a one zone model, a correction method was required to reduce the difference in heated areas of the model compared to the reality of the way New Zealanders heat their homes. The percentage of each house that is heated was determined, and then multiplied by the total heating energy. For example, if 50% of the house was heated then 50% of the total heating energy use was calculated to give a more realistic heating energy use.

This method was tested in the HEEP Year 8 report (Isaacs et al, 2004) and was found to correlate well with the suggested method in the ALF3 manual (Stoecklein and Bassett, 2000) of modelling only the heated areas of the house.

As different spaces are heated to differing extents, each type of space was given a weighting. Bedrooms and utility spaces generally will not be heated as intensively as the family rooms of houses. The family room is where approximately two-thirds of household heaters in HEEP are located. Table 30 gives the weightings for each space.

	Living room	2nd living room	Bedrooms	Utility Rooms
Weighting	1.0	0.5	0.5	0.2

Table 30: Weighting of spaces for heating

If the 2nd living room is the only living room heated, then its weighting is increased from 0.5 to 1.0. If occupants report they heat the living spaces and the utility rooms, then the area of each space would be multiplied by the weighting. In the majority of houses HEEP monitored only the temperatures in one bedroom and one living room, so there is no way of checking whether all reported spaces are actually heated.

Results of this method can be seen in Figure 34 and Figure 35. Both graphs show the same data, the centre line is where ALF calculated heating energy equals the actual heating energy. The red outer lines on Figure 35 show 20% below and above that line. On Figure 34 the red outer lines show ± 2000 kWh. The correlation (r^2) between the heating energy derived from HEEP and the ALF3 model is 16%.

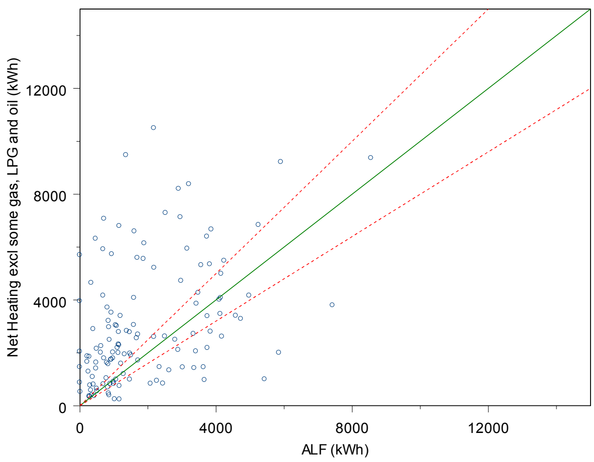


Figure 34: ALF3 vs reality – 20% lines

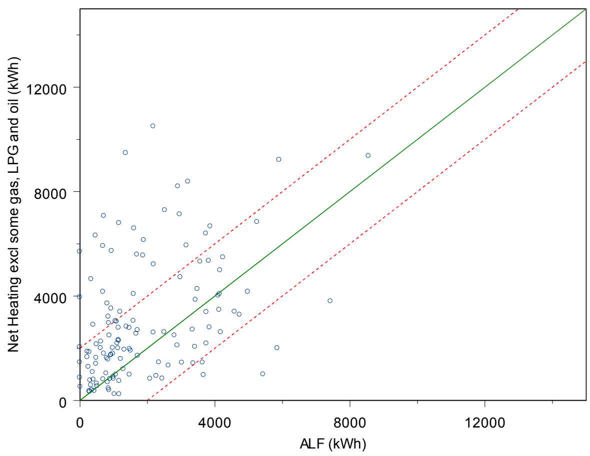


Figure 35: ALF3 vs reality – 2000 kWh lines

Explanations of the calculation of net heating energy are given in Section 8.4.

8.2.3 Issues with reported house heating

Self-reported information has been used to establish the proportion of the house that was heated. For the majority of HEEP houses, only the temperatures in the living room and master bedroom are monitored, so it is not possible to compare the measurements and the self-reported information.

In addition, the occupant provided information on what rooms are heated varies for each house. Often the occupants only provide general information on the bedrooms, living room or utilities heating and to what schedule. Information often is not collected (or volunteered) on which specific bedroom(s), living room(s) (if there is more than one) or utility room(s) are heated. A certain amount of checking can be carried out to determine what is possible or most likely e.g. if the house only has fixed heaters in some rooms, then it is more likely that those rooms will be heated than other rooms. Similarly only two occupants are unlikely to heat all five bedrooms.

During data entry only the self-reported information was input. In some cases the database entries were then double-checked using measurements, photos of the house and appliances. With the different field staff and the occasional occupant filling in the questionnaire, the answers are not always consistently recorded e.g. the heater description may have been written as the appropriate coding was not clear. During data entry it is only possible to enter a code, so the heater with only a description could be missed. To ensure the database is as accurate as possible, cross-checking with photos and other information collected during installation is required.

8.3 Heating levels for the whole house

There are problems with determining what spaces are heated and to what extent e.g. are the bedrooms heated for as long as the living room and to the same temperature? Therefore, a second method was developed based an overall house temperature.

This overall representative house temperature was calculated for the heating times by using the average of the two living room temperatures, the average of the bedroom temperature and the average of the external temperature to account for the unheated spaces. Heating energy was then calculated for the whole house.

Figure 36 shows the distribution for this overall average house temperature by region. As expected, the average house temperature temperatures (Figure 36) are lower than the living room temperatures (Figure 33). With so many houses showing average temperatures below 14°C, it would be expected that the reliability of using ALF3 would be affected. The red dotted line is at 14°C and the black at 16°C.

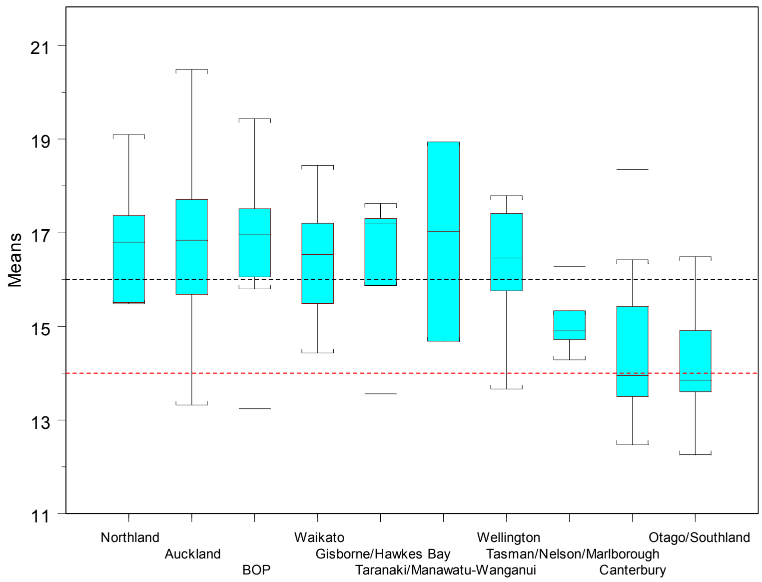


Figure 36: Average house temperatures during measured heating times

The results of this method can be seen in Figure 37 and Figure 38 with the centre line on each graph representing X=Y. The red lines on Figure 37 show + and – 20% and on Figure 38 they show + and – 2000 kWh.

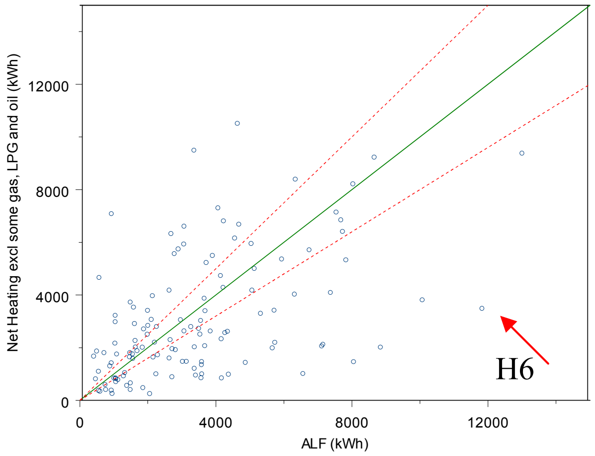


Figure 37: ALF3 vs reality – 20% lines

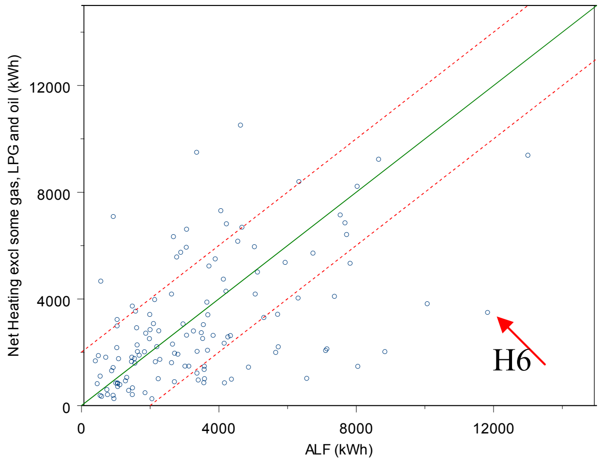


Figure 38: ALF3 vs reality – 2000 kWh lines

There is a better correlation overall (44%) than the results of the heated zone method, although these improvements are not found for all houses. It must also be remembered that the net heating energy estimate from HEEP has an unknown degree of error.

One house that does not work well for this method is House 6 (indicated by an arrow in Figure 37 and Figure 38), although in the zoned method this house had ALF3 energy within 20% of the HEEP energy estimate.

Possible reasons that the whole house temperature method was not successful for House 6 include:

- Very low heating temperature in a warm climate – ALF3 becomes very sensitive to each slight temperature change. Although temperature was 16°C inside, outside was about 13°C so there is only a small temperature difference and hence a very small change in indoor temperature has a large impact.
- House 6 is a two-storey house with most of the temperature sensors upstairs, as well as most reported heating. Therefore the temperature downstairs (half of the house) will be a lot cooler resulting in an inaccurate whole house temperature. Any multi-storey house could have similar problems.

8.4 House heating energy

On completion of the removal of monitoring equipment from the last 100 HEEP houses this year, space heating energy was able to be estimated for most HEEP houses. Exceptions include:

- Two houses where oil was used as a main heating fuel; which have yet to be included in the space heating energy estimate.
- At the beginning of HEEP monitoring, methods were being used for the first time in some cases. In particular, data for LPG heater use is limited for the earlier houses – Wellington and Hamilton.

All HEEP houses have natural gas, electricity, LPG and solid fuel monitored. Totals of each energy type are monitored, including the hot water separately and any fixed heating appliances such as a wood burner, under-floor heating and gas fires. For one-quarter of the houses the appliances (including portable heaters) are randomly selected and monitored on a monthly basis. As portable space heaters are not always monitored separately, it is necessary to estimate the heating energy.

It is difficult to determine space heating energy for reasons including the:

- varying outputs of different heating appliances;
- differing occupant heating habits; and
- lack of stable heating regimes

8.4.1 Electric heating and reticulated natural gas

Due to these difficulties in determining space heating, it has not been possible to use tools based on static 'average' inside temperatures. Instead it has been necessary to develop tools to extract heating energy use from the detailed energy monitoring.

The total electricity and gas use can have the hot water energy use removed, and can then be averaged by weeks, and a linear regression model fitted for energy use vs external temperature. For the purposes of analysis, it was assumed that no significant heating energy was used in the summer months from January to March, and thus the highest energy use in this period could be taken as the base. Energy use over this base can be attributed mainly to space heating, although there will be some extra lighting and cooking use in most houses over winter. There is no accurate way of separating the lighting and cooking use from the space heating at this stage. For this reason there is an unknown error which will vary by house depending on occupant behaviour.

8.4.2 Solid fuel burners

This year the method for calculating energy usage of solid fuel burners was completed (reported in Section 5).

8.4.3 Portable LPG cabinet heaters

Portable LPG cabinet heaters (LPG heaters) are each measured separately. The majority of households in the HEEP sample with LPG heaters have only one LPG heater; the remaining HEEP LPG households have two.

The method used to measure the LPG heater use is to monitor the operation of each panel of the LPG heater. A description of this measurement method is given in the HEEP Year 4 (Camilleri et al, 2000) and the HEEP Year 6 (Isaacs et al, 2002) reports which also provide some analysis of the use of these heater types. Further analysis of the use of LPG heaters is given in the HEEP Year 7 (Isaacs et al, 2003) and HEEP Year 8 (Isaacs et al, 2004) reports.

As LPG heaters are portable appliances they are frequently brought into (either newly acquired or from storage) or removed from the heated areas of the household. The preparation of an LPG heater for monitoring requires about 30 minutes and it is usually completed during the HEEP installation. As the LPG heaters come and go from the sample houses, there will be some delay from when a heater is newly introduced into a household to when it is being monitored.

Another source of missing data for the LPG heaters is due to the complex nature of their monitoring. When there are any faults with any of the thermocouples (working loose, connection problems, shorting-out) then often no calculation of the LPG heater energy use can be made.

Simple extrapolation methods have been applied to account for these periods of missing data so that good estimates of the space heating contribution of LPG heaters can be made.

8.4.4 Examination of models

There are a number of reasons why the HEEP houses cannot be modelled in ALF3 exactly as they are used.

With ALF3 being capable of modelling, only one zone problems arose when choosing the heating schedule and heating level. Although it is possible to model only those areas that are heated unless the house is centrally heated (approximately 5% of the HEEP sample), the spaces that are heated in the house are often heated to differing (and unknown) extents.

ALF3 provides four different schedules for heating, but it is unlikely that occupant use will fit into one of these schedules all the time (or even some of the time). Occupant schedules (as well as the climate) vary and it is unlikely that they switch on or off the heating at the same time each and every day. Very few HEEP houses have time clock controlled central heating (about 5%) or time clock controlled unit heaters.

Houses in real life can be heated overnight or intermittently, while solid fuel burners take a while to warm up and cool down and have varying outputs depending on the quality of the fuel. These issues make it hard to model heating.

There are limits on modelling building components and use of the house cannot always be averaged into the one value that is often needed.

One hundred and thirty-five houses have been used for the comparisons reported here. The full set of 397 randomly selected houses could not be used due to one or more of a number of reasons – in order of significance these are:

- could not determine heating times
- could not determine heating months
- could not calculate a heating estimate
- could not calculate the area heated for the house
- could not model – insufficient information on house.

Non-randomly selected houses were not used in this analysis. Not only was monitoring in many of these houses carried out for less than full year, but often less data was available as most were monitored in the early years of HEEP.

8.5 Discussion

Conclusions from this comparison of all the HEEP houses do not differ greatly from the Year 8 comparison of 89 houses with ALF (Isaacs et al, 2004). This provides confidence to support the use of ALF within the HEERA model.

One noticeable difference this year is that the high space heating energy use houses in HEEP are predominantly solid fuel users. Therefore the HEEP energy estimate is not necessarily as accurate as previous years where the high users have been houses with central or fixed heating, which was often separately monitored for the study.

Two methods for adapting the ALF3 results to work for a house that does not have all rooms heated were tested. Neither can be considered more correct than the other, but different methods will suit different houses depending on their heating patterns.

Overall, ALF3 appears to provide a reasonable estimate of space heating use, but now that we have more information on New Zealander's heating patterns the regional heating seasons could be altered to match reality better. A shorter heating period in the evening may be more realistic for most current houses, although this may not be as valid for new houses. The possibility of making ALF a multi-zone tool could also be considered, although this might take away from the simplicity and ease-of-use of the tool.

Internal gains from appliances, people and hot water standing losses could also be examined in greater detail. The gains from hot water systems are modelled realistically, although they depend on the hot water system e.g. an externally-mounted instant gas system will provide no 'internal' gains. Internal gains from appliances and occupants are realistic, although will vary from house to house.

9. STANDBY AND BASELOAD

Standby and baseload power consumption has been reported in HEEP since the Year 3 report (Stoecklein et al, 1999). These early estimates of standby and baseload power consumption have been instrumental in raising awareness of this important energy use in Australasia. Since then, standby power consumption reduction has been used as an energy conservation measure during power crises, and has been regulated for some appliances as part of the joint Australian/New Zealand performance standards for appliances.

Now that the HEEP monitoring is complete, full, 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 studies are non-random, with limited geographical or demographic coverage, or are desktop studies with some spot measurements taken of new appliances. For the first time ever, anywhere, a full account of standby losses for houses is presented.

9.1 Data

Data on standby and baseload power use comes from three sources within HEEP:

1. **End-use data**: 10 minute monitored energy data from individual appliances
2. **Power measurements**: spot measurements of the standby power carried out with a power meter at the time of the house installation
3. **Survey**: occupant survey recording the number of each appliance type, and its usage.

By combining information from these three sources, a complete picture of household standby and baseload power consumption can be constructed.

The monitored **end-use data** is the most detailed and provides information not only on the standby power level, but also on how long the appliance spends in standby mode, information which cannot be gathered in any other way. There were 1,026 unique appliances monitored in this way.

Due to resource limitations, the monitored end-use data is only collected in the one-quarter of the HEEP houses that were subject to detailed end-use monitoring. These resource limitations also limited the number of monitored appliances, so coverage is not complete for all appliances and some minor appliance types were not monitored.

Spot **power measurements** were carried out in all the HEEP houses by an auditor going through the house recording information on every appliance in the house. The information recorded included type, make, model, serial number, label information, measured power consumption, measured standby power, and the standby status. How much information was recorded depended on the type of appliance, with appliances such as whiteware and entertainment equipment having all information recorded, and minor appliances like blenders etc only have their presence recorded. If an appliance was found to be plugged in and switched on, a standby power reading was taken, and the state recorded – this allowed some information about what percentage of minor appliances (such as chargers) are left in standby mode, and is a valuable complement to the end-use data.

Survey data is recorded for the major appliance types. The occupant survey included questions on the number of each appliance in each house and the usage (e.g. constant, daily, weekly etc). Some additional information is collected for heating and cooking appliances. This information is primarily used for creating estimates of appliance stock levels, but for some appliances like heated towel rails it can be used to estimate energy consumption in the absence of energy monitoring

9.2 Methodology

The methodology for estimating standby losses and baseload was first described in the HEEP Year 5 report (Stoecklein et al, 2001) and is summarised here.

Standby power is drawn by an appliance when it is not in operation but is connected to the mains. Depending on the appliance type, this can range from nil (for example a non-electronic dryer) to 20 W or more (for example a television). These power consumptions may seem trivial (1 W continuous power is approximately 9 kWh per year and costs about $1.30 at 15c/kWh), but since most households have many such appliances, the actual energy consumption could become a significant fraction of the total energy consumption of a household.

9.2.1 Definition of standby power and baseload

The definition of standby power, prepared by a consensus panel for the IEA (International Energy Agency) (IEA, 1999) is:

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

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

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

a) It defines the lowest continuous power demand that must be met by a network (or generation system), so has a large part to play in the network load factor.
b) It includes a group of appliances that have the potential for demand reductions.

9.2.2 Standby estimation

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

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

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

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

The analysis method for calculating the standby power and losses is based on the frequency distribution of the appliance power consumption. For example, a fridge compressor is on for most of the time and, when the compressor switches off, the fridge has a standby power of about 17 W. The frequency distribution for such a fridge is given in Figure 39.

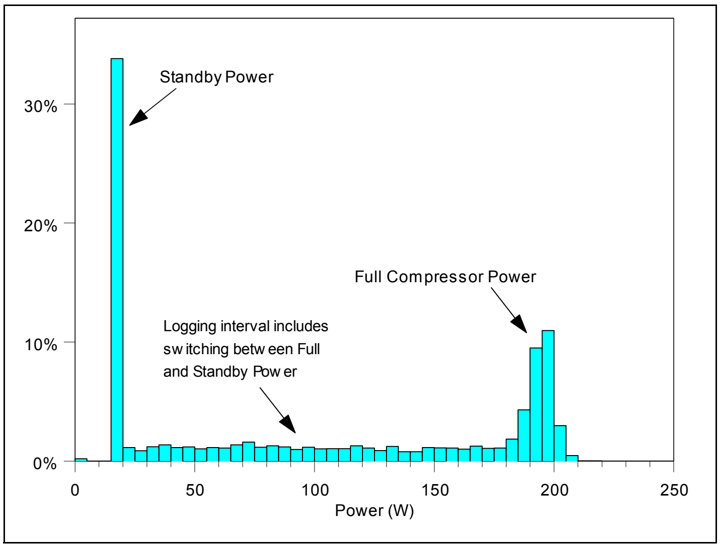


Figure 39: Fridge power frequency

The distribution in Figure 39 has two strong peaks: one at about 190 W corresponding to full compressor power, and another at about 17 W corresponding to the standby power. Power uses in between these peaks are the fridge switching on or off some time during the 15 min sampling interval used in this case, so an intermediate power use is recorded. Later monitoring used a 2 minute sampling interval.

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

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

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

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

9.3 Standby power and energy

For the purpose of reporting, the monitored household appliances have been divided into eight groups. The full range of standby data described in this section can also be generated for the individual appliance types:

- **Entertainment**: audio component, DVD player, games console, miscellaneous entertainment, radio, separate radio cassette, Sky/Saturn decoder, stereo, television, video
- **Kitchen**: bench top mini-oven, bread maker, coffee maker, Crockpot, dishwasher, electric oven, electric range (hobs + stove), extractor fan, food processor, frying pan, jug, juicer, microwave, mixer, Rangehood, separate electric grill, small kitchen appliance, toasted sandwich maker, toaster, waste disposal
- **Laundry**: dryer, iron, washing machine
- **Miscellaneous – large**: pool pump, spa pool
- **Miscellaneous – small**: alarm clock, cellphone charger, charger, electric blanket, electric fence, electric organ, electric power tool, garage door opener, hairdryer, lamp, miscellaneous gear, miscellaneous household appliance, miscellaneous personal, plug in air freshener, sewing machine, shaver, toothbrush, vacuum, waterbed
- **Refrigeration**: freezer, fridge, fridge freezer
- **SOHO (Small Office, Home Office)**: answer phone, computer, computer monitor, cordless phone, fax machine, intercom, miscellaneous computer peripherals, printer
- **Space conditioning**: air conditioner, fan, dehumidifier, heater.

There are also a group of hard-wired appliances with small, but potentially measurable standby loads. These include electric ranges, residual current devices (RCD) now required on domestic electric circuits; fixed sensor lights and security alarm systems. These systems could total 3 – 5 W average standby per house.

Figure 40 summarises the power demand for each of the different monitored household appliance groups, while Figure 41 provides an overall analysis of the energy used by the different groups. The difference relates to the amount of time the appliance is turned on and in standby mode, and the relative proportions of the different appliances. For example, the 'entertainment' group is not only the largest group in terms of standby (Figure 40), but as they are plugged in for most of the time and they are found in many houses, their overall impact is 51% of the energy used for standby (Figure 41). Conversely, the 'Miscellaneous – Large' group (pool pump and spa pool) has a high standby, but is only found in a relatively few houses, and therefore has very little impact on the overall standby energy use.

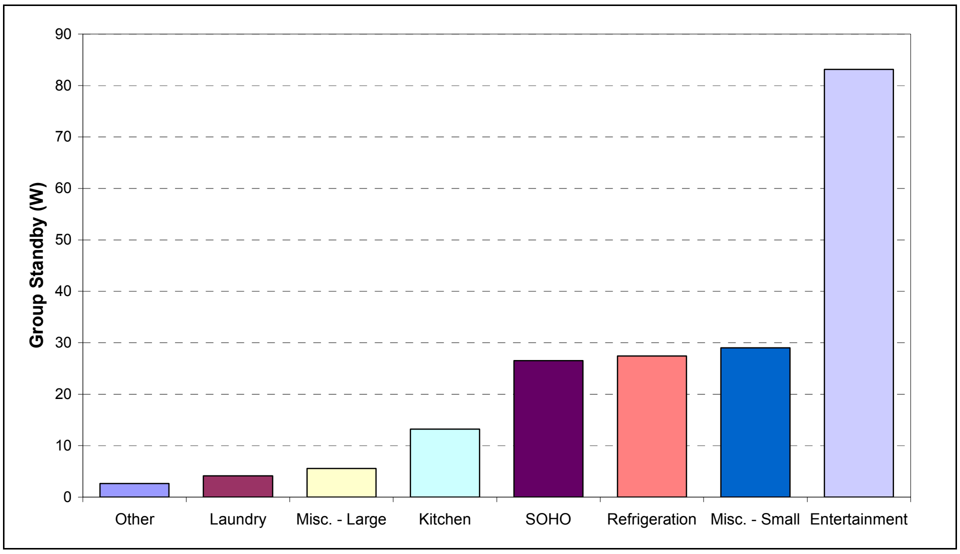


Figure 40: Standby power for household appliance groups

The five appliance types measured to have the highest standby electric power are (in alphabetical order):

- fridge/freezers
- instant gas water heaters
- refrigerators
- Sky/Saturn television set-top boxes
- video recorders.

In almost all cases the level of standby power consumption is a consequence of the design, and could if desired be significantly reduced.

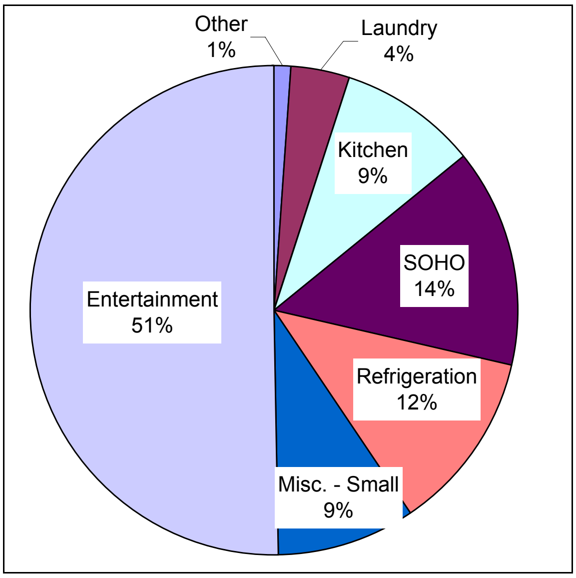


Figure 41: Standby energy

The average energy use per house for standby is equivalent to 58 W continuous i.e. the average New Zealand house is spending nearly $80 a year (at 15 c/kWh) just keeping these appliances powered-on while they wait to be used.

The overall impact on the nation's electricity demand, as mentioned above, is a combination of the individual appliance standby-by power, the proportion of time it is plugged in and 'turned on' at the wall (even though it may not be in use) and the size of the appliance population. Just because an appliance type has a high standby power (Figure 40) does not mean they are major loads of the electricity system.

The top five appliance types in terms of their current impact on the electricity system are (in alphabetical order):

- fridge/freezers,
- home computer (includes computer box and monitor)
- stereo
- television
- video recorders.

These five highest appliance types account for more than half the total household standby energy consumption. It is interesting to note that three out of the top five are in the 'home entertainment' grouping.

It is important to note that as appliances increase their market penetration, the importance of their standby energy use increases, and vice versa. For example, video recorders are being replaced by DVD players/recorders. If each older, higher standby power video recorder is replaced by a more efficient, lower standby power DVD player then the national standby power demand of this appliance group will reduce. However, if DVD players/recorders achieve a greater market penetration, or the new appliance has similar standby power, then the overall impact may be unchanged or possibly even result in an increase in standby power demand on the electricity system.

9.4 Heated towel rails – an example of baseload

The HEEP survey questionnaire records how many heated towel rails there are in each house, and how often they are used, as self-reported by the occupant. The usage is recorded in categories as summarised in Table 31. More that half of the heated towel rails are on constantly, and dominate the energy consumption for this appliance type.

Usage Category	Assumed Hours Per Week	% of houses
Constant	168	56%
Daily	35	11%
More than 1 per week	20	3½%
Approximately 1/week	10	1½%
Approximately fortnightly	5	1½%
Approximately 1 per month	2	5½%
Less than 1 per month	0.5	10%
Never	0	10%

Table 31: Heated towel rails by usage category

The hours of use per week for each category are needed to calculate the energy consumption. Some early HEEP surveys of 128 houses included occupant self-reported hours of use, and the 'assumed hours per week' given in Table 31 are based on these estimates.

The average power rating of heated towels is also needed. This is not usually known by the occupants, and often no label is visible, and with fixed wiring it is not possible to conduct a power measurement. The HEEP survey included power estimates for a small number of towel rails, giving an average of 70 W ± 10 W.

Combining the number of heated towel rails with the usage information and the average power rating gives the average power consumption per house for heated towel rails 21 W ± 2 W. The 95% confidence interval (CI) is 16.75 to 25.25 W. Nationwide for 1.4 million households, this is an average of 30 MW ± 3 MW, of which almost all is 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 32: Heated towel rail average power use

Since only about half the heated towel rails are used constantly, and there are only about 0.6 towel rails per house, most of the heated towel rail energy consumption is from a small fraction of houses.

A single heated towel rail used constantly costs more than $100 per year to operate, and can easily be 10% or more of the total electricity consumption in a houses that uses them. Reductions of energy consumption, either by informing people of the real cost of operation or by installing timer switches could give worthwhile, cost-effectively energy savings at an individual household level, as well as nationally.

9.5 Baseload

The baseload of a house is the typical lowest power consumption when everything that is usually switched off is off. It is made up of the standby power of appliances, continuous loads like heated towel rails, and other appliances that are always on, and faulty refrigeration appliances.

9.5.1 Baseload estimation

The methodology for estimating the baseload was described in the HEEP Year 5 report (Stoecklein et al, 2001), and is provided below.

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

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

9.5.2 Results: baseload

The average baseload demand is 112 W ± 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 150 MW of continuous load – equivalent to an average Waikato hydro-power station.

The standby power consumption contributes 58 W ± 3.8 W and heated towel rails 21 W ± 2 W to this total, leaving 33 W ± 6 W to be accounted for in the calculated average New Zealand house baseload.

Hard wired appliances that could not be monitored could account for 3 – 5 W.

Faulty refrigeration appliances could easily account for 15 W ± 10 W of base or standby load per house (see the HEEP Year 8 report for further discussion – Isaacs et al. 2004), and the remainder of 14 W ± 12 W is not statistically different from zero. So we conclude that the baseload is fully accounted for by the estimated standby power, heated towel rail consumption, and faulty refrigeration appliances, and that it is unlikely that there are any other large components of the baseload left unaccounted.

10. WET-BACK WATER HEATING

10.1 Introduction

In addition to the direct use of purchased fuels for the production of heated water, many New Zealand homes make use of a 'wet-back'. The wet-back takes heat from a solid fuel burner (the rest being used to heat the house or cook food) and store the heated water in a hot water cylinder – normally the main household cylinder, but in some cases a dedicated cylinder.

Wet-back water heating monitoring was first implemented in HEEP in 1999, initially on a trial basis, and then as part of full-scale monitoring. Prior to 1999 there were only 3 wet-back systems in the monitored houses. This section briefly describes the monitoring regime, but does not attempt to describe the many false starts, dead-ends and changes to the methodology.

Wet-back heating systems were monitored by measuring the temperature of the cold inlet, and either the cylinder wall temperature or the hot water outlet pipe temperature. It was found to be impractical to monitor water flows. In the end, it was found that monitoring either the hot outlet or the cylinder wall temperature alone was sufficient to allow estimation of the wet-back energy inputs, in conjunction with heat output estimates from the solid fuel burner.

10.2 Calibration of wet-back systems

The final calibration of the wet-back systems commenced after the successful calibration of the solid fuel burner heat outputs. The method establishes a correlation between the rate of increase of cylinder temperature which, assuming no water draw-off, is directly proportional to the energy input, and the solid fuel heat input.

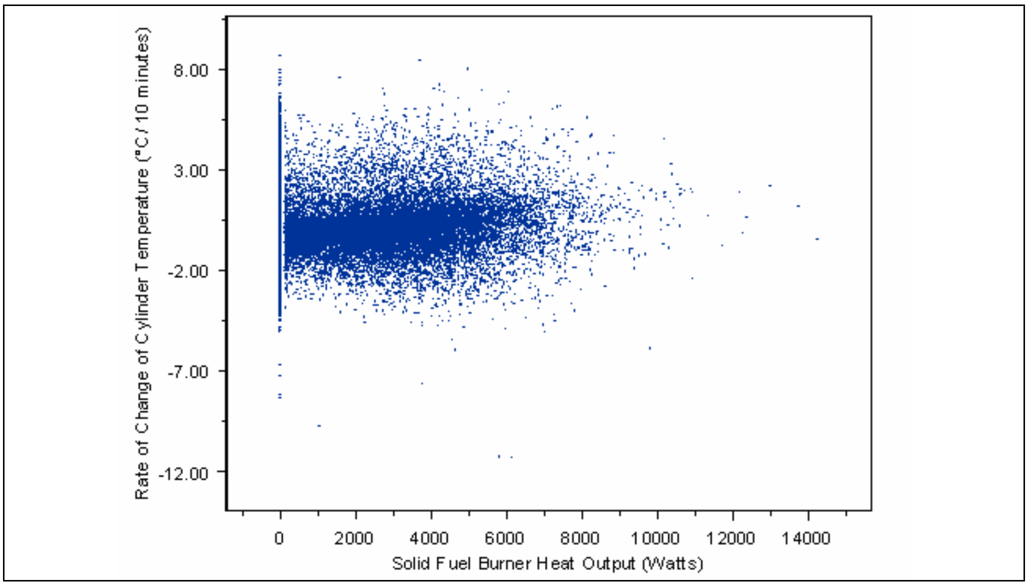


Figure 42: Solid fuel burner output vs rate of change of cylinder temperature

An example of the data at 10 minute intervals is given in Figure 42. Where there is a correlation between the two there is also a lot of scatter. To reliably fit a linear model to this data, the data were aggregated by solid fuel burner input into 100 W bins, as illustrated in Figure 43. Note that in Figure 43 the number of data points averaged in each 100 W interval varies, and at the higher end, there are very few points. When a weighted linear regression line was fitted to Figure 43 it had a slope of 0.0001038, which when rescaled from rate of temperature change per Watt of solid fuel heat input to change in energy per Watt of solid fuel heat input gives 0.125 W/W. So for this wet-back connection, for every Watt of heat output of the solid fuel burner for space heating, 0.125 W goes into the hot water cylinder.

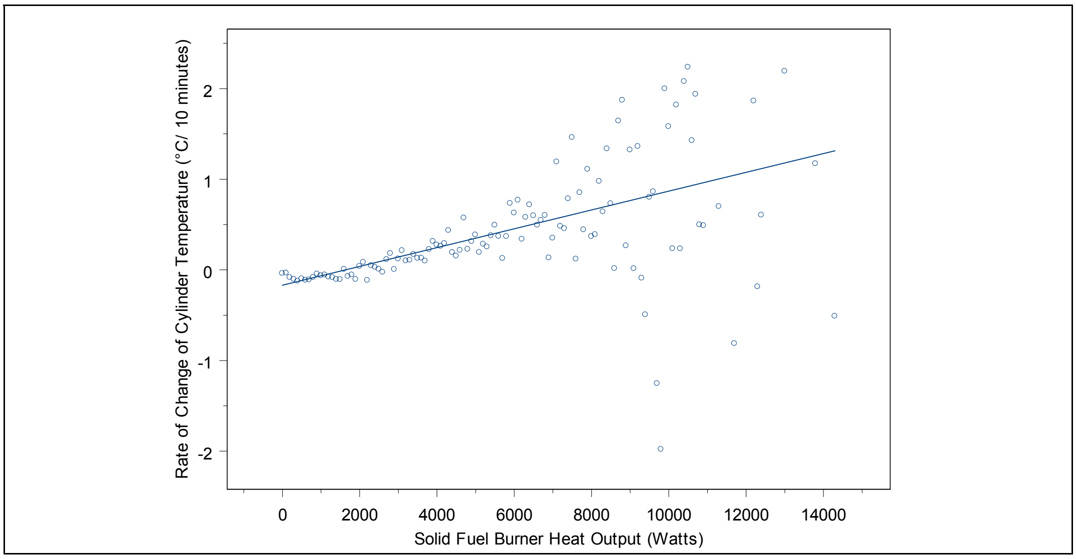


Figure 43: Solid fuel burner output vs and rate of change of cylinder temperature

The method used gives the slope of the relationship, but the intercept is not meaningful. Since the fitted line slope is insensitive to the addition or subtraction of a constant, the standing losses of the hot water cylinder are not accounted for. To account for them, a power equal to the standing losses is added when the wet-back connection is actively supplying energy to the hot water cylinder.

Figure 44 shows the combined electric and wet-back hot water energy used by one system for a whole year. The electricity was turned off between about April and November for this house, and the wet-back was the sole source of energy for hot water over that period. This can be seen in the sudden change in the pattern in the top panel, which is 10 minute data. In the lower panel, the upper line is the weekly moving average of the combined wet-back and electricity energy consumption – this energy consumption is fairly consistent between the summer months and the winter months, when the wet-back is the sole heating source.

This is a good indication that the calculation of this wet-back energy is correct, as the energy consumption is driven by the demand of the household for hot water. For this house, the annual hot water energy consumption was about 2,400 kWh, with about 900 kWh from electricity and about 1,500 kWh from the wet-back.

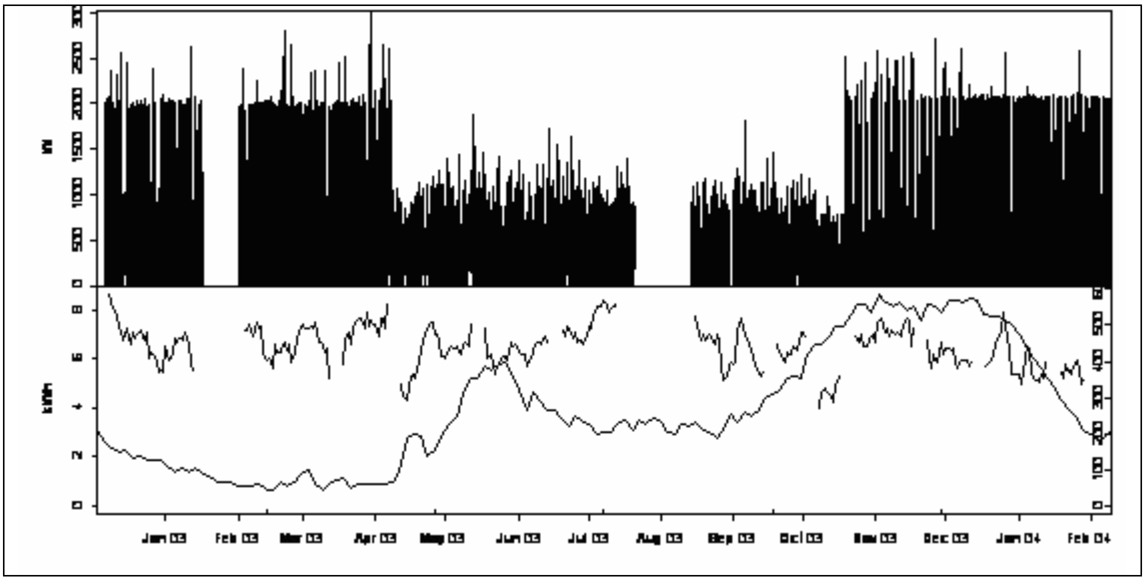


Figure 44: Combined electric and wet-back water heating energy

A number of other wet-back systems were tested to trial the method. Generally, the method as described works well. In some cases where there is a lot of hot water drawn off during periods when the wet-back connection was operating, the method failed, as the rapid draw-off is equivalent to an energy output of 10-30 kW for the hot water system, and the water temperature drops rapidly. This destroys any positive correlation between the rate of change of water temperature and solid fuel heat input. In these cases, a subset of data was taken when the electricity consumption was zero, and when the rate of change of temperature was positive.

In other cases, this method was not sufficient to deal with water draw-off, and a different subset was taken when the water temperature was above the low point of the thermostat deadband. Effectively, this only takes those instances where the hot water cylinder is being overheated to some extent by the wet-back connection. This helped in some other cases.

The overriding advantage of this method of calibration is that it establishes the wet-back energy input as a fraction of the solid fuel heat input. The calibration of the wet-back system itself requires only a small amount of data – in some cases only a few days of data is enough. As the monitoring of the hot water cylinder and wet-back connection and solid fuel burner involves at least two data loggers (for electricity and thermocouple temperatures) and at least three thermocouples, the chances of any one channel of data being invalid due to logger or wiring faults or loose wires is increased. Once the calibration factor is determined, the wet-back energy data is calculated from only one monitored logger channel: the solid fuel burner. Using a continuous heat balance of the hot water cylinder would generate much more missing data.

The fraction of the solid fuel heat input that goes to the wet-back varies considerably between systems. (Note the solid fuel heat input is the gross heat input to supply the energy delivered as space heating. The wet-back energy is in addition to this heat input). Typically a wet-back connection to an enclosed wood burner has an output 5-

10% of the solid fuel burner heat output. For dedicated chip heaters, the fraction is much higher, mainly due to the very low space heating output of these types of burners (they have a water jacket around the combustion chamber so most of the heat goes into the water and not the room).

10.3 Estimates of wet-back energy heat inputs

The average wet-back provides 1000 kWh ± 200 kWh per year per house that has a wet-back system.

On average, for houses with wet-back systems, about 20% of their total hot water energy is supplied by the wet-back. About 5% of houses with a wet-back system get all (100%) of their hot water supplied by the wet-back, although most of these systems are dedicated solid fuel water heaters. Overall, roughly 5% of the national total hot water energy is supplied by wet-back water heaters.

There are still some chip heaters in use (seven chip heaters were used in the HEEP houses), even though many of them are very old. There are a few modern chip heaters (like the Butler), though they are outnumbered by the older types and by wet-back connections to solid fuel burners.

There is huge regional variation in the wet-back energy. Some wet-backs provide only a few percent of the total hot water for a household. Some systems provide more than two-thirds.

This is readily explained as in colder climates the solid fuel burners are used more often, more intensively, and for more months of the year, so more energy is fed into the wet-back circuit. This is also reflected in the number of wet-back systems, with few in warm climates, and a lot in cold climates.

In three of the 29 locations monitored, around 20% of all hot water energy was supplied by wet-back, and in winter time this was nearly 50%, and even higher during the evening peak. In areas like this which often have a limited electricity supply capacity, it appears that wet-backs are making a large contribution to managing peak electricity demand in winter.

Wet-back systems generally have higher standing losses than electric cylinders alone, due to more pipes and pipe penetrations. The extra losses could be of the order of 0.4 kWh per day. About 90% of wet-back systems provided more energy than the extra standing losses over a year. For houses that do not use the wet-back, removing the pipes and sealing the holes with insulation would reduce standing losses slightly. The high losses coupled with the short operating hours suggest that wet-backs are not a good option for water heating in warm climates.

11. HOT WATER SYSTEMS

> *"Men have gone to the moon and marvelled, but no greater event occurred on this earth than the abundance of soap and the unheralded arrival of hot and cold water by the turning of a tap. It is a gift of my lifetime, as is the leisure to use it. A rocket to the moon put millions of miles on to exploration potential; but hygiene – made possible by instant hot and cold water – probably doubled our life span".* (Lee 1977)

Today the provision of hot running water is considered a fundamental household requirement, yet it is only since the 1960s that the majority of New Zealand houses have had an on-demand hot water supply.

This section briefly reviews the history of the provision of hot water in New Zealand homes, compares selected results from the 1971/72 household electricity study with the HEEP sample, sets out the current New Zealand Building Code requirements and provides a detailed analysis of the HEEP sample. Hot water systems were last reported in the HEEP Year 7 report (Isaacs et al, 2003), but the sample is now considerably increased in number, and covers all of New Zealand.

The analysis in this section, unless otherwise stated, refers to proportions of individual cylinders i.e. if a house has more than one cylinder, all the cylinders will be included in the analysis. Unless otherwise specified, the analysis is based on randomly selected HEEP houses.

Of the randomly selected HEEP houses, 90% have one hot water system, 9% have two systems and 1% have three systems. None have more than three hot water systems. The proportions are almost the same for the non-random houses, except no non-random selected house has three hot water systems.

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

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

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

11.1 Historical review

It was not until the 1860s that piped water was available in main New Zealand cities (e.g. Dunedin 1866, Wellington 1865, Auckland 1866)[8], and for some years after that that piped water was available in some houses. From the 1910s, indoor toilets became common, but it was still many years before either the house joined up to the outdoor toilet or an indoor toilet was available in the majority of New Zealand homes (Salmond, 1986). By the 1945 Census, 67% of New Zealand homes had a flush toilet although this grew quickly – by the 1956 Census 81% of homes had a flush toilet and by the 1966 Census 94% of homes were so equipped (NZ Department of Statistics 1952, 1959, 1969).

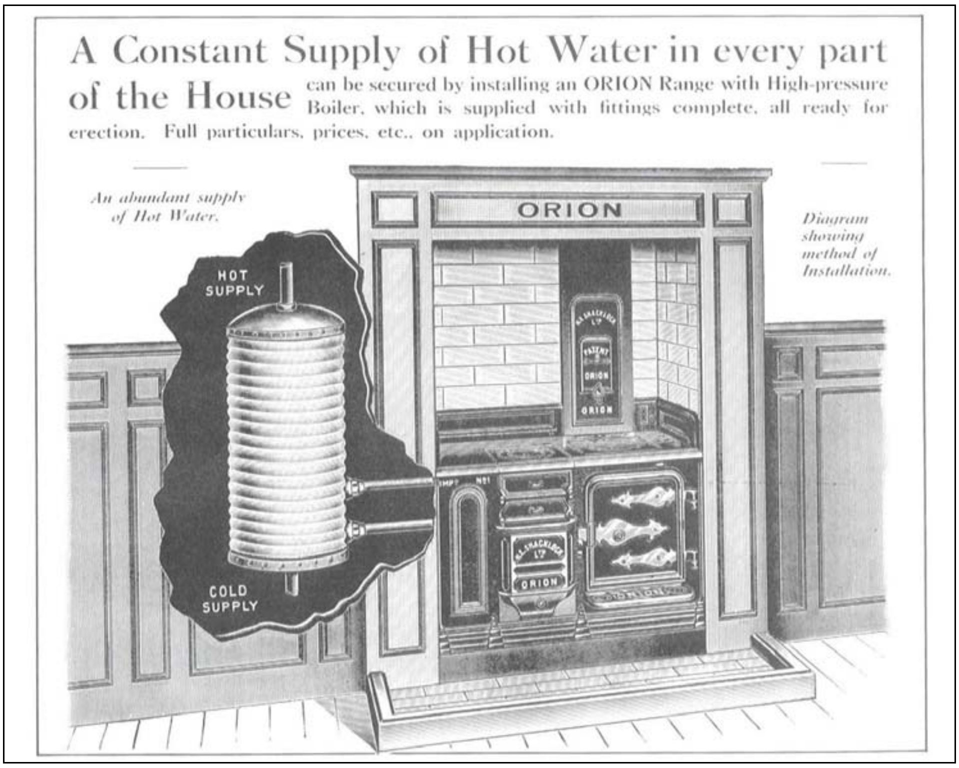


Figure 45: Hot water from the stove

Until the 1930s, and even up to the 1950s in many households, much hot water was produced from solid fuel heating through attachments to solid-fuelled cooking stoves, as illustrated in Figure 45 (Cochran 1980). In addition, so-called chip-heaters produced water for bathing and kitchen use and the traditional fuel-fired 'copper' was used for clothes washing. Even today, some water heating is achieved from solid fuel burning in 'wet-back' attachments to log fires, especially in areas where space heating is needed for a significant part of the year.

During the period prior to the 1960s, when coal gas was common, gas-fired 'instantaneous' water heaters ('califonts' and 'geysers') were common. With

[8] See: www.wellington.govt.nz/services/watersupply/history/history.html
www.aucklandcity.govt.nz/auckland/introduction/bush/chronology.asp
www.cityofdunedin.com/city/?page=water_su

increasing distribution of electricity, and the associated decline of the coal gas industry, electricity rapidly became the dominant fuel. It was not until natural gas became available in the 1970s that gas started to make a comeback for water and space heating (Williamson & Clark, 2001). Even in 2004, only 14% of New Zealand homes had a mains gas connection (Table 25, Statistics NZ, 2004h), although large bottle (45 kg) LPG gas is being used in non-reticulated areas for hot water supply.

11.1.1 Census data

Prior to the 1945 Census there is little data available on the availability of hot water in New Zealand homes. In that Census, for the first time a question was asked about the availability of hot water supply. Although the precise question has changed over time, Figure 46 plots the responses from all available Censuses (NZ Department of Statistics 1952, 1959, 1964, 1969, 1975, 1980, 1982b, 1987b; Statistics NZ, 1997). The hot water questions are provided in full in Section 15 Appendix – Census DHW Questions (page 123). Of particular importance is that the question in the 1986 Census asked only whether the hot water supply was ‘Electric’, ‘Gas’, ‘Other’ or ‘No hot water supply’ – this does not permit a detailed analysis of the ‘Other’ fuel source as in other Censuses.

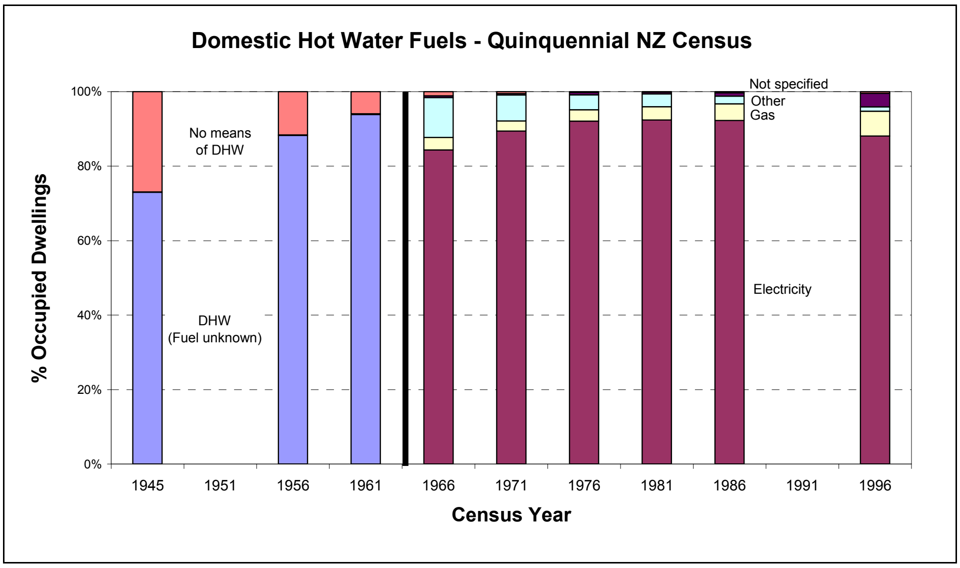


Figure 46: NZ Census 1945-1996 domestic hot water by fuel type

In 1945, 1956 and 1961 the Census question was only concerned with the availability of hot water service. In 1945, 26.9% of households reported that they had no means of hot water service – they would have heated water in a container either on the stove or in the laundry ‘copper’. When it took so much work – carrying inside not the water but also the heating fuel – it is not surprising that bathing was limited to once a week, and most often to ensure cleanliness for Sunday church.

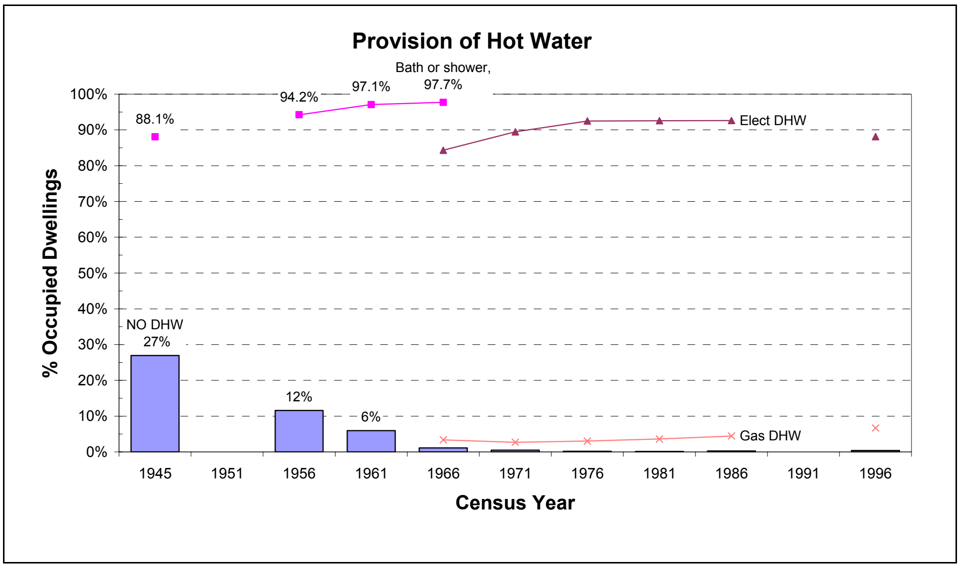


Figure 47: NZ Census 1945-1996 % dwellings with no DHW

Figure 47 shows that in 1945, 27% of households lacked a hot water service, but over the next decade this proportion more than halved so that by 1956 only 11.6% of household lacked a hot water service. The proportion fell to 5.9% by 1961 and 1.1% by 1966. By 1996 – the last Census in which a question on hot water service was asked – there were only 4,917 dwellings (out of the then total of 1,276,332 'Private Occupied Dwellings') which lacked a hot water supply.

Even in 1945, 88% of households had either a bath or shower – suggesting this amenity was present in at least some of the 15% of households that lacked a hot water service. In those houses the hot water would have been 'batch brewed' – heated in a pan or basin on the stove, and carried to the bath, just as would have been the case 50 years earlier. The proportion of homes with a bath or shower grew rapidly, and by 1966 (the last year in which this question was asked) one or the other was found in 97.7% of households.

As from 1966 almost all houses had a hot water service, so the Census could then ask about the type of fuel being used. Figure 48 shows that in the majority of houses, this fuel was electricity.

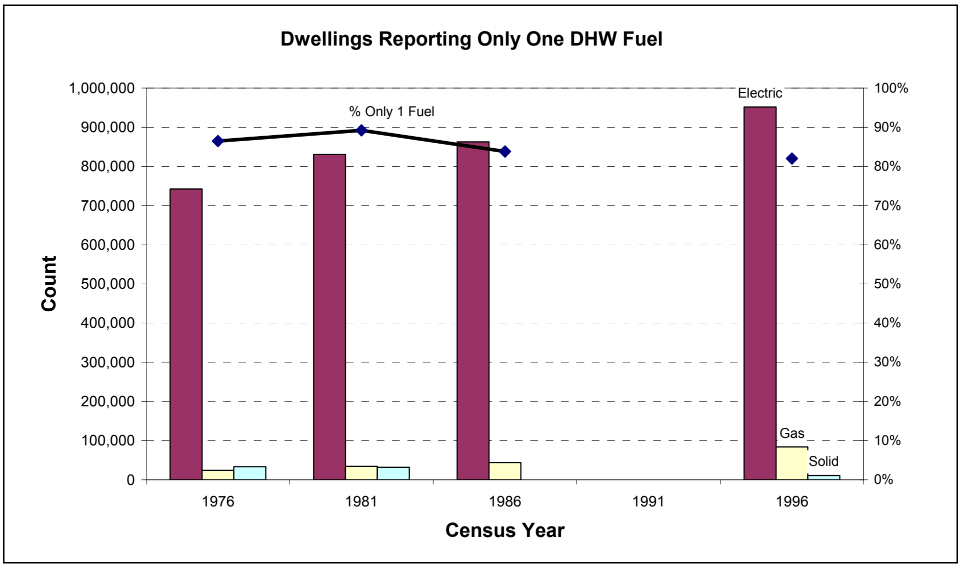
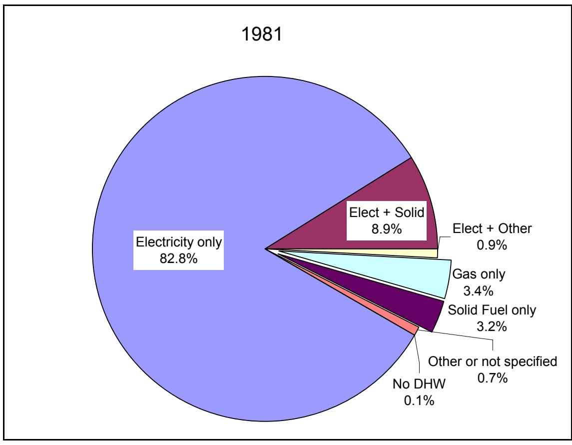


Figure 48: NZ Census 1976-1996 dwellings with only one DHW fuel

In the 1996 Census a total of 1,046,886 households (82% of all households) reported only one fuel used for hot water provision – 951,759 (75% of all households) reported only electric water heating, 83,646 (7%) only gas water heating, 10,821 (0.8%) only solid fuel water heating and 660 (0.05%) only solar water heating.

Figure 48 also shows that there has been a decline in the proportion of households with only one hot water fuel. The highest proportion (89%) of households with only one fuel occurred in the 1981 Census, which reduced to 84% in the 1986 Census, and reduced again to 82% in the 1996 Census. This may be due to some households wishing to have higher security of hot water supply, and achieving this when adding hot water systems by choosing a different secondary fuel. For example, the proportion of houses with both electric and another fuel hot water system has increased from 11% of dwellings in 1981 to 15% in 1996.



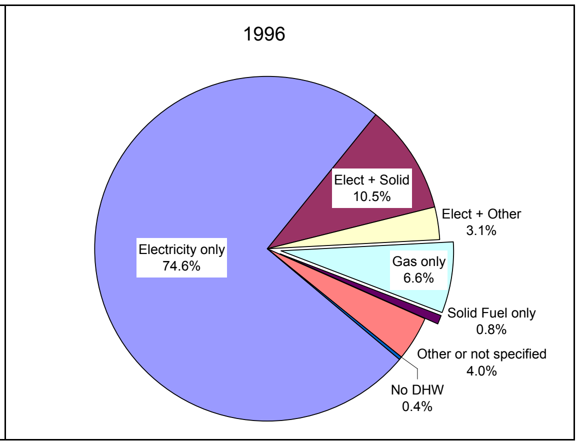


Figure 49: 1981 DHW fuels **Figure 50: 1996 DHW fuels**

Figure 49 and Figure 50 provide the proportions of household reporting use of different fuels for domestic hot water (NZ Dept of Statistics 1982b; Statistics NZ 2005).

The 'fall' in the proportion of electric-only hot water is matched by the increase in electricity with solid fuel and use of gas (mains and bottle).

There is also an increased in the 'Other or not specified' category from 0.7% to 4%, but the majority of this is in the number of households that did not specify what fuel was used for hot water, increasing from 4,689 (0.5% of total dwellings) to 47,127 (3.7%) in 1996.

The number of homes reporting 'no hot water service' has increased from 1,329 in 1981 to 4,917 in 1996. These are in both cases less than 0.5% of the total number of dwellings, and it is unlikely that this reported change has any significance.

11.1.2 Electric hot water

Electric hot water heating dates back to 1915, when Lloyd Mandeno (then the Tauranga Borough engineer, but later a major force in the development of electricity in New Zealand) developed the first storage hot water heater for use in the first all-electric house:

> *"…Lloyd Mandeno then got stuck in and built the system. He made the hot water container of heavy gauge galvanised iron and fitted two elements, one 350 W and one 500 W. This sat in a larger container, around which he packed a 6 inch thick layer of screened pumice for insulation before placing it under the roof above the ceiling, with short drops of concealed pipe leading to the sink and the bathroom".* (Rennie 1989)

The fatal flaw did not become obvious for a couple years, when the galvanised iron corroded through. The solution – a copper cylinder – remains the basis for the low-pressure electric hot water cylinder still used in most New Zealand homes.

> *"It can be claimed that New Zealand was at the forefront in the development of electric water heating loading. These heaters have been designed for use in the domestic and commercial field and also in dairy sheds. The systems generally are thirty (136 litre) to forty (181 litre) gallon storage-type heaters, fitted with an electrical heating element varying from 0.75 kilowatts [sic] to 2 kilowatts capacity, the majority being of the order of 0.75/1 kilowatts.*
> *Originally electricity for water heating was sold on a fixed annual charge, irrespective of consumption, but severe power restrictions demanded a revision of this policy. The metering of these systems was made compulsory as was the fitting of thermostats to control their operation and this has resulted in a very great saving in unit consumption. When the water in the cylinder reaches a predetermined temperature, the supply is automatically cut off until such time as usage and the drop in temperature requires further supply to restore the water to its original heat level. Loading statistics have shown that under normal circumstances, storage water heaters are operating on the supply for an average of 12 to 14 hours per day only. This lends itself admirably to control over periods of peak, and a recent development has been the centralised control of supply to water heaters by various systems all of which*

operate relay on the consumer's premises. A signal superimposed on the reticulation system actuates the relay which disconnects the supply to the water heater over times of peak, a further signal restoring supply after this period has passed". (Speer, 1962)

The domestic price of electricity halved between 1923 and 1935, which coupled with the lack of coal gas 'smell' and a more modern image rapidly increased market penetration. Electric load management could be achieved by a consumer operated switch – permitting the choice of either hot water or the cooking range, but not both at the same time (Rennie, 1989).

By the late-1940s, the modern home cook book provided detailed electrical guidance for the householder with little knowledge of electricity:

"The size of heater required is dependent on two factors:—

1. *Quantity of hot water required.*
2. *Time in which heating must be accomplished.*

Water heating during off-peak load hours is generally procurable at cheap rates. Hours of use are usually from 10 p.m. to 7 a.m. All day water-heating service is also generally procurable at reasonable rates.

For night heating the size of electric element required is approximately 1 kW per 20 gallons storage capacity. For 24 hours service this may be halved, i.e., 500 watts, or 600 watts will be found to be ample. Recently there has been considerable development in storage cylinders of the quick recovery". (Whitcombe & Tombs, 1948)

A 40 gallon (180 litre) cylinder with only a 1.2 kW heater could take up to eight hours to provide a full tank at 60°C. No problem if the main hot water loads were large and intermittent – washing dishes, washing clothes or a bath for the household – but this was not the sole issue of concern.

Until 1967 electric supply authorities paid for bulk supply solely on the basis of peak demand, providing a strong incentive for control. Storage hot water systems were recognised as providing an ideal opportunity for load management. Time clocks were installed in the 1920s, and were followed by 'pilot wire' controls (a separate signal wire being installed in each house) in the 1930s. The 'ripple control' system (a signal at a special frequency is fed through the power lines and detected by a tuned relay in the house) was first introduced in 1949 by the Waitemata Electric Power Board, and then quickly spread throughout the country (Rennie, 1989).

Changing patterns of behaviour and occupant expectations have lead to different demands on the hot water supply. Dishwashers are present, and most likely have replaced hand washing, in 44% of houses (Statistics NZ, 2004h), while automatic washing machines and improved laundry detergents have led to a shift away from hot or warm water washes to cold water washing. The most important shift is that the weekly bath has been replaced by the daily shower – this now requires a constant stream of constant temperature warm water, which may not be achievable at a safe temperature with only a small cylinder lacking a tempering valve.

Nowadays a range of different electric hot water systems are available. Instant water heaters (either open vented or in-line) can turn cold water into warm water in a small unit which can be mounted close to the point of use, eliminating the need for both hot and cold water piping. These systems require larger heater elements (4 kW to 14 kW) and heavier duty wiring than the more common storage water system (e.g. www.instanthotwater.co.nz, www.atmor.co.nz). Storage electric water heaters are available in a range of sizes from 25 litres to 400 litres with single elements from 1.2 kW to 6 kW, and with hot water production from 0.3 litres/min (20 litres/hour) to 1.7 litres/min (100 litres/hour).[9]

11.1.3 Gas water heating

Reticulated coal gas became an important energy source for cooking and heating. Coal gas was first extracted from coal at a plant in Auckland in 1862, and by the end of the decade gasworks were operating in Wellington, Christchurch and Dunedin. By 1900, coal was the main source of energy in New Zealand. Production exceeded one million tonnes in 1900, nearly all produced from underground mines by large numbers of men using picks and shovels. The State Coal Mines were established in 1901, and coal production continued to increase rapidly, doubling to two million tonnes by 1910. Electricity reticulation expanded after World War One, when there were 56 gasworks in the country, but coal still accounted for more than 50% of the primary energy market in 1940.[10]

By the end of Word War Two there were 46 gasworks still operating, with some 200,000 consumers. These numbers declined to 100,000 by 1956. By 1965 there were only 33 operating plants. The discovery of natural gas at Kapuni, Taranaki in 1959 was the start of the renaissance of gas, but it was not until 1971 that it was delivered to residential consumers. The delay included not only full testing and proving of the resource, but also the construction of a pipeline throughout the North Island. Then some 86,000 premises, plus a number of large industrial complexes, had to be converted from coal gas to natural gas (Veart, 2000). The discovery of the Maui field in 1969 allowed the development of large-scale gas-based projects, as well as expansion of the gas pipeline.

The South Island remained isolated, with only Dunedin sending a reformed gas based on LPG through the old pipelines. Nowadays, only central Dunedin (Otago Citigas)[11] is supplied with Tempered LPG (TLP), while Christchurch, Queenstown and Wanaka[12] central business districts are on LPG vapour from a centralised LPG facility. Some housing estates in the South Island also have LPG vapour supply. Other domestic and commercial customers not connected to the natural gas pipeline use tanks filled, or delivered, by a dedicated LPG transport industry.

A range of gas storage and continuous flow hot water heaters are available. Gas storage water heaters range in volume from 135 litres to 360 litres consuming gas at

[9] See *Rheem Hot Water Manual* available from www.rheem.com.au

[10] See *History of Coal Mining* www.crownminerals.govt.nz/coal/mining/history.html, accessed 8 June 05

[11] See http://www.toddenergy.co.nz/te/pages/main/gas/industrial/warmingupthearts.htm

[12] See http://www.rockgas.co.nz/3-reticulation.asp

rates from 35 MJ/hr (10 kW) to 200 MJ/hr (56 kW), while providing hot water flows from three to 13 litres per minute (averaged over an hour). Gas continuous water heaters consume 80 MJ/hr (22 kW) to 250 MJ/hr (70 kW) while providing a hot water flow from 10 to 32 litres per minute.[13]

11.1.4 Comparison of gas and electric hot water systems

Table 33 provides a summary comparison of the size, power demand and hot water flow rate for electric and storage and continuous flow systems.

	Volume litres	Fuel MJ/hr	Use kW	Water Flow litres/min
Electric storage	25 to 400		1.2 to 6	0.3 to 1.7
Electric continuous	-		4 to 14	0.3 to 2
Gas storage	135 to 360	35 to 200	10 to 56	3 to 13
Gas continuous	-	80 to 250	22 to 70	10 to 32

Table 33: Electric and gas hot water system comparison

The ability of gas to provide higher energy flows (higher power) enables a gas system to provide greater volumes of heated water. This is of interest to consumers, as the HEEP sample includes eight houses with LPG hot water systems.

11.2 Baths and showers – 1971/72 to HEEP

Although modern houses are likely to have both a bath and shower (and very often more than one of each) different amounts of hot water, and hence energy, are required for each. Table 34 provides design values for water temperature and volume for bath and shower (Southcorp, 2001). It suggests a 'normal' bath would be expected to use at least two times as much hot water as a shower, although this obviously depends on the depth of the bath, and the flow rate and length of time the shower is in use.

Appliance	Temp.	Quantity of Mixed Water	User's Requirement
Normal bath	40°C	45-145 L	Minimum wait to fill bath to required level and ability to top up with hot water as bath water cools.
Spa bath	40°C	200-350 L	As above, with emphasis on quick filling over increased volume. A spa bath holding 300 L of mixed water would take 20 min to fill at 15 L/min flow rate.
Shower	40°C	25-70 L or more	Ability to adjust flow rate to desired or more degree varying from 7 to 30 L/min and to adjust temperature from 40°C down to 'chill off' temperature at will. Freedom from temperature fluctuations due to other draw-offs.

Table 34: Hot water requirements for baths and showers

The 1971/72 Electricity Study (NZ Department of Statistics, 1973a) recorded information on the number of baths and showers in the house, and their relative use by house occupants. The results were presented comparing the number of occupants, the number of showers and baths, and their comparative usage. This data was only

[13] See data sheets available on www.gas.co.nz, accessed 10 June 2005.

published for the 1,749 houses with permanently-wired electric hot water cylinders (Table 12a). Five main divisions were reported: **Bath only**: bath used more than shower (**Bath > Shower**); bath used the same amount as the shower (**Bath = Shower**); shower used more than the bath (**Shower > Bath**); and **Shower only**. A small '**Other**' category includes houses that lack either a bath or a shower. For the purposes of this analysis, it has been assumed that houses with 'only' a shower or a bath only use that facility.

HEEP Survey section B.2 asks house occupants for information on their use of hot water. This includes for the house the number of baths, showers and shubs (small enclosed bath unit with a shower fitting). For each individual, this includes their usual weekday bath or shower usage. The data on bath and shower usage is available for 385 HEEP houses.

The following two figures summarise the relative use of baths and showers for the two studies separated by approximately 30 years – Figure 51 for the 1971/72 study and Figure 52 for HEEP. For consistency, the HEEP sample has been limited to houses with one or more electric cylinders i.e. excluding houses with only gas or solid fuel hot water systems.

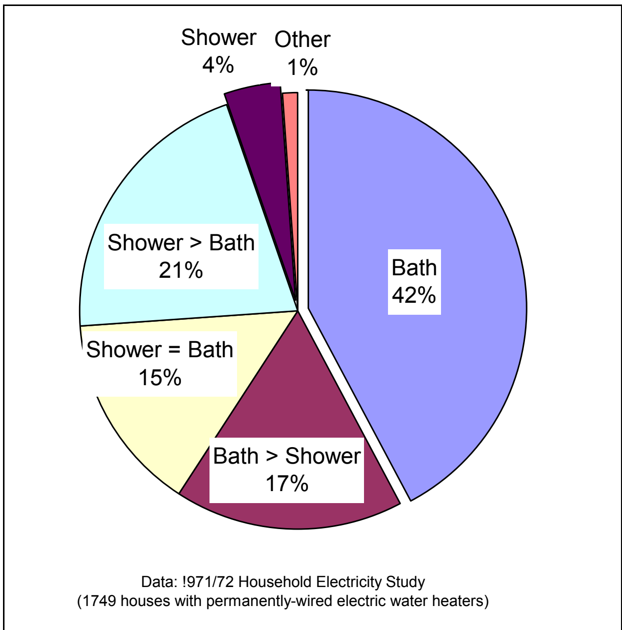


Figure 51: Use of baths and showers 1971/72

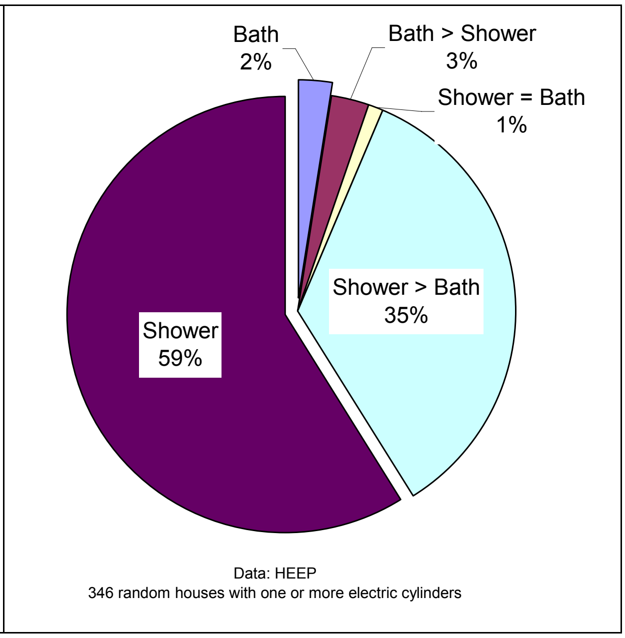


Figure 52: Use of baths and showers HEEP

Figure 51 and Figure 52 show there has been a major change in bathing habits over the past 30 years. In 1971/72, 59% of the households with one or more permanently wired electric cylinders mainly or solely used the bath. Over 30 years later, this has reduced to 2% of the HEEP houses with one or more electric cylinders. There has been a sizable growth in the use of showers, increasing from 25% in 1971/72 of households using the shower, or mainly the shower, to 94% in the HEEP sample.

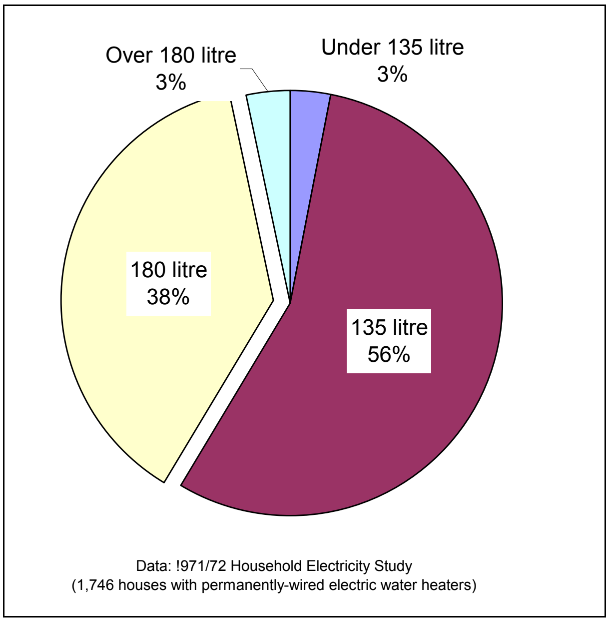


Figure 53: Total DHW volume 1971/72

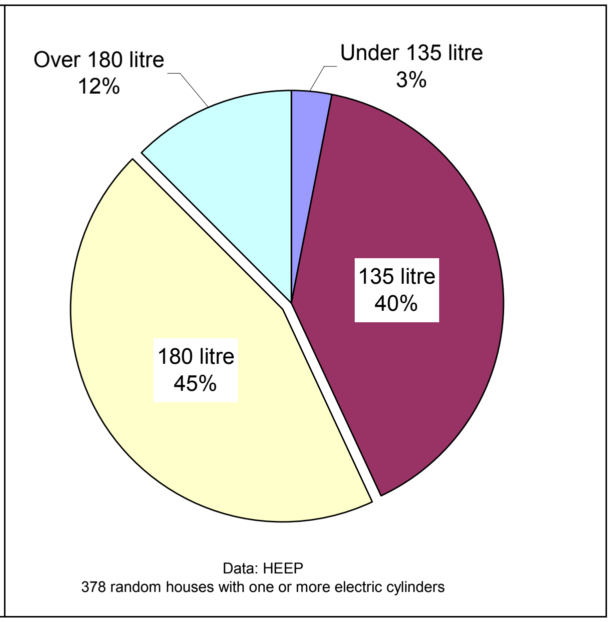


Figure 54: Total DHW volume HEEP

The ability of household hot water systems to provide hot water for this changed use has not altered to the same extent. Figure 53 and Figure 54 compare the total volume of house hot water cylinders for the 1971/72 study and the HEEP random houses. The houses with a total of 'under 135 litre' cylinder volume are in the main electric under-sink or point-of use-cylinders. The proportion of smaller 135 litre cylinders has reduced from 56% to 40%, while the houses with 180 litre total cylinder volumes have increased from 38% to 45% of the sample. Houses with over 180 litres of hot water cylinders have increased from 3% to 12% over the 30 years between the studies.

There has been a 13% increase in the weighted-average size of household hot water systems – from 150 litres per household in the 1971/72 study to 170 litres in the HEEP study. The number of people per house has reduced by 15% – from an estimated 3.4 in the 1971/72 study to a calculated 2.9 in the 346 HEEP houses with electric water cylinders and data on the number of occupants.

11.3 New Zealand Building Code requirements

Table 35 gives the Objective of **Clause G12: Water supplies** as set out in Schedule 1 of the Building Regulations 1992 (New Zealand Building Code).

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

Table 35: Building Regulations 1992 – extract from 'Clause G12: Water supplies'

These objectives are in turn met by the requirements of the Acceptable Solution and Verification Method. Table 36 sets out the portion of the Acceptable Solution to **Clause G12: Water supplies** (including Amendment 5, February 2004) which deals with 'Temperature Control Devices' and 'Safe Water Temperatures'. In broad terms, the Acceptable Solution requires thermostats to be of a quality set out in the appropriate Standards, safety cut-outs to control dangerous temperatures, appropriate temperature limiting mechanisms (to a level depending on the type of users) and a storage temperature to limit possibility of infection from Legionella pneumophila (Legionnaires' disease) bacteria.

6.5	**Temperature control devices**
6.5.1	Electric thermostats shall comply with NZS 6214 or AS 1308.
6.5.2	Energy cut-off devices shall be designed to: a) Be reset manually, and b) Disconnect the energy supply before the water temperature exceeds 95°C.
6.14	**Safe water temperatures**
6.14.1	**Maximum temperatures** The delivered hot water temperature at any sanitary fixture used for personal hygiene shall not exceed: a) 45°C for early childhood centres, schools, old people's homes, institutions for people with psychiatric or physical disabilities, hospitals, and b) 55°C for all other buildings. COMMENT: 1. At greatest risk from scalding are children, the elderly, and people with physical or intellectual disabilities, particularly those in institutional care. 2. Sanitary fixtures used for personal hygiene include showers, baths, hand basins and bidets.
6.14.2	**Hot water delivered from storage water heaters** a) An acceptable method of limiting hot water temperature delivered from storage water heaters is to install a mixing device between the outlet of the water heater and the sanitary fixture. b) Tempering valves shall comply with NZS 4617 or AS 1357.2.
6.14.3	**Legionella bacteria** Irrespective of whether a mixing device is installed, the storage water heater control thermostat shall be capable of being set at a temperature of not less than 60°C to prevent the growth of Legionella bacteria.
6.14.4	The water temperatures within flow and return circulating systems shall be maintained at not less than 60°C. COMMENT: Alternative methods of controlling Legionella within hot water circulating or warm water systems may include chlorine disinfection, UV sterilisation, high temperature pasteurisation combined with system flushing as part of a documented maintenance programme.

Table 36: NZBC Acceptable Solution G12/AS1 – water temperature and control

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

11.4 House and cylinder age

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

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

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

If the exact year of house construction has not been determined, for the purposes of comparison the mid-year of the decade has been used. This can lead, in a small number of cases, to cylinders appearing to be older than the house. For example, if the house was believed to have been built in the early 1970s, the decade of construction would be recorded as '1970-79' and the year of construction calculated as '1975'. If the cylinder year of construction was labelled '1970', this would make it apparently five years older than the house. The cylinder date would suggest that the house was actually built in 1969 or 1970, but to ensure valid comparisons, the cylinder has not been used to age the house. For the purposes of analysis, these cases are taken as the cylinder having the same decade of manufacture as the construction of the house.

The difference between the house and hot water cylinder age have been used to check for obvious errors, either in data recording or data entry.

For the purposes of allocating cylinder thermal performance, where present, the Standards 'mark' and associated standard (see Table 37) were used to categorise to the appropriate thermal performance grade, and provide an indication of the cylinder age.

Cylinder Grade	Standard	Title
D	NZS 720: 1949	Thermal storage electric water heaters
C	NZS 720: 1975	Thermal storage electric water heaters with copper cylinders
B	NZS 4602:1976	Low pressure thermal storage electric water heaters with copper cylinders
A	NZS 4602:1988	Low pressure copper thermal storage electric water heaters

Table 37: Electric hot water cylinder standards

Table 38 provides descriptive statistics on the electric and gas hot water cylinders in the HEEP random house sample. There are 363 cylinders using electricity and 37 using gas. Note that these may be alone, or in combination with other heat sources such as a solid fuel burner wet-back or solar water heater. Over half of the gas cylinders were over 10 years-old at the time of inspection, while most electric cylinders were over 16 years-old. Cylinder sizes were similar for electricity and gas, with the median volume 140 litres for electricity and 150 litres for gas.

Cylinder	Electric Storage				Gas Storage			
	Min	Median	Mean	Max	Min	Median	Mean	Max
Year of Manufacture	1938	1986	1983	2004	1971	1994	1991	2002
Age (years)	0	16	19	64	1	10	10	30
Volume (litres)	14	140	156	315	34	150	150	300

Table 38: HEEP electric and gas cylinder descriptive statistics

11.5 Water temperatures

Previous research has found that New Zealand home hot water temperatures are higher than in other countries (Waller, Clarke & Langley 1993). To begin to understand the factors that determine hot water temperatures in New Zealand houses, the data collected by the HEEP study can be analysed.

11.5.1 System types

All houses in the sample have one or more hot water systems, although not all systems are fully operational. Table 39 lists the HEEP codes for the various types of hot water systems, and the number of houses reporting each type in the survey. The number of systems is greater than the number of houses, as some houses have more than one type of hot water system.

Hot Water System (survey response)	Systems Count
Electric Cylinder (incl. night rate)	313
Electric + Solar Cylinder	3
Electric + Solid Fuel (Wet-back) Cylinder	63
Electric + Solar + Wet-back	3
Solid Fuel Cylinder	2
Gas Cylinder	34
Instant Gas	20
Other	2

Table 39: HEEP hot water systems

Table 39 shows that the majority of the HEEP hot water systems (71% for the analysed sample) have only an electric storage water cylinder – an electric element located inside an insulated tank of water, with the temperature controlled by a thermostat. Sixteen percent of the systems are have an electric cylinder with some form of supplementary heating, either solar, wet-back or a combination. Eight percent of the water heating systems are gas storage systems, 5% are instantaneous gas and less than 1% are solid-fuel-only. There are a total of seven systems incorporating a solar water heater.

Electric D-grade	Electric B-grade	Electric A-grade	Gas Instant	Gas Storage

Figure 55: Examples of hot water cylinders

Figure 55 provides illustrations of the different types of hot water cylinders found in the HEEP sample. The 'worst' water cylinder lacked any insulation (i.e. bare copper).

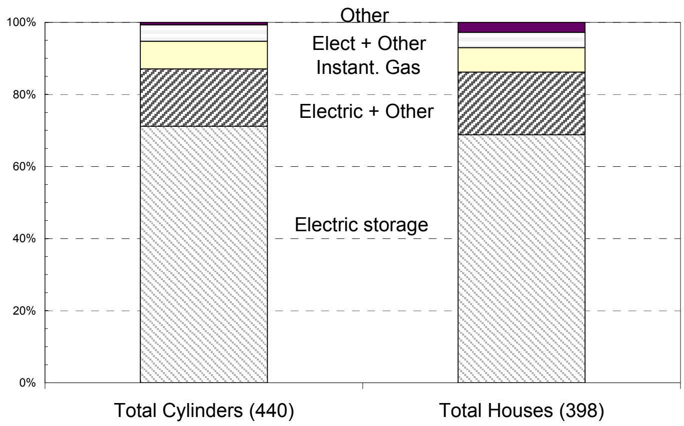


Figure 56: Hot water systems – by type and houses

Figure 56 gives the proportions of the different types of hot water systems for both the total number and the systems found in each house. The proportions are similar – the main difference relates to the houses with both electric and gas storage systems.

11.5.2 Hot water service

House occupants don't like to run out of hot water. As part of the HEEP survey, house occupants are asked: "Do you sometimes run out of hot water?" Eighteen percent of the households replied "Yes" to this question.

Table 40 summarises the responses categorised by the 'main' means of hot water heating. Note that where a house has had to be replaced in the sample (most often due to the occupants moving and the new occupants not wishing to continue as part of

HEEP) the replacement is also included in this table. It should also be noted that each house may have more than one method of heating hot water, using one or more different fuel types. Numbers may not add to 100% due to rounding.

Do you run out of hot water?	YES	NO	No Answer
Electric storage	19%	76%	4%
Electric + Other	19%	79%	3%
Gas storage	18%	82%	0%
Gas instantaneous	0%	95%	5%
Other	0%	100%	0%
Overall average	**18%**	**78%**	**4%**

Table 40: Hot water adequacy by fuel type for randomly selected houses

Table 40 shows that on average 18% of households report that they 'sometimes' run out of hot water – with almost the same proportions for natural gas and electric storage, but no shortage of hot water for other system types. Examination by cylinder size also found no significant difference in the adequacy of hot water provision for houses with 135 or 180 litre cylinders, whether fuelled by natural gas or electricity.

Do you run out of hot water?	Mains Pressure	Low Pressure	Total
Electric Cylinder	15%	21%	20%
Gas Cylinder	18%	18%	18%
Instant Gas	0%	NA	0%
Electric + Solid fuel Wet-back Cylinder	0%	20%	20%
Average	**12%**	**21%**	**19%**

Table 41: Hot water adequacy by system pressure

Table 41 provides a breakdown by water pressure and fuel type for those households that answered this question (i.e. excluding 'Don't Know'). There does not appear to be a significant difference between the different fuel types and pressures for storage hot water systems. Instant gas systems, all of which are mains pressure, reported no problems with running out of water.

Only 9% of households have the hot water cylinder located outside the conditioned house space. Over three-quarters of households (80%) have the hot water cylinder located in a cupboard inside the house. For these cylinders all waste heat (i.e. cylinder standing losses) will be contributing to the house winter space heating and in some cases a significant proportion.

Two-thirds (66%) of households used the space around the hot water cylinder for linen or clothes storage.

Only 30 households reported the use of a hot water cylinder wrap.

11.5.3 Cylinder sizes

Table 42 tabulates the number of hot water systems and the cylinder volume. As instantaneous gas water heaters do not store water, the cylinder size is reported as ‘missing’. The majority of hot water systems are electric (87%), so sizing distribution is dominated by electric systems.

Table 42 shows that most cylinders are either 135 litres (30 gallons) (42%) or 180 litres (40 gallons) (40%), with the remainder being split almost equally between the small cylinders located close to their end-use (e.g. under sink kitchen hot water) and larger cylinders. Six percent of the cylinders lack a ‘volume’ – in the main these are instantaneous systems, but in a few cases it was not possible to inspect the cylinder to determine the volume e.g. cylinder completely built into a cupboard.

There are almost equal numbers of 135 and 180 litre electric cylinders. The distribution pattern differs for the smaller number of gas storage cylinders with 35% at 135 litres and 24% at 180 litres, but 33% are instantaneous (i.e. no water storage).

		Cylinder Nominal Volume							
System	**Missing**	**25**	**50**	**75**	**135**	**185**	**250**	**350**	**Total**
Electric Storage Cylinder (only)	7	10	10	5	133	141	4	3	313
+ Solar + Solid Fuel Wet-back	-	-	-	-	-	-	2	1	3
+ Solar Water Heater	-	-	-	-	-	1	1	1	3
+ Solid Fuel Wet-back	1	1	-	-	31	22	8	-	63
+ Oil	-	-	-	-	-	-	1	-	1
Gas Storage Cylinder (only)	2	-	-	1	18	12	-	1	34
Instant Gas Heater (only)	18	1	-	-	-	1	-	-	20
Instant Gas + Solar	-	-	-	-	1	-	-	-	1
Solid Fuel Storage Cylinder (only)	-	-	-	-	-	1	1	-	2
TOTAL	28	12	10	6	183	178	17	6	440

Table 42: Hot water systems by fuel source and cylinder volume

Cylinder size (volume) distribution varies by location. Close to half of the cylinders (49%) in the sample are in the top of the North Island, under one-third (31%) in the bottom of the North Island and the remaining one fifth (20%) in the South Island.

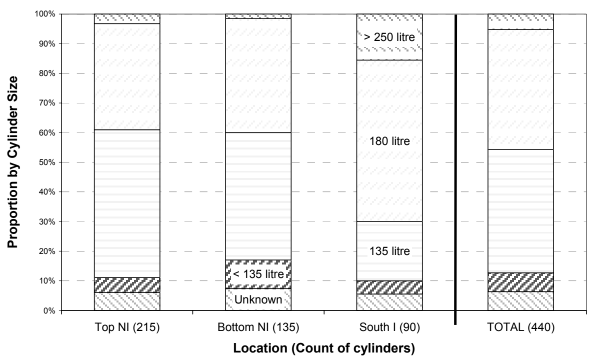


Figure 57: Cylinder size by region

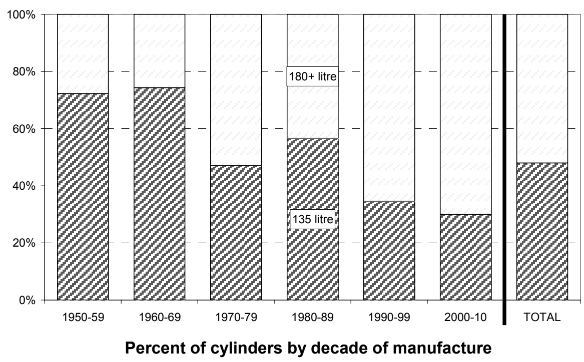


Figure 58: Cylinder size by age

Figure 57 shows that the upper North Island sample (Northland, Auckland, Hamilton, Tauranga etc.) 53% of the cylinders are 135 litres and 41% are 180 litres or greater. In the lower North Island sample (Taupo, Rotorua, Gisborne, Napier, Wanganui, Wellington, etc.) 46% are 135 litres while 44% are 180 litres or greater. In the South

Island (Blenheim, Tasman, Christchurch, Oamaru, Dunedin and Invercargill) the reverse is the case, with 21% of the cylinders at 135 litres and 74% at 180 litres or greater.

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

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

Jaye et al (2001) reporting on a telephone survey of 111 craftsmen plumbers from throughout New Zealand found that respondents believed that "older homes were likely to have smaller hot water cylinders set at higher temperature to compensate for small capacity". Figure 58 examines the age distribution proportion for the 135 litre and large (greater than or equal to 180 litre) cylinders in the sample. The time period starts with the decade of the 1950s, as the sample size in the earlier decades is too small to permit a reasonable comparison. For the period from 1990, 60% of the cylinders in the sample are 180 litres or greater.

11.5.4 Water pressure

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

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

- **cylinder age** – electric cylinders older than 30 years are 'low pressure'
- **cylinder photo** – cylinders marked 'low pressure' or '7.6 m head' are 'low', while cylinders marked 'mains pressure' are 'mains'
- **cylinder insulation grade** – D and C grade electric cylinders are 'low' pressure
- **system type** – instantaneous gas are 'mains' pressure

- **house exterior photograph(s)** – a roof vent pipe indicates the system is 'low', although the reliability of this methods is not considered to be high and is used as an allocation in the 'last resort'.

After these manual allocation methods were applied, the system pressure could not be categorised for only 29 systems (7% of the sample).

Of the houses for which pressure data is available, under three-quarters (72%) are low pressure and just over one-fifth (21%) are 'mains' pressure.

Fuel and System	Low Pressure	Mains Pressure	Unknown	TOTAL
Electric Storage	303	57	23	383
Gas Storage	11	17	6	34
Gas Instantaneous	-	20	-	20
Other	3	-	-	3
TOTAL	317	94	29	440

Table 43: System pressure by fuel type

Table 43 provides the counts for the different system types by pressure. The majority of electric storage systems are low pressure (79%), while the opposite is true for gas storage systems (32%). Figure 59 analyses the hot water system pressure by region and overall. The number of cylinders in each region is given in brackets.

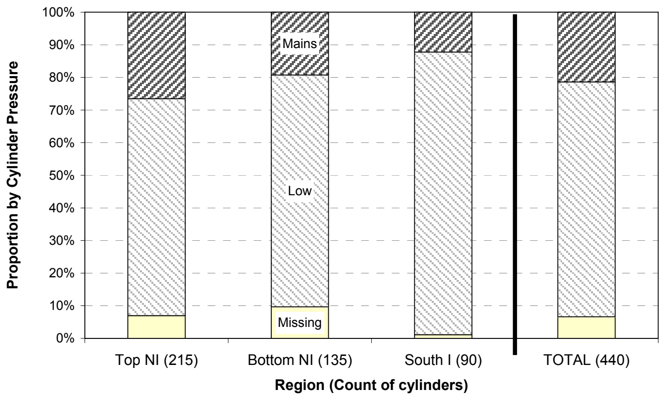


Figure 59: System pressure by region

Figure 59 suggests a regional pattern for the use of mains pressure systems – the further south, the greater the proportion of low-pressure cylinders. The increase is from 72% in the top of the North Island, to 79% in the lower North Island to 88% in the South Island (calculated only for cylinders for which pressure information is available).

This distribution also relates to the availability of natural gas, as mains pressure systems are more often gas fuelled (see Table 43).

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

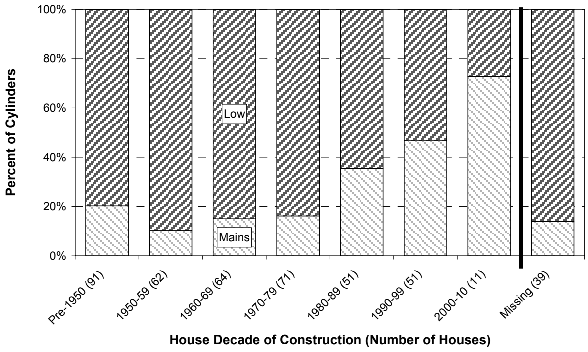


Figure 60: Pressure by house decades

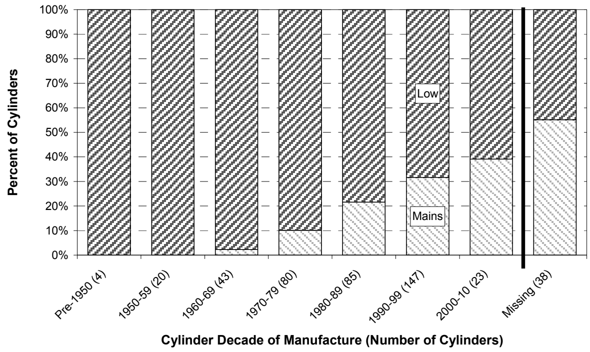


Figure 61: Pressure by cylinder decades

Figure 60 shows the distribution of hot water pressure by house decade of construction, and Figure 61 by cylinder decade of manufacture. There are no cylinders manufactured before 1930 in the sample and very few in the following two decades, so both figures start from the 1950-59 decade.

Figure 61 shows that mains pressure cylinders date from the 1960-69 decade, while Figure 60 suggests that while there has been steady increase in the market penetration of mains pressure systems, a number of older houses have been retrofitted from low-pressure to mains pressure systems.

11.5.5 Hot water cylinder age

Houses have a longer life than hot water cylinders, and it is expected that as hot water cylinders fail they will be replaced, often with the same size although not necessarily with the same pressure. Figure 60 illustrates that even very old houses (which originally would have had low-pressure systems) are being retrofitted with mains pressure hot water systems. For those houses and cylinders for which date information is available, about one-quarter (28%) of the houses (but two-thirds (63%) of the hot water cylinders) were built or manufactured since 1980. The oldest cylinder in the sample dates from the 1930s. The data does not show any obvious link between the size of cylinders in the HEEP houses and their lifetime.

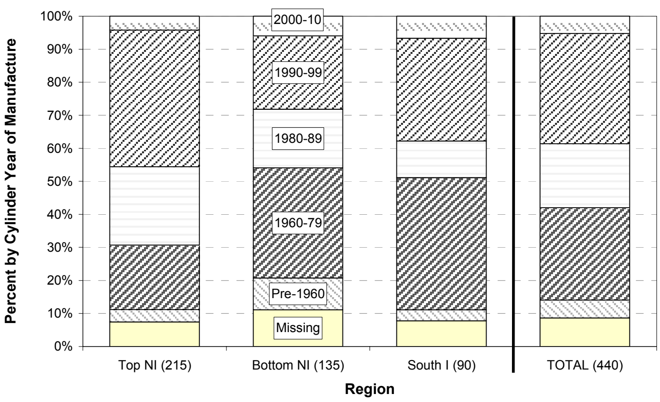


Figure 62: System age by location

Figure 62 shows the distribution of cylinders by year of construction and regional location. The grouping of construction years is based on the approximate years when a significant change in cylinder thermal performance occurred (see Table 37). Most pre-1980 cylinders are 'C' or 'D' grade, and many 1980s and later cylinders are 'B' grade. 'A' grade cylinders have only been required since 2003.

Six percent of the cylinders for which both cylinder and house age are available were manufactured before 1960; 31% were manufactured in the period from 1965 to 1980; 58% from 1980 to 1999, and the remaining 6% after 2000. Figure 62 shows a regional trend, with a higher proportion of younger cylinders in the top of the North Island (75% manufactured after 1980) compared to those in the South Island (53%)

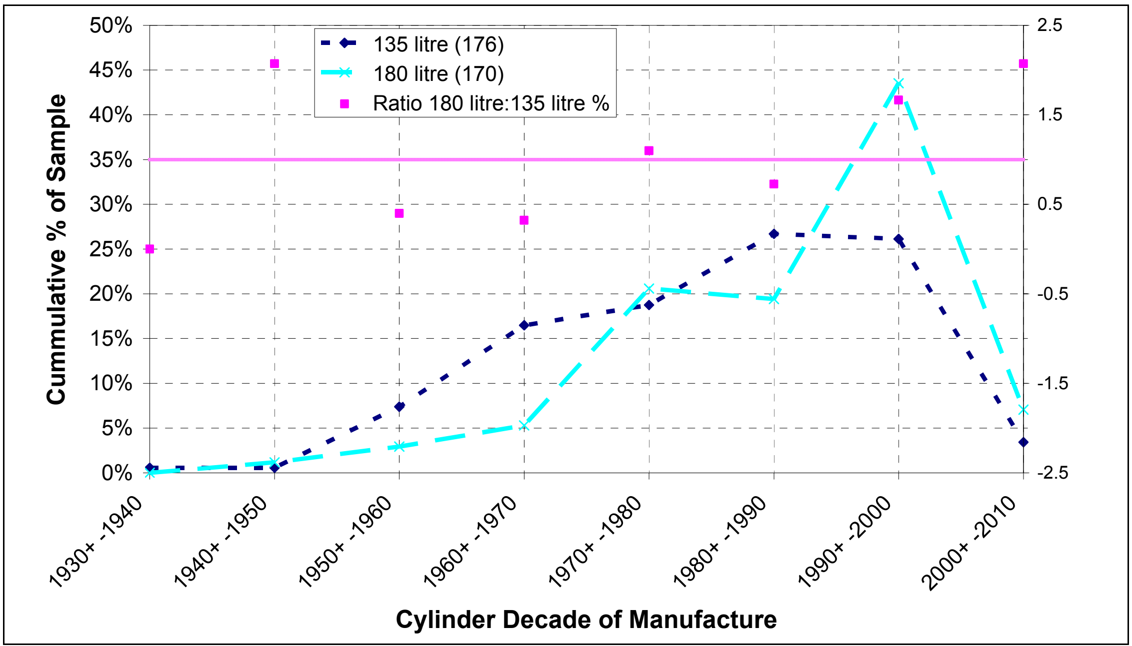


Figure 63: 135 and 180 litre cylinders by decade of manufacture

Figure 63 illustrates the age distribution by decade of manufacture for 135 and 180 litre cylinders. The curves fall off at the right hand end of the graph, as the last decade is actually only the four years until 2004 – the time of the last HEEP house installation – not the full 10 years for the other decades. From the 1940s through the 1980s, 135 litre cylinders were more popular than 180 litre cylinders but during the 1990s this popularity had shifted, and now it is the 180 litre cylinder than is being used in more homes. The ratio between the percent of 135 and the percent of 180 litre cylinders are also plotted (as a small square marker) for each decade. This goes above one (i.e. the proportion of 180 litre cylinders equals the proportion of 135 litre cylinders first in the 1970s, and from then more 180 litre cylinders are found).

Figure 64 provides an analysis of the age of the hot water cylinder (by decade) compared to the age of the house (by decade). Figure 64 includes the 370 cases where both the decade of house construction and cylinder manufacture are available:

- just under one half (46%) of the cylinders are the same decade as the house – suggesting they were installed when the house was built
- 9% of the cylinders are only one decade younger than the house – suggesting little replacement in the first decade of life
- the remaining 45% of cylinders are two or more decades older – suggesting this is when most failures and replacements occur.

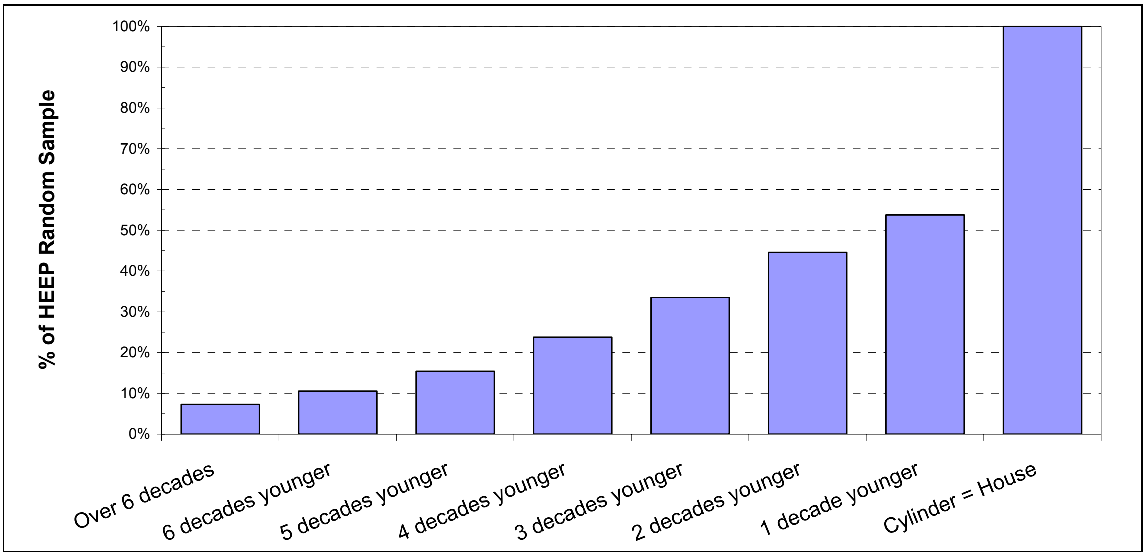


Figure 64: Cylinder manufacture compared to house construction decade

House Year	Years Ago	% of Total	Cylinder Same Decade as House	Cylinder Replaced
1890-1909	96-115	5%	0%	100%
1910-1929	76-95	7%	0%	100%
1930-1949	56-75	9%	6%	94%
1950-1969	36-55	31%	27%	73%
1970-1989	16-35	32%	56%	44%
1990-2004	15-0	16%	83%	17%

Table 44: House and cylinder age comparison

On average, 46% of hot water cylinders are in the same decade as the house, but Table 44 shows this proportion varies with house age.

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

Cylinder	Type	Usual Working head	Life Expectancy
Copper	Low pressure	2 – 7.6 m	20 – 50 years
Copper	Low pressure	12.2 m	20 – 40 years
Glass Lined steel	Mains pressure	35 – 50 m	12 – 20 years
Stainless Steel	Mains pressure	35 – 50 m	20 – 40 years (estimate)

Table 45: Life expectancies of cylinder types

Table 45 sets out life expectancies for different cylinder types from Williamson & Clark (2001)[14]. The potentially long lifetime of older copper cylinder, low-pressure systems is supported by the results shown in the previous figures for the HEEP houses. Note that the cylinder life expectancy is affected by a range of issues specific to the house and area, notably the water quality.

[14] Note: Table uses data originally provided by BRANZ, but is quoted from Williamson & Clark 2001.

11.5.6 Cylinders and house size

The physical attributes of a house (e.g. floor area, number and size of hot water cylinders) are far less flexible than the number of people that can be living in the house. Figure 65 and Figure 66 include 'instantaneous' hot water systems – these are shown as having 'zero' volume. In many cases the cylinder volume, the floor area and the number of occupants will be the same, so both figures use random 'jitter' in order not to overlay all the points.

Figure 65 compares the floor area of the monitored houses with the total volume of hot water cylinders – in houses with more than one cylinder this is the calculated total volume of all cylinders. Figure 65 suggests that designers and builders in some cases have placed some value on providing larger hot water volumes for larger houses.

Figure 66 compares the total volume of hot water storage to the number of occupants, and again there is no clear link. This would suggest that the provision of hot water designed into the house is not matching the likely number of occupants over the lifetime of the house.

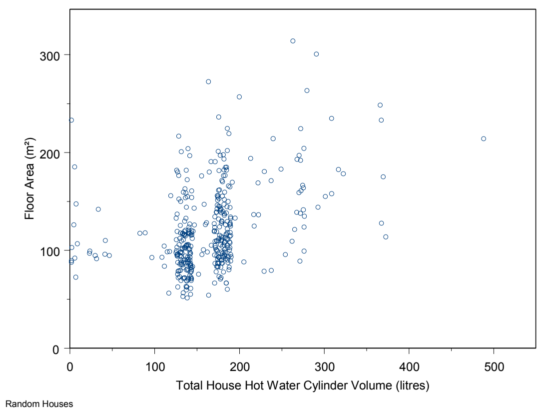


Figure 65: Total hot water volume vs floor area

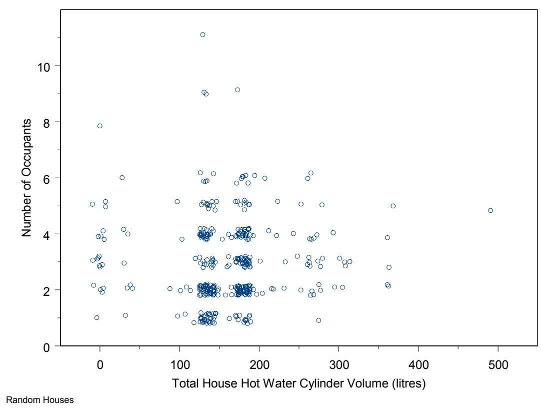


Figure 66: Total hot water volume vs number of occupants

11.5.7 Delivery capabilities

The BRANZ Ltd *House Condition Survey* conducted in 1999 compared the size of the electric hot water cylinder to the potential household occupants (Clark et al, 2000). They calculated the potential number of people in a house as being the number of bedrooms plus one. The requirements per person were assessed at around 45 litres per day, which is a conservative average daily figure taking no account of particular occupant circumstance which could result in a much higher short-term hot water demand e.g. everyone wanting to shower at the same time. The analysis only considered surveyed houses with a single hot water cylinder and it was found that just over half of those houses had adequate electric hot water storage.

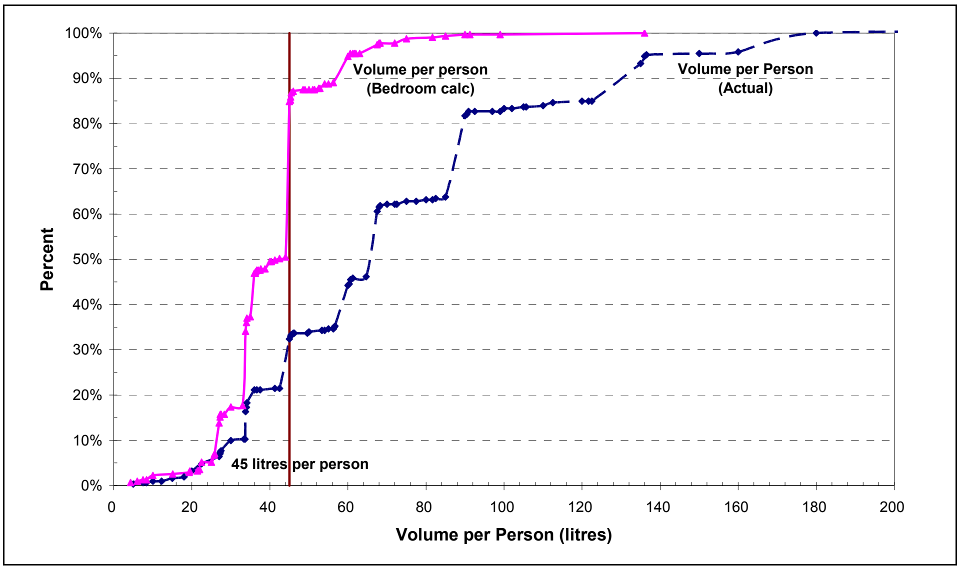


Figure 67: Single electric DHW systems – litres per person

The same analysis has been carried out for the 311 HEEP houses with one electric hot water cylinder. Figure 67 plots two cumulative-percent curves for the HEEP houses:

1. the left curve (solid line) uses the same calculation method as used in the House Conditions Survey (Volume/(Number of bedrooms + 1)); while
2. the right curve (dashed line) is based on the actual number of people in the house (Volume/Number of Occupants).

The curves show obvious 'steps' that relate to the steps in the sizes of hot water cylinders available on the market, and the discrete number of house occupants.

The calculated approach gives a similar result to that found in the 1999 house condition survey – just over half the HEEP houses with one electric cylinder have adequate storage volume (i.e. 45 litres or greater). When the calculation is carried out using the actual number of occupants at the time of the HEEP survey, only 21% of houses with only one electric cylinder have less than 45 litres per person of electric hot water cylinder storage.

There a number of possible reasons for this difference:

- where occupants have a choice, they will limit their demand (i.e. number of occupants) to match the ability of the hot water system to provide the required hot water supply
- where occupants have no choices, they may increase the hot water storage temperatures to ensure the supply matches their demand
- occupants may change their life stage faster than they change their house, and hence hot water system e.g. the parents of family that once had young children may age in place, and not shift houses

11.5.8 Water temperatures by cylinder size

As part of the HEEP monitoring equipment installation, the hot water tap temperature is measured at the tap closest to the hot water cylinder. The hot water is allowed to run until the temperature is considered to be stable, and then it is then read using a digital thermometer. Either a Dick Smith Electronics 'Digital Pocket Thermometer' or 'Digital Stem Thermometer' is used. These have resolutions of 0.1°C and a claimed accuracy of ± 1°C. Calibration testing has been undertaken, and correction curves prepared. The reported water temperatures have now been corrected for publication.

	Min	Median	Mean	Max
135 litre	36°C	64°C	64°C	88°C
180 litre	22°C	60°C	61°C	99°C

Table 46: HEEP 135 and 180 litre cylinder statistics

Table 46 provides descriptive statistics for all fuel type 135 and 180 litre cylinders based on the measured temperature at the tap nearest to the cylinder.

Figure 68 shows the temperature distribution for electric 135 and 180 litre cylinders, both as 'bell' curves. The numbers of each cylinder size are given in brackets. The two cylinder sizes have statistically different temperature distributions (t=2.93, p-value 0.0036), with the mean temperature at 64°C for the 135 litre cylinders and 61°C for the 180 litre cylinders. Extremely high water temperatures were usually found to be due to a faulty thermostat

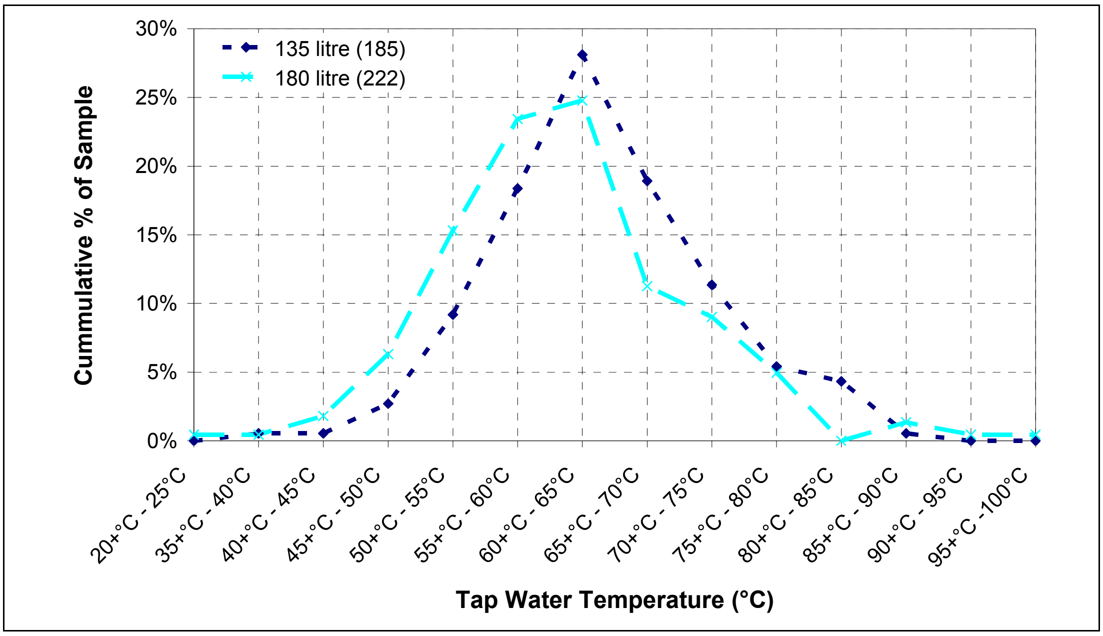


Figure 68: Distribution of hot water tap temperature by electric cylinder volume

It should be noted that this does not mean larger cylinders always have safe hot water temperatures, as is shown by the maximum tap temperatures in Table 46. Tap temperatures above 65°C are found in 41% of the 135 litre cylinders and 27% of the 180 litre cylinders. Thus about one in four of the 180 litre cylinders have even more dangerously high water temperatures, compared with more than two out of every five of the 135 litre cylinders.

The HEEP temperature measurement is taken at a tap as close as possible to the hot water cylinder. In many cases this will be in either the laundry or kitchen. Since 1993 it has been a requirement under the New Zealand Building Code Clause G12 for a mechanism to limit tap temperature to be installed (e.g. a 'tempering valve') on the supply to any 'sanitary fixture used for personal hygiene' (see Table 36). It is possible that some tempering valve installations permit water to be delivered at cylinder temperature to the laundry or the kitchen sink, as these are not considered to be 'sanitary fixtures'. The presence, or absence, of a tempering valve was recorded for 462 out of the 530 hot water systems. Of these, 16% of these had a tempering valve fitted.

The HEEP installation also measures the hot water temperature at the shower. A comparison of the 'tap' and 'shower' hot water temperatures for the 70 houses which had a tempering valves, and in which both shower and tap temperatures were available, found 10 houses (14% of the sample) where the tap nearest the hot water cylinder (often over the laundry sink) could be by-passing the tempering valve. In 17 cases (24%) there was a tempering valve present, and the temperature delivered at the tap nearest to the cylinder was greater than 60°C.

For the cylinders 'lacking' a tempering valve (i.e. none was found in inspection of the hot water cupboard), in 37% of the cases the nearest tap was more than 5°C hotter than the shower – with the majority of these ranging from 5°C to 25°C hotter. For two-thirds (66%) of these cylinders, tap water temperature was over 60°C. This suggests that in at least some cases there was an over-temperature control within the shower mixer.

Just under one-third (32%) of the measured shower hot water temperatures were above 60°C, one in 12 (8%) were over 70°C, and 1% were over 80°C.

11.5.9 Electric thermostats

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

- **rod type**: usually concealed within the element box, it is not easily accessible to the householder. It is usually set during installation by the electrician, and requires the removal of the cover plate and the use of a screwdriver to change the setting. "Rod type thermostats appear in many older cylinders and are not noted for their accuracy" (Williamson & Clark 2001). It is possible to replace rod type thermostats with capillary type thermostats.
- **capillary:** consumer-adjustable thermostats are generally based on a capillary type thermostat that "are generally regarded as more accurate and more reliable than rod type thermostats" (Williamson & Clark 2001). The control knob is usually on the outside of the element box, and hence readily accessible to the user. This style of thermostat is covered by New Zealand Standard **NZS 6214:1988:** "Thermostats and thermal cut outs for domestic thermal storage electric water heaters (alternating current only)".

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

As the common rod type, immersion thermostats are not marked with the date of manufacture, so it is difficult to examine their reliability over time.

New Zealand completed conversion to the SI (metric) system in 1976 (McLauchlan, 1989), when temperatures stopped being monitored in units of Fahrenheit (°F) and shifted to Celsius (°C). Although stock currently on the shelf continued to be sold, a reasonable assumption is that if a thermostat is marked in Fahrenheit it is of at least this age.

Thermostat settings are recorded in the units given on the thermostat, and then converted to Celsius during processing. A flag was set during the data entry to record if the thermostat was marked in Fahrenheit or Celsius. For 30 of the thermostats the units of temperature marks were not recorded, giving 427 for which the temperature units were recorded. Seventy thermostats had markings in Fahrenheit (16% of the cylinders for which this was recorded).

Glass-lined, mains pressure cylinders are designed only to operate to a maximum temperature of 70°C to 82°C depending on the vitreous-enamel lining (Southcorp, 2001). All valve-vented cylinders are required to be fitted with an over-temperature cut-out as a safety device should the primary thermostat fail.

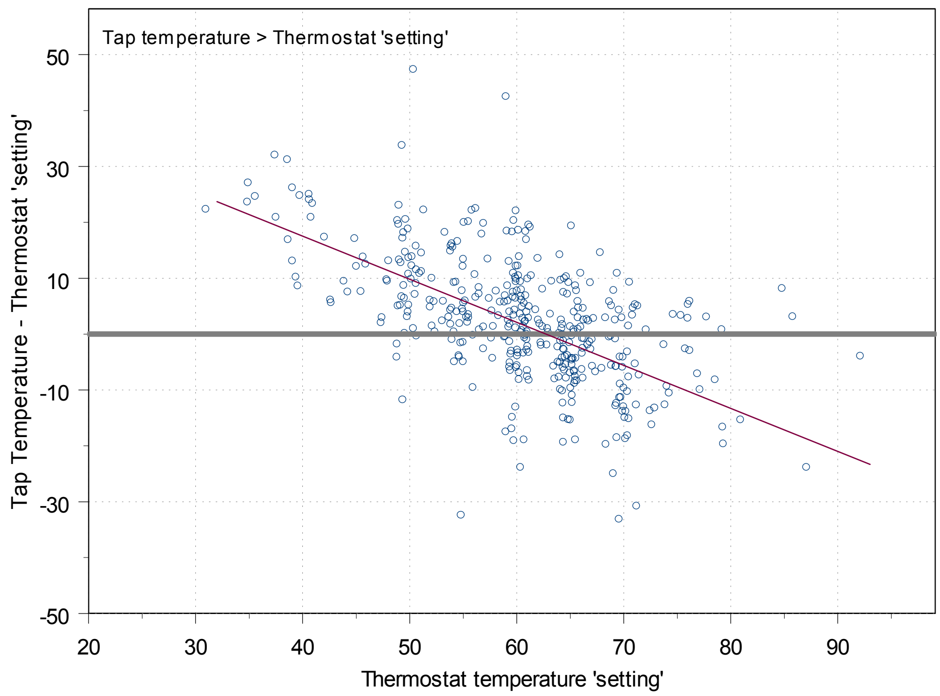


Figure 69: Variation between thermostat setting and delivered water temperature

Figure 69 plots the thermostat set temperature (x-axis) and the difference between the thermostat set temperature and the actual delivered temperature at the tap nearest to the hot water cylinder (y-axis), for the 398 electric cylinders for which both tap and thermostat setting temperatures were available.

If thermostat settings were perfectly matched to the tap temperatures, the points would all fall on the zero horizontal line (i.e. Tap Temperature = Thermostat Temperature), but this is clearly not the case. Only in 9% of the cases is the tap temperature within ±1°C of the thermostat temperature, 36% are within ±5°C and 66% are within ±10°C.

One-quarter (25%) of the thermostats read more than 5°C hotter than the water at the tap (tap cooler than thermostat), but over one-third (39%) of the thermostats read 5°C cooler than the tap (tap hotter than thermostat). In 22% of the cylinders the tap was more than 10°C hotter than the thermostat reading, but only in 7% of the cylinders was the tap was more than 20°C warmer and in 2% the tap was less than 20°C cooler than the thermostat.

A linear regression found a reasonable relationship (r^2 = 34%) centred around 61°C, but there is a wide spread of temperature differences.

The distribution of the temperature differences in Figure 69 is close to a normal distribution (skewness = 0.17), and with a sample standard deviation of 11.2°C. This is somewhat higher than would be desirable, and reflects the inability of rod type thermostats to provide good temperature control.

When the thermostats are separated into temperature markings, they have different intercepts – 64°C (r^2 = 44%) for those marked in °F and 61°C (r^2 = 32%) in °C. A t-test suggests these are two different distributions (t=4.33, p-value 0). This would suggest that older rod type thermostats deliver hotter water than the newer versions.

11.5.10 How hot?

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

The only part of the hot water system that most householders can readily alter is the thermostat (even if not a consumer-adjustable design). The amount of energy stored in the hot water cylinder is directly related to the cylinder volume and water temperature.

For example, the total energy stored in 135 litres of water at 75°C (42 GJ) is almost exactly the same as the energy stored in 180 litres of water at 55°C (41 GJ)[15]. The useful 'hot' water is that above body temperature (37°C), and this changes the

[15] The Specific Heat of water at 40°C (the energy to raise one litre by 1°C) is 4.1786 $MJ.l^{-1}.°C^{-1}$.

relationship. The 135 litre cylinder at 75°C actually holds nearly 60% more useful hot water than the 180 litre cylinder at 55°C (22 GJ compared to 124 GJ). The 135 litre cylinder at a dangerously hot 75°C is equivalent to cylinder twice as large (270 litre) at a safe water temperature of 55°C.

One consequence of the unsafe, higher water temperatures is an increased chance of skin burns.[16]

The drive for adequate warm water for showers has been shown in some circumstances to overcome safety considerations:

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

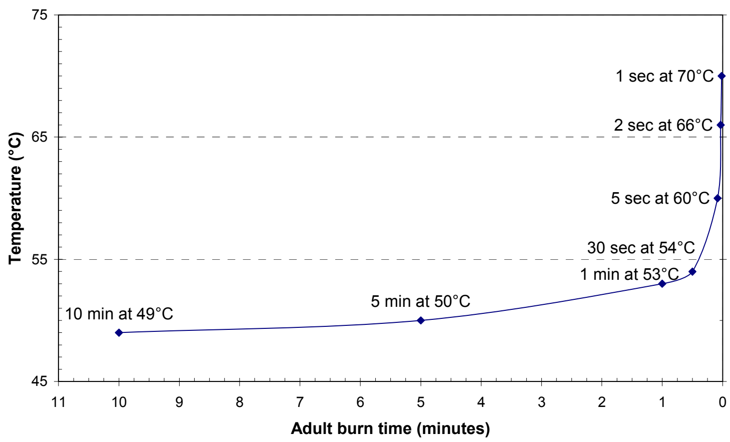


Figure 70: Adult skin (full thickness) epidermal burn time

Figure 70 gives the exposure time needed for hot water to cause full thickness epidermal burns of adult skin at various water temperatures (Katcher, 1981 adapted by Waller, Clarke & Langley, 1993). Hot water is more dangerous to the very young and the elderly, whose skin is less able to withstand higher temperatures. For a child placing their skin into water at 54°C only 10 seconds is required for a full-depth burn, compared with 30 seconds for an adult (Jaye et al, 1999).

Turning down the thermostat may result in short-term benefits (both safety and energy efficiency), but unless the system provides adequate hot water to meet the needs of the house occupants, the thermostat can readily be 'turned up'. Such campaigns also do not consider the poor performance of most electric hot water cylinder thermostats, and this may be even more critical to reducing the opportunity for hot water burns. It also needs to be recognised that only the use of tempering valves can ensure that unsafe temperatures are not possible (see Section 11.3).

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

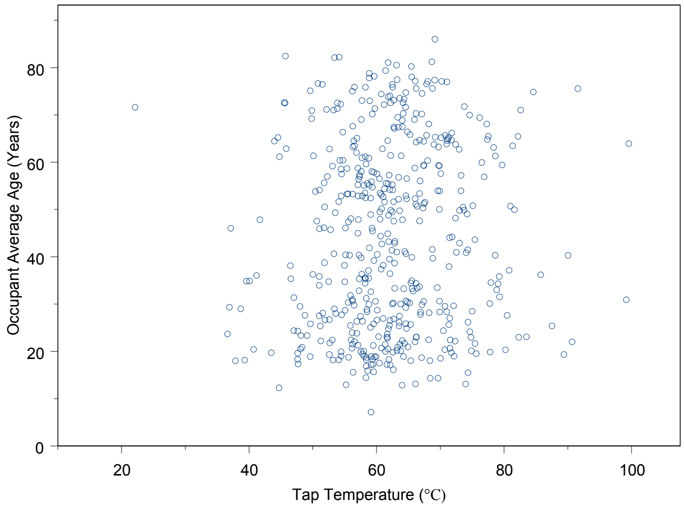


Figure 71 compares the nearest tap hot water temperature with the average age of the house occupants. There is no significant relationship.

No link was found with the age of the youngest or the oldest person and hot water temperature, suggesting that age is no barrier to the provision of dangerously hot water.

Figure 71: Hot water temperature vs occupant average age

Figure 72 gives the thermostat setting distribution, and Figure 73 the tap temperature distribution for the randomly selected HEEP houses. As gas hot water systems tend not to have the thermostat marked in a temperature, the 452 cylinders in Figure 72 include only 6% that are not electric. The 489 cylinders in Figure 73 include all hot water systems for which a tap temperature has been measured.

The median for the thermostat setting is 60°C and for the tap temperature it is 62°C. However, the thermostat distribution has a skew of -0.2 (i.e. is asymmetric towards lower thermostat settings), and the tap temperature distribution skew is +0.2 (i.e. asymmetric towards the higher delivered water temperatures).

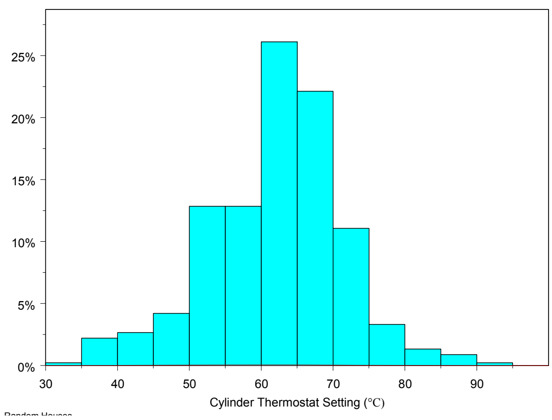


Figure 72: Thermostat setting distribution

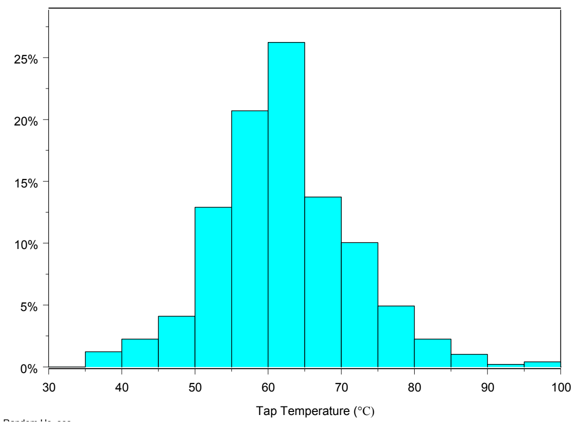


Figure 73: Tap temperature distribution

Figure 74 shows the thermostat settings and resulting nearest tap water temperatures for 398 electric hot water cylinders in the randomly selected HEEP houses, and this is also summarised in Table 47. The temperature and thermostat data is recorded at the time of installation of the HEEP monitoring equipment. The installation involves a detailed inspection of the hot water cylinder and its surroundings, and the measurement of water temperatures at the tap nearest to the cylinder after the water had run long enough to ensure maximum temperature had been reached. In a small number of houses, the cylinder had recently had such a large draw-off that the water temperature was obviously incorrectly low. Each point in Figure 74 represents one cylinder, with solid markers showing a tempering valve is present. Note that there are 46% more cylinders reported here than in the HEEP Year 7 report (Isaacs et al, 2003).

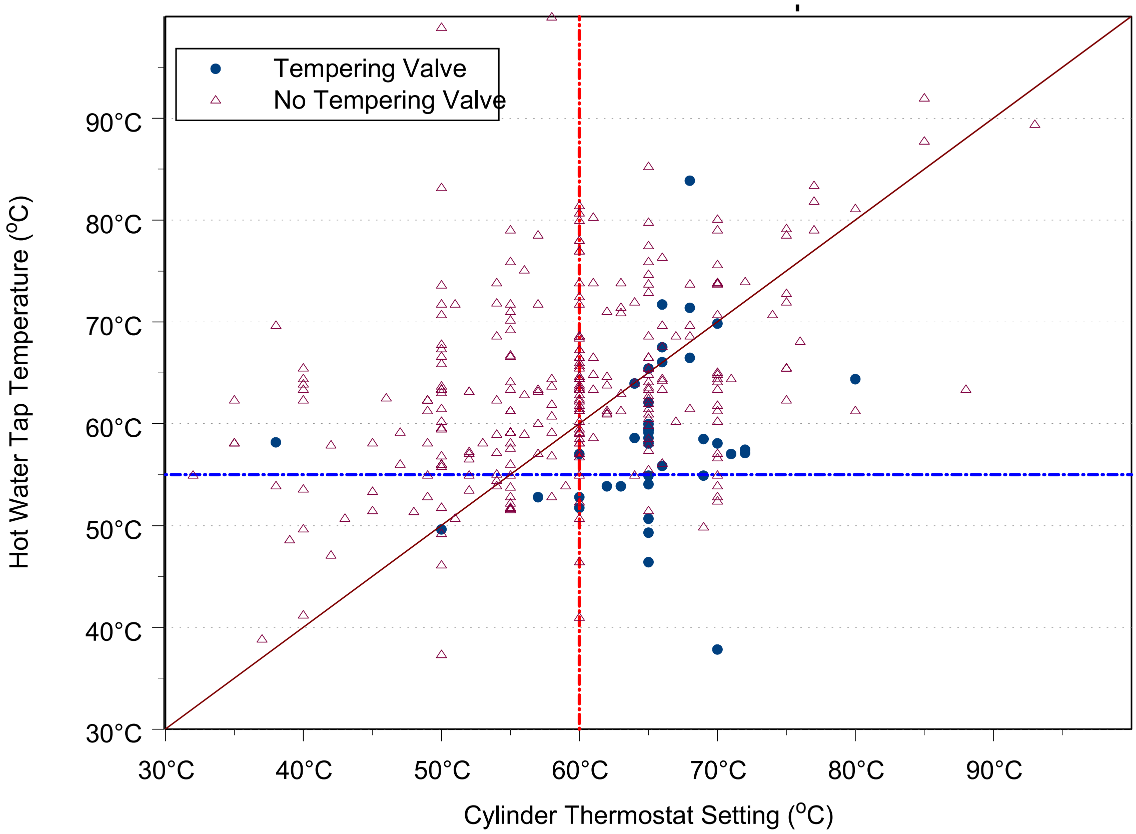


Figure 74: Thermostat setting vs tap hot water temperature

Tap >60°C & Thermostat <=60°C 17%	**Tap >60°C & Thermostat >60°C** 43%
Tap <=60°C & Thermostat <=60°C 18%	**Tap <=60°C & Thermostat >60°C** 21%

Table 47: Count of thermostat setting vs tap hot water temperature

Table 47 reports that 60% of the hot water cylinders deliver water at temperatures over 60°C (i.e. dangerously hot). As illustrated in Figure 69, the thermostat setting can bear little resemblance to the measured actual water temperature, so the recorded settings given in Figure 74 and Table 47 only provide an indication of the house occupants' expectations.

Table 36 (Section 11.3) set out the requirements of the New Zealand Building Code Clause G12 'Water Supplies', which in brief require the use of a tempering valve to permit hot water storage to be above 60°C and water delivery to be below 55°C.

The vertical (thermostat > 60°C) and horizontal (delivered water <55°C) dotted lines on Figure 74 illustrate these two constraints for housing. The sloped line in Figure 74 illustrates the expected situation if a tempering valve was not present – the temperature of the delivered water would equal the thermostat setting (assuming perfect operation of the thermostat).

Figure 74 raises a number of health issues about the provision of hot water from domestic electric hot water cylinders:

- **60% of the cylinders delivered clearly UNSAFE water temperatures:** 60% of the measured tap temperatures were above 60°C, although if the systems with tempering valves are excluded this was 66% of those cylinders. Eighty-one percent of all the hot tap temperatures are above the NZBC maximum of 55°C, and this includes the 35% with delivered water temperatures over 65°C. In some cases, shower controls incorporated a temperature limiting device, but even so 32% of the 'hot' shower temperatures were above 60°C.
- **One-third of the cylinders had INACCURATE thermostat control:** Only two thirds (66%) of the delivered water temperatures are within ± 10°C of the thermostat setting. However, about one in five (22%) of the delivered water temperatures are more than 10°C higher than the thermostat setting – in other words even if people set the thermostat to what they believe to be a 'safe temperature', in one fifth of cases the tap temperature may be too hot.
- **OLD THERMOSTATS are less accurate than newer ones** – 60% of thermostats marked in Fahrenheit (i.e. most likely made prior to 1975) deliver water more than 5°C warmer than the setting, compared to 35% of the thermostats marked in Celsius. The rod type thermostats are long lived, with 16% of the sample marked in Fahrenheit – suggesting a minimum life of longer than 25 years.
- **One-half of the thermostats set at a SAFE TEMPERATURE delivered UNSAFE hot water:** 35% of the cylinders had the thermostat set at 60°C or under, but about one-half of these houses had water over 60°C being delivered at the tap (i.e. 17% of all the cylinders in the sample). Thus, even if the occupants attempted to ensure safe temperature water was delivered through correct setting of the thermostat, the thermostat was not providing it.
- **One out of seven houses with a TEMPERING VALVE delivered hot water over 60°C**: only 16% of the cylinders (for which thermostat and water temperature data was available) had tempering valves to ensure water would be delivered at a 'safe' temperature. Of these systems, 33% were delivering water at less than 55°C, 43% between 55°C and 60°C, and 24% at a temperature above 60°C – although the maximum measured hot water delivery temperature for a cylinder with a tempering valve was only 84°C, compared to the maximum of 100°C for one electric storage system without one.

These results help to identify potentially important hot water health and safety issues in New Zealand homes. The HEEP data could be used to develop a range of tools to assist in the development of hot water safety programmes.

12. HOT WATER STANDING LOSS METHOD UPDATE

These are the final results of standing loss estimates for hot water cylinders. The methodology is identical to the HEEP Year 7 and 8 reports. The only changes are the addition of standing losses for wet-back hot water systems

12.1 Standing losses

For those systems where a period of house vacancy could be identified, the standing losses during those periods were used. Where a vacancy period could not be found the standing losses based on the profile were used, provided that more than 10 recharge events per day on average occurred, which was a criterion established by comparison with the vacancy period estimates. Standing losses could be estimated for 262 of the hot water cylinders for which volume and grade data were also available. For wet-back hot water systems, where possible, standing losses were also estimated.

Grade	Volume (Litres)	Standing Loss (kWh/day)	SD	No.
A or B	135	2.1	0.1	51
C or D	135	2.8	0.2	56
Wrapped	135	1.8	0.1	9
A or B	180	2.2	0.1	76
C or D	180	2.7	0.2	28
Wrapped	180	2.1	0.3	10
A or B	270	3.0	0.4	8
Gas	135	4.1	0.3	15
Gas	180	4.2	0.4	9

Table 48: Standing losses of hot water cylinders

As there are only small numbers of A and C grade cylinders, and their theoretical standing losses are very close to those of B (for A) and D (for C) grade cylinders, Table 48 groups the grades into 'A or B', and 'C or D' grades, with a 'Wrapped' group for those with cylinder wraps. No grading data is available for the gas cylinders.

Table 48 shows 'A or B' grade cylinders have lower standing losses than the 'C or D' group. This is highly statistically significant for both the 135 and 180 litre cylinders.

There are only a small number of 'wrapped' cylinders. However, the nine 135 litre wrapped cylinders have an average standing loss of 1.8 kWh per day, lower even than the 'A or B' grade cylinders. The wrapped 180 litre cylinders have on average a standing loss of 2.1 kWh/day. Cylinder wraps clearly do work.

Standing losses for electric systems are about 33% of the total energy use, on average. Total energy use for gas systems is about double that of electric systems.

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

Table 49 and Figure 75 provide revised estimates for total energy consumption and standing losses for four cylinder types: electric storage, electric night rate storage, natural gas storage and natural gas instant. This data could be calculated for 375 cylinders where total energy use ranges from 7.3 (electric night rate storage) to 15.4

kWh/day (natural gas storage). Average standing losses range from 27% (natural gas storage) to 43% (electric night rate storage) of the total energy use.

Appliance	Total energy kWh/day	SD	Count	Standing Loss kWh/day	SD	Standing Loss % of Total Energy
Electric Storage	7.3	0.2	318	2.4	0.1	33%
Gas Storage	15.4	1.1	27	4.2	0.2	27%
Gas Instant	12.2	1.4	15	0.0	0.0	0%
Electric Night Store	6.3	0.6	15	2.7	0.3	43%

Table 49: Total energy consumption and standing losses by system type

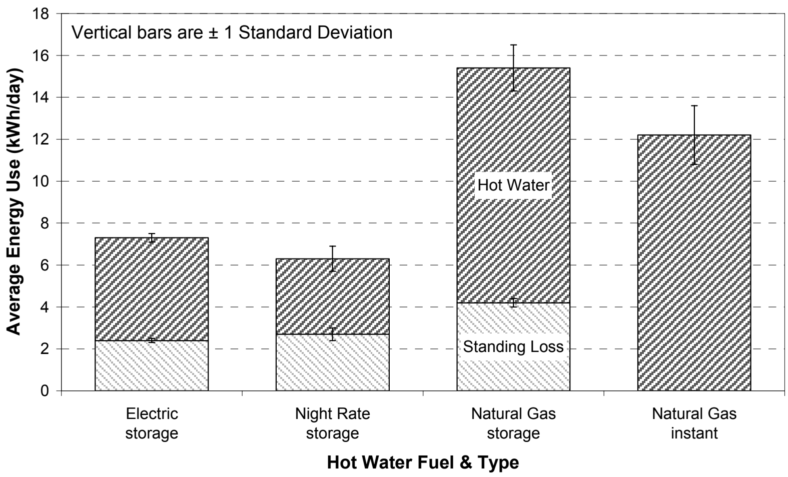


Figure 75: Energy consumption and standing losses by system type

12.2 Potential savings for installing cylinder wraps

The wrapped cylinders from HEEP have standing losses of 1.0 kWh/day less than the unwrapped cylinders for 135 litre systems, and 0.6 kWh per day less for the 180 litre cylinders. If these are typical of the energy savings for wrapping cylinders, then the ongoing savings from installing wraps on the approximately 240,000 unwrapped 135 litre and 160,000 180 litre systems would be 122 GWh per year, with a retail electricity cost of about $20 million per year.

There are also additional potential savings for wrapping both larger and smaller cylinders (numbering about 50,000 cylinders), although HEEP estimates of the achieved savings from wraps are not available due to the insufficient number of monitored systems.

Cylinder wraps and pipe insulation could also give energy savings for A or B grade systems, although the savings would be smaller. Assuming a conservative 0.3 kWh/day saving, the potential ongoing savings for the approximately 600,000 A or B grade systems would be 66 GWh per year, with a retail electricity cost of about $10 million per year.

13. FUTURE

Now that HEEP data collection is completed, our focus is on reporting analysis and developing the HEERA model. The HEEP database is a robust, statistically sound sample of New Zealand houses which can now provide both a critical energy use database and a platform for modelling the energy performance of New Zealanders in their domestic dwellings.

There are also a number of other issues of the use of energy in houses that remain to be examined with the benefit of the HEEP data. Of particular importance is the impact of thermal insulation on household energy use. The 1971/72 household electricity study suggested that insulated houses used more energy than uninsulated houses. Now HEEP has full space heating energy use, this and other issues can be examined.

From its start, HEEP has received its main science funding from the Building Research levy and the New Zealand government's Government Foundation for Research, Science and Technology. The funding from these sources continues until the end of June 2008, and is built around three objectives.

Objective 1: '**Energy Use in Residential Buildings**' is now complete. It provided scientific support to the monitoring and data collection. It ensured that HEEP database of energy use, construction, air and water temperatures from 400 randomly selected houses from around New Zealand, was of suitable quality to meet the needs of later work.

Objective 2: '**Energy Demand Model**' has been underway for the past two years, and is due to be completed by the end of June 2006. It will enable energy efficiency opportunities to be quantified and economically evaluated by further developing the Annual Loss Factor (ALF) and Energy End-use Resource Assessment (EERA) into the integrated HEERA model.

Objective 3: '**Promotion of Residential Energy Efficiency**' commenced at the start of July 2005, and is focusing on ensuring that the new management efficiencies and policy opportunities enabled by the HEERA Energy Model and the HEEP database are taken up in the energy, health, housing, construction and welfare sectors.

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

14. REFERENCES

14.1 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 1.2 (page 2) at the current advertised price. The full reference for each report is given below:

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

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

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

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

Year 5: Stoecklein A., Pollard A., Camilleri M., Amitrano L., Isaacs N., Pool F. & 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 Ltd *Study Report 11*, Judgeford, Porirua.

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

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

Year 8: Isaacs, N., Amitrano, L., Camilleri, M., French, L., Pollard, A., Saville-Smith, K., Fraser, R. & 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*, Judgeford, Porirua.

14.2 HEEP *BUILD* articles

The BRANZ magazine *BUILD* has published results from HEEP on a regular basis. Articles published in the year to 30 June 2005 are:

Isaacs N.P. 2004. *Supply Requires Demand – where does all of New Zealand's energy go?* **BUILD** 85:76.

Isaacs, N.P. 2004. *From Kaitaia to Bluff – HEEP at work*. **BUILD** 83:82.

14.3 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 Ltd website. Hard copies can also be purchased online from the BRANZ Ltd Bookshop. The list provided here is current to 30 June 2005.

Isaacs N.P. 2005. **Nice and Cosy?** Presentation to New Zealand Institute of Environmental Health, National Conference. Wellington, 17 March 2005.

Isaacs N.P., Amitrano L., Camilleri M., French L., Pollard A. (BRANZ Ltd), Saville-Smith, K., Fraser R. (CRESA). 2004. **Energy, Wealth and Well-being – where is the link?** (Revised). *The 2005 Housing and Health Research Seminar – the challenges of home heating*. Wellington School of Medicine & Health Sciences, 9 February 2005.

Isaacs N.P, Amitrano L., Camilleri M., French L., Pollard A. (BRANZ Ltd), Saville-Smith K., Fraser R. (CRESA). 2004. **Energy, Wealth and Well-being – where is the link?** *Social Policy, Research and Evaluation Conference*. Wellington, 26 November 2004 (BRANZ Conference Paper 109).

Isaacs N.P. 2004. *Supply Requires Demand – where does all of New Zealand's energy go?* In ***People and Energy: how do we use it? Proc. of a conference organised by the Royal Society of NZ in Christchurch, 18 November 2004.*** Royal Society of NZ Misc. Series 66:3-16 (BRANZ Conference Paper 110).

Isaacs N.P. 2004. **Domestic and Neighbourhood Energy Usage.** Presentation to *New Zealand Energy Modelling Workshop #1*. Victoria University of Wellington, 20 Oct 2004. See: www.mcs.vuw.ac.nz/events/EMW [File: emw_1_2004_isaacs.pdf]

Isaacs, N.P. & Camilleri, M. 2004. **Temperatures in NZ Homes or the Tyranny of the (Below) Average.** Paper to the *10th UK Thermal Comfort Interest Group Meeting*. Oxford Brookes University, 14 September 2004.

Isaacs, N.P., Camilleri, M. & Pollard, A. 2004. *Household Energy Use in a Temperate Climate*. In **American Council for Energy Efficient Economy (ACEEE) 2004 Summer Study on Energy Efficiency in Buildings**, **23–28 August 2004**. Pacific Grove, California (Paper 313, Panel 1) pp1:141 – 1:153 (BRANZ Conference Paper 108).

Isaacs, N.P., Camilleri, M.T. & Pollard, A.R. 2004. *Housing, Health and Energy*. In Howden-Chapman, P. & Carroll, P. (eds.). **Housing & Health – Research Policy and Innovation.** Steele Roberts Ltd for He Kainga Oranga, Housing and Health Research Department of Public Health, Wellington School of Medicine and Health Sciences.

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Stoecklein, A., Pollard, A., Camilleri, M., Amitrano, L., Clark, S. & Isaacs, N.P. 2002. *Findings from the Household Energy End-use Project (HEEP).* In **Proc. International Symposium on Highly Efficient Use of Energy and Reduction of its Environmental Impact.** Osaka, 22-24 January 2002 (BRANZ Conference Paper 102).

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

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

Stoecklein, A., Pollard, A., Camilleri, M., Tries, J. & Isaacs, N.P. 2001. *The Household Energy End-use Project: Measurement Approach and Sample Application of the New Zealand Household Energy Model.* In **Proc. CIB World Building Congress.** Wellington, April 2001 (BRANZ Conference Paper 87).

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15. APPENDIX – CENSUS DHW QUESTIONS

Table 50 lists the various Censuses in which questions were asked about hot water supplies or heating, and Table 51 provides the actual question asked (Statistics 2001a). Note that the 1986 Census question did not permit respondents to differentiate the 'other' fuel type.

Dwelling Form Question	1945	1951	1956	1961	1966	1971	1976	1981	1986	1991	1996	2001
Water Supply												
• hot water service	✓		✓	✓	✓	✓	✓	✓	✓		✓	
Heating of Dwelling												
• water heating of main supply					✓	✓	✓	✓	✓			
• water heating of secondary supply							✓	✓	✓			

Table 50: NZ Censuses historical summary 1945-2001 – hot water questions

Census	Topic	#	Question
1966	DHW	10	State type of hot water service used (electric, gas etc.). (Add "shared" to the answer where use is shared by occupants of other flats etc.)
1971	DHW	11	State type of hot water service used (electric, gas etc.). Add "shared" to the answer, where use is shared by occupants of other flats etc.
1976	DHW	7	Water Heating (a) State type of hot water supply, for example, electric, gas, fuel oil: (b) If a second type is used, please specify Notes: This question refers to a hot water supply available from a piped system or from a tap fitted to a water heater, including all types of gas califonts. "Second type" refers to an additional or supplementary hot water supply available from one or more taps. For example, where the min supply is an electric hot water cylinder, "second type": could be a coal range, chip heater or wet-back. Do not include electric jugs or kettles.
1981	DHW	7	Type of Hot Water Supply (*):Tick box which applies: • Electric • Gas (mains) • Wood, coke or coal • Solar • Other or nil – specify e.g. oil fired, NIL
1986	DHW	7	What type of hot water supply do you have in this dwelling? Tick one or more boxes: • Electric • Gas • Other (such as wood, solar) • No hot water supply
1996	DHW	15	Tick as many circles as you need to show which of the following are ever used in this dwelling for **water heating**. • no water heating ever done in this dwelling • electricity • mains gas • bottled gas • wood • solar heating • other fuel(s) – Print fuel(s) (Note: If you heat water with a wet-back, show the fuel(s) used)

Table 51: NZ Censuses 1945-1996 – text of hot water questions[17]

[17] Census questionnaires are available from the Statistics New Zealand website: www.statistics.govt.nz