STUDY REPORT

No. SR 133 (2004)

Energy Use in New Zealand Households

Report on the Year 8 Analysis for the Household Energy End-use Project (HEEP)

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Energy Use in New Zealand Households – HEEP Year 8 Report
December 2004
Executive Summary

This is the eighth 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). The report provides:

- a review of the **importance of energy end-use data** to New Zealand energy planning
- preliminary analysis of the **emerging social data**
- information on the use of **LPG heaters**
- an analysis of **temperatures** found in New Zealand homes
- a comparison of the **space heating energy use with the ALF3** programme
- a literature review of **international demand-side energy models**
- background details to the **development of the HEERA model**.

Please note that all the results, monitoring and analysis methodology reported here are copyright to BRANZ and not available for wider use without explicit permission. The results reported in this paper are subject to change as data processing proceeds.

HEEP in action

HEEP has continued to contribute to the national energy debate in the past year. The creation of the Electricity Commission, the release of a 'Sustainable Energy' discussion paper, and the ongoing development of the National Energy Efficiency and Conservation Strategy, have all shown the need for improved understanding of energy supply and energy demand. Most importantly, understanding of energy demand can be used to identify opportunities to deal with energy supply issues, rather than taking the simplistic option of new supply investment.

The exploration of the HEEP research into previously uncharted residential energy use has already given some important insights. Some early examples are listed, and as the analysis progresses with the completion of monitoring, further insights can be expected.

- **Time-of-use profiles** – real profiles for different consumer groups
- **Domestic hot water** – quantifying losses due to cylinder and pipe insulation
- **Water conservation** – use of mains and low pressure hot water for showers
- **Winter temperatures** – living room and bedroom temperatures
- **Thermal insulation** – impact on energy use and space temperatures
- **Lighting power** – importance as a component of peak power demand
- **Appliances** – standby energy use while waiting to be used
- **Faulty appliances** –energy and cost benefits from identification and replacement.

What uses household energy?

For the past 30 years, almost all knowledge of household energy use has been based on the 1971/72 Household Electricity Study. As the title suggests, that study was concerned solely with electricity use – the use of other fuels (e.g. for water heating, cooking or heating) was recorded, but no estimate was made of that fuel use. Figure i shows electricity by end-use as found in 1971/72, and Figure ii provides comparable HEEP results for Auckland.

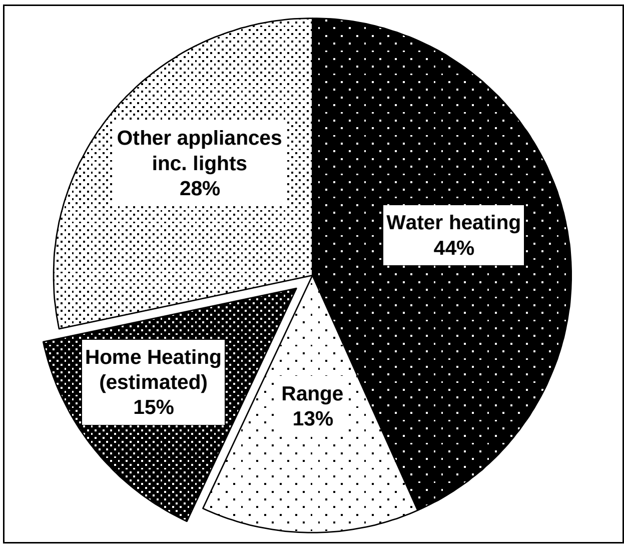

Figure i: 1971/72 NZ electricity end-uses

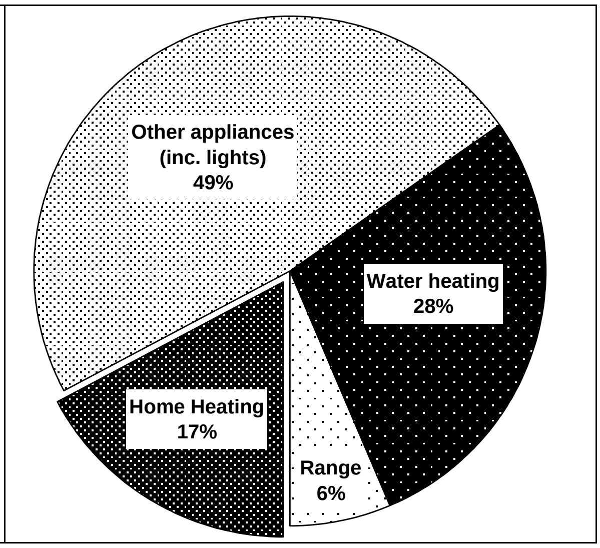

Figure ii: HEEP Auckland electricity end-uses

Whilst the household electricity use is similar (average 8,400 kWh/yr in 1971/72 compared to 7,900 kWh/yr average for the Auckland HEEP houses), the main three end-uses of electricity have shifted considerably from the pattern found in 1971/72.

A closer examination of the HEEP data finds that lighting (about 15%) and refrigeration (about 10%) each account for a sizable portion of the electricity use. The importance of these uses have not previously been recognised, possibly due to a lack of end-use data or perhaps because each is only a small power load. However, a small load turned on and used for a long time (e.g. a heated towel rail operating all day, all year) uses as much energy as a large load turned on for a comparatively short time (e.g. electric clothes dryer used 90 minutes daily).

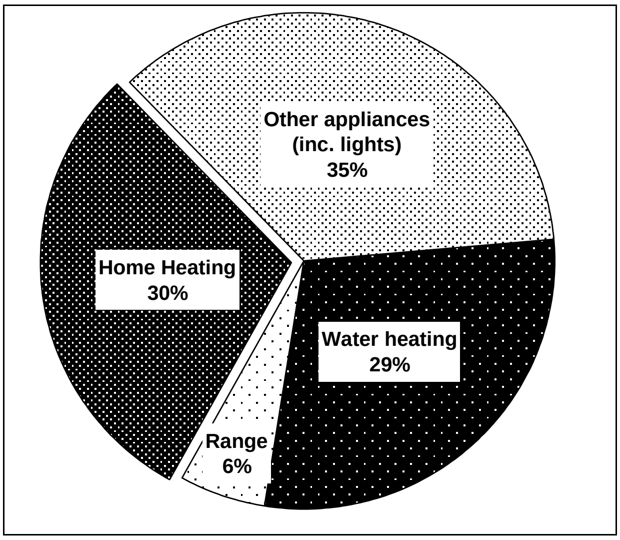

Figure iii: Residential energy end-uses – all fuels

Understanding household electricity use does not provide an adequate understanding of energy use. Although electricity can provide all house uses, very few households use only electricity. In particular, most households use more than one space heating fuel.

Figure iii gives a preliminary energy estimate based on the 300 randomly selected HEEP houses in Auckland, Wellington, Christchurch, Dunedin, Invercargill, Whangarei and Tauranga, and in locations on the Kapiti Coast, Otago, Northland and Waikato. The values may change as wet-back and solar water heating are included.

Lighting and peak power

May 2004 saw the spectre of winter power outages in the top of the South Island due to potential peak demand electricity transmission capacity constraints. HEEP identified lighting as a noticeable use of household electricity, and a significant part of peak power demand.

Analysis of the HEEP database suggested that the peak lighting load was about 200 W per house. For the 230,000 houses in the area of the South Island expected to be subject to peak power constraints, this is a peak load of 47 MW.

The HEEP surveys showed that on average there are 20 incandescent lamps, one compact fluorescent lamp (CFL) and one halogen lamp in houses. Halogen lamps can not be simply replaced by CFL, as the fittings are not suitable. Of the incandescent lamps, some will be in fittings unsuitable for CFL, not all are high use, and some are not used at peak times. A comparison of the average lighting power to the peak power load suggested that, on average, two incandescent lamps per house could be usefully replaced by CFL. This would reduce the peak power demand by 35 MW (i.e. from 47 MW to 12 MW) without reducing the service provided to house occupants.

The replacement of a 100 W incandescent lamp that is used all evening by a 25 W CFL at a cost of $10 (including GST and installation), will save the householder $16.38 per year. It will also reduce peak electricity demand at a cost equivalent to $130 per peak kW. The capital cost of the incandescent lamps, assuming a service life of 1,000 hours, is actually 50 cents higher than the capital cost of the CFL, also giving the householder a capital benefit.

In some houses more lamps could be expected to be ‘on’ at peak times – kitchen, living room, hallway, study, dining room – and these may provide additional peak power reductions, but would need to be considered on a house-by-house basis.

Faulty appliances

As the number of appliances in New Zealand homes increases, it is to be expected that some will fail. In many cases the failure will be obvious e.g. the television fails to work, and the appliance will be replaced. However, HEEP monitoring results are showing that when some appliances fail the failure mode does not alert the users to the failure. Such appliances may continue to consume more energy than necessary, but not provide the expected service.

For example, refrigeration equipment (refrigerators, refrigerator/freezer combinations or freezers) uses about 10% of household electricity. The HEEP survey has found that 55% of the refrigerators, 50% of the refrigerator/freezer combinations and 80% of the freezers are more than 10 years old (i.e. manufactured before 1994). This age is significant, as ozone depleting CFC refrigerants and blowing agents were phased out in 1994.

What happens when refrigeration appliances fail? HEEP monitoring has found that nearly one in five refrigeration appliances have a problem – approximately 10% are faulty, with a further 8% marginal. Nationwide, this is equivalent to over 400,000 appliances.

The number of refrigeration appliances with problems is so large that there is an opportunity for real benefits – not only to the individual household (through improved food storage and energy savings), but also to the nation (through reduced electricity demand) and to the wider world (through correct identification of failure and recovery of the CFC gas).

HEEP estimates that each faulty refrigeration appliance uses about 550 kWh per year more than they would if operating properly – a cost of about $90 a year per appliance. Taking into account the faulty and marginal refrigeration appliances, the unnecessary expenditure could easily reach $30 million per year. If these appliances were replaced by modern appliances using half the energy of a correctly operating old appliance, the benefits could easily double.

Emerging social data

HEEP has always undertaken a detailed survey of house occupants. HEEP currently holds socio-demographic information for 399 households that can be analysed in relation to indoor temperatures, energy use, energy consumption behaviours and, eventually, in relation to the energy performance of dwellings. Of those dwellings, the 296 for which monitoring has been completed can also be analysed in relation to total fuel use.

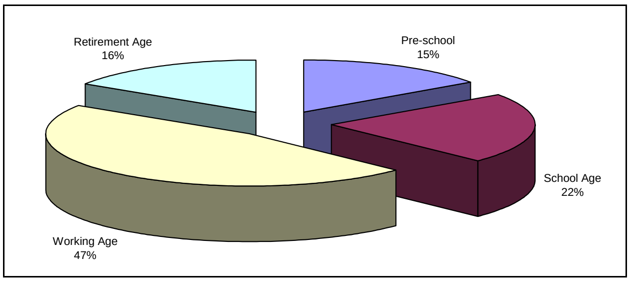

Figure iv: Age of youngest household member

The pre-dominant HEEP household is couple-with-children which make up 35.5 percent of the households, followed by couple-only households (31 percent), with one-person households at 13.1 percent.

Figure iv profiles the HEEP households in relation to critical life stages associated with the youngest household member. Just over a quarter of the households had no adult member of the household in employment (25.2 percent), while 17.4 percent were households in which all the adult members were in full-time employment. The other largest category of households is that with a mix of adults in full-time and not-in-employment.

The Luxemburg method was used to calculate equivalised household income, in order to control for household size effects. The data emerging from this analysis appear to show some connection between household income and indoor temperature, and some variation in energy use according to household composition and life stage characteristics – but these analyses are very preliminary and may be subject to change.

Nevertheless, when considering winter evening living room mean temperatures, it does appear that lower equivalised income groups are over-represented in those dwellings which might be described in comparison to other HEEP dwellings as cold or below average. Conversely higher income groups tend to be over-represented in dwellings which are hot by comparison to other living room mean evening temperatures.

By contrast, similar but again very preliminary analysis, suggests little association between mean evening living room temperatures and household life stage. Households with the youngest member in retirement appear to be slightly under-represented in the dwellings that are relatively cold and somewhat over-represented in the dwellings that are relatively warmer. Similarly, households with the youngest member being a pre-school child tend to be slightly over-represented in relatively cold households and in households with above average mean evening living temperatures. They are, however, under-represented in dwellings that could be categorised as being relatively hot.

The results of this work have the potential to play an important role in the development of the relationship between social and energy policies.

LPG heaters

The monitoring for HEEP in 2003 and 2004 has found a large increase in the number of LPG heaters. This may relate to the monitoring design which commenced in major population centres followed by minor centres, leaving minor urban and rural areas to the last two years of monitoring. The total HEEP sample now includes 157 portable, flueless LPG heaters.

There has been a small narrowing of the difference in the proportion of households with dehumidifiers in LPG owning and non-LPG heater owning households since the HEEP Year

7 report. For the current sample, 22% of houses without LPG heaters had a dehumidifier, while 31% of houses with LPG heaters had a dehumidifier.

Over 40% of the LPG heaters are used for less than five hours per week during winter months, with half the heaters spending about 90% of this time on one setting. For these heaters, about two thirds use the low or economy setting (equivalent to about 1.5 kW).

Indoor temperatures

The 1971/72 temperature study found a strong consistency in the differences between inside and outside temperatures, and concluded that this indicated that "in homes throughout New Zealand, rooms tend to be heated to certain levels above the surrounding outside air temperature, rather than to a universal absolute temperature level."

This would not appear to be the case for the HEEP sample, with the temperature differences between the inside and outside ranging from 4.6°C in the Northern North Island to 7.4°C in the Southern South Island. Excluding the Southern South Island (average 14.7°C), average living room temperatures are close to 16°C over the rest of the country. The majority of houses (72%) report heating start in April or May and finish in September or October.

HEEP analysis continues to be based on a winter heating season from June to August (inclusive) and the evening period as the time from 17:00 to immediately before 23:00. Overall, there is constant heating in the living rooms of approximately 10% of the HEEP houses, mainly in Southland/Otago, the Central North Island and the East Coast of the North Island. These areas also have a higher proportion of houses with solid fuel burners.

House age group	Winter evening living room (± SD)	Bedroom overnight (± SD)
Pre-1978	17.6 ± 0.1°C	13.2 ± 0.1°C
Post-1978	18.6 ± 0.2°C	14.5 ± 0.2°C

Table i: Winter temperatures by insulation level

Houses built after 1 April 1978 were required to include a minimum level of insulation, while insulation was not required in older houses. Table i shows a 1.0°C difference in living room evening temperatures between pre- and post-1978 houses, and 1.3°C in overnight bedroom temperatures. This temperature difference remains consistent with that reported in previous HEEP reports, although average temperatures have risen. This increase could be due to the large number of solid fuel burners in the current monitoring. Examination of the heating schedules found that occupants in pre-1978 houses do not use significantly different heating times to those in post-1978 houses.

Fuel	Temperature	Sample count
LPG	17.1 ± 0.2°C	54
Electricity	17.2 ± 0.2°C	108
Gas	18.0 ± 0.4°C	33
Solid Fuel	18.7 ± 0.2°C	152

Table ii: Winter evening living room temperatures by heating fuel

The fuel type also plays a role in establishing house temperatures. Table ii illustrates that houses heated with gas or solid fuel are warmer than electric and LPG-heated houses. Note that 'gas' includes reticulated gas and the large home gas (LPG) cylinders. LPG represents only the portable cabinet type LPG heaters, generally with a 9 kg gas bottle.

The heating system is also important, as houses with gas central heating or enclosed solid fuel burners are the warmest group with average evening temperatures over 18°C, while electric heaters or LPG have average temperatures around 17°C. Living rooms heated with open fires are the coolest, with average temperatures of 16°C.

ALF and HEEP household space heating energy use

HEEP produces estimates of annual heating energy use in the monitored houses, while the Annual Loss Factor, 3rd edition (ALF3) estimates the annual heating energy required for a residential building based on the house physical location and construction, and a selected heating schedule.

ALF3 models were prepared for 181 HEEP random houses. Only houses with electricity, natural gas and LPG heating were included, with locations from Kaikohe to Invercargill. No limits were placed on occupants, locations or any other house characteristics.

Areas identified as potentially causing differences between the HEEP estimate and the ALF3 model include the accuracy of HEEP space heating estimate methods, differences in internal energy gains due to appliances, different occupant behaviour and changes in the number of occupants, different space heating zoning and different time patterns (months of year and hours of day).

It was found that after making allowance for these differences, the energy used by households that are consistently heated is able to be estimated by ALF3 to within ±20%. This is a very acceptable result. All HEEP houses will be modelled in the coming year.

Residential energy-use model

An international literature review was undertaken of residential models in the United Kingdom, the USA, Canada and New Zealand. The results will be used to assist in the development of the Household Energy Efficiency Resource Assessment (HEERA).

The review included surveys of the condition and occupancy of housing stock, programmes to model house heating, and energy scenario models. These models include both *top-down* (emphasis on macroeconomic trends and relationships) and *bottom-up* (emphasis on physically-based engineering-type variables).

HEERA is a bottom-up type scenario model that allows the investigation of trends in energy consumption and the impact of energy efficiency options on energy use and greenhouse gas emissions from a range of viewpoints. HEERA does not currently include a macroeconomic equilibrium mechanism to provide an energy-price feedback to the demand-side. However, when the effects of policy options which change the price of the fuels need to be taken into account, and if end-use fuel-price elasticities justify it, this could be developed.

The database supporting HEERA is disaggregated at the regional, dwelling type, end-use and appliance levels. It includes variables to represent occupant socio-economic and demographic characteristics. This enables the historic and projected estimation of residential energy use, energy supply and greenhouse gas emissions. These sub-models calculate the dwelling and appliance stock, and the space heating, water heating, cooking, lighting, refrigeration, laundry and electrical appliance energy use.

Dwelling and appliance stock models simulate dwelling and appliance stock changes through a dynamic balance between the annual addition of new stock and removal of old stock.

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

The rest of the models calculate the energy used by dwellings for water heating, cooking, lighting, refrigeration, laundry and electrical appliances with the use of household demographics and operation, e.g. family type, size, composition and income, water and energy use, temperatures and usage regimes.

HEEP activities and reports

Data collection will be completed in 2005, when full data from 400 randomly selected houses will be available. Until then, the annual reports provide preliminary results from our research. Each report includes the increased house sample that becomes available when the previous year's monitoring is complete. This report includes data from 300 randomly selected houses, as well as non-random selections. Regional coverage now includes Auckland, Wellington, Christchurch, Dunedin, Invercargill, Whangarei and Tauranga, and in locations on the Kapiti Coast, Otago, Northland and Waikato. The final year of monitoring is mainly rural locations.

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

- importance of household income or compositions on energy use
- importance of different aspects of house construction on indoor temperatures
- energy time-of-use profiles

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

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

Copies of the full Year 8 report are available from BRANZ using the order form below:

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ENERGY USE IN NEW ZEALAND HOUSEHOLDS

Report on Year 8 of the Household Energy End-use Project (HEEP) – December 2004, BRANZ Study Report SR 133

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REFERENCE

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

ABSTRACT

This is the eighth 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). The report provides a review of the importance of energy end-use data to New Zealand energy planning, preliminary analysis of the emerging social data, information on the use of LPG heaters, an analysis of temperatures found in New Zealand homes, a comparison of the space heating energy use with the ALF3 programme, a literature review of international demand-side energy models and background details to the development of the HEERA model. Data collection will be completed in 2005, when full data from 400 randomly selected houses will be available.

Acknowledgements

The funding support of the following organisations over the full term of the HEEP research is gratefully acknowledged:

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

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

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1. INTRODUCTION

This is the eighth annual report on the Household Energy End-use Project (HEEP). It provides an overview of the monitoring programme, discusses future monitoring and provides preliminary 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.

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1.1 HEEP in action

HEEP has continued to contribute to the national energy debate in the past year. The creation of the Electricity Commission,[i] the release of a 'Sustainable Energy' discussion paper,[ii] and the ongoing development of the National Energy Efficiency and Conservation Strategy[iii] have all shown the need for improved understanding, not only of energy supply, but also energy demand.

The exploration of the HEEP research into previously uncharted residential energy use has already given some important insights. The following examples are early results (some of which are further developed in this report), and as the analysis progresses with the completion of the monitoring portion of the project, further insights can be expected. These examples illustrate the type of opportunities that result from improved understanding of energy end-uses. Most importantly, understanding of demand can be used to identify specific opportunities to deal with specific energy supply issues, rather than taking the simplistic option of reverting to investment in new supply.

- **Time-of-use profiles**
  Although the New Zealand electricity market has been based on half hour time-of-use profiles since April 1999, there is little evidence that tariff profiles are anything more than based on the shape of all the electricity consumed at the local grid exit point, minus the electricity consumed by commercial and industrial consumers. HEEP monitors all household fuels on at least a 10 minute basis, and can therefore generate time-of-use profiles for specific groups.

- **Domestic hot water – standing losses**
  The New Zealand Standard for the energy performance of domestic water heaters is based on laboratory testing, but the energy performance of hot water systems in actual homes is more complex and difficult to measure.

  The energy used to provide household hot water relates to two issues: social (the amount of water used by people for different tasks), and technical (the energy used to heat water and maintain it at temperature). HEEP has quantified, for the first time in New Zealand, these two components:

[i] For further information see: www.electricitycommission.govt.nz
[ii] Available from: www.med.govt.nz
[iii] For further information see: www.eeca.govt.nz

- ‘Delivered hot water’ represents the social portion of the energy use – the average use is between 4.2 kWh/day for electric night storage systems and 12.5 kWh/day for natural gas instantaneous systems. This includes the energy used to heat any water that remains in the pipes after ‘use’.

- ‘Standing losses’ represent the technical portion of the energy use, and range on average from nothing for natural gas instantaneous systems (with electronic ignition) to an average of 4.1 kWh/day (27% of total gas use) for natural gas storage to an average of 2.6 kWh/day (34% of total electricity use) for electric storage systems.

Both the delivered hot water and standing losses vary from house to house, and from cylinder to cylinder, depending on a range of factors. These will include the cylinder size, age, insulation, thermostat type and water pressure, and the pipe material, insulation and length. HEEP is now exploring these differences, and those between fuel types.

- **Water conservation**
  There is an interesting inter-relationship between water and energy use. At the regional level, the provision of mains water involves a sizeable energy investment, principally in the form of pumping water from storage to the point of use. In the home, energy is used to raise the temperature of the water, so any action that leads to a change in hot water use will result in an increase in energy.

  Traditionally New Zealand homes have been provided with ‘low’ pressure hot water systems – often a copper hot water cylinder with a ceiling mounted ‘header’ tank. Seventy eight percent of the HEEP hot water systems are low pressure, with the remainder ‘mains’ pressure. A major use of hot water is for showers, where the ‘length of shower’ is measured not in water consumption, but by time. On average, mains pressure water systems have a higher flow rate than low pressure systems – averaging 10.6 litres per minute compared to an average of 7.2 litres per minute.

  HEEP has been able to quantify the impact of a low-flow shower head on water and energy use based on actual measurements. In Auckland (where there are charges for both potable water supply and waste water removal), the savings from fitting a low-flow shower head would be of the order of $90 per year for one shower per day – or $360 for a four person household. About half of the financial savings are from water and half from energy savings.

- **Winter temperatures**
  New Zealand has a relatively mild climate – ‘temperate with sharp regional contrasts’ according to the *CIA World Factbook* (CIA, 2003) – leading to the expectation that indoor temperatures are also temperate. The measured facts differ from this assumption.

  HEEP has provided the first nationwide data on the temperature patterns found in New Zealand homes. Current HEEP work suggest that the winter heating season includes the period between June and August (inclusive), and during this season the living room is heated in the evening between 17:00 and 23:00. In the remainder of the house, and during the day, only minimal heating is used in most New Zealand houses.

  The average winter evening temperature in the current 300 house sample follows a normal distribution, with an average temperature of 17.3°C and a standard deviation of 0.2°C. Importantly, about 28% of these average temperatures are below the healthy minimum of 16°C (WHO, 1987). Further work is being undertaken to explore the reasons behind these heating patterns and resultant temperatures. These results will also be used to improve design guidance and thermal modelling tools.

- **Impact of thermal insulation**
  Houses built since 1 April 1978 are required to have minimum component levels of thermal performance, generally achieved by the addition of thermal insulation, but in some cases provided as an intrinsic part of the construction technology.

  HEEP monitors the living room and bedroom temperatures. HEEP analysis has found that there is a relationship between the age of the house and the winter evening average temperatures. Based on the 400 house sample, we can conclude that living rooms in post-1978 houses are on average 1.0°C warmer (18.6°C compared to 17.6°C).

  HEEP research has also found that households seldom heat bedrooms overnight, but post-1978 bedrooms are still 1.3°C warmer (14.5°C compared to 13.2°C), so this is achieved at no purchased energy cost – it is a benefit from the body heat of occupants and any energy using appliances e.g. clock radio, lights, etc. It is possible other issues are also important (e.g. different occupancy groups, house construction, etc) and this is being investigated.

- **Lighting and peak power**
  May 2004 saw the spectre of winter power outages in the top of the South Island due to potential peak demand electricity transmission capacity constraints. HEEP has identified lighting as a noticeable, but not major, use of household electricity. More importantly, HEEP has found that lighting is a significant component of peak electric power demand.

  Peak lighting electricity use closely coincides with peak system power demand. Analysis of the HEEP database suggested that the peak lighting load was about 200 W per house. For the 230,000 houses in the area of the South Island expected to be subject to peak power constraints, this is a peak load of 47 MW.

  The HEEP surveys showed that on average there are 20 incandescent lamps, one compact fluorescent lamp (CFL) and one halogen lamp in houses. Halogen lamps can not be simply replaced by CFL, as the fittings are not suitable. Of the 20 incandescent lamps, some will be in fittings that are not suitable for CFL, not all are high use, and some are not going to be used at peak times. A comparison of the average lighting power to the peak power load suggested that, on average, two incandescent lamps per house could be usefully replaced by CFL. This would reduce the peak power demand by 35 MW (i.e. from 47 MW to 12 MW) without reducing the service provided to house occupants.

  The replacement of a 100 W incandescent lamp that is used all evening, with a 25 W CFL at an assumed cost of $10 (including GST and installation), will save the householder $16.38 per year. It will also have the effect of reducing peak electricity demand at a cost equivalent to $130 per peak kW. The capital cost of the incandescent lamps, assuming a service life of 1,000 hours, is actually 50 cents higher than the capital cost of the CFL, also giving the householder a capital benefit.

  In some houses more lamps could be expected to be ‘on’ at peak times – kitchen, living room, hallway, study, dining room – and these may provide additional peak power reductions, but would need to be considered on a house-by-house basis.

It is often argued that energy efficiency gains can be reduced by the behaviour of house occupants. In this case sunset in the top of the South Island is about 17:00in winter, so if the house is occupied by 17:30, the lights will be turned on thus ensuring the calculated peak power benefits will be obtained.

Future analysis of household lighting was used to assist in the development of the 'Eco bulb' promotion of higher efficiency compact fluorescents as a replacement for incandescent bulbs.[iv]

- **Appliances – standing by**
  Standby power is drawn by some appliances when not in operation but connected to the mains. Depending on the appliance type and age, the standby can range from zero (e.g. a non-electronic dryer with a clockwork timer) to 20 W or more (e.g. many televisions). These power consumptions may seem trivial (1 W continuous is approximately 9 kWh per year and costs about $1.20), but since most households have many such appliances, the energy consumption may be a significant fraction of the total household electricity use.

  Standby power also appears to be growing rapidly, due to the proliferation of electronic and computer controllers in appliances, and the increasing ownership of electrical goods.

  The baseload electricity demand of a house is 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).

  HEEP monitoring results were the first quantification of the impact of standby and baseload power for New Zealand houses. HEEP data suggests that standby and baseload power accounts for about 12% of household electricity – about 4% from heated towel rails, 5% from major appliances (e.g. washing machines, TV, etc) and the remaining 3% from a wide range of smaller or less popular appliances.

  These results have already provided critical data to support the development of appropriate testing and standards for Minimum Energy Performance Standards and Energy Labels. Further analysis can be undertaken of the HEEP data to better identify key growth areas, and their likely impact on the electricity system.

- **Faulty appliances**
  As the number of appliances in New Zealand homes increase, it is to be expected that some will fail. In many cases the failure will be obvious e.g. the television fails to work, and the appliance will be replaced. However, the HEEP monitoring results are showing that when some appliances fail the failure mode does not alert the users to the failure. Such appliances may continue to consume more energy than necessary, but not provide the expected service.

  For example, refrigeration equipment (refrigerators, refrigerator/freezer combination or freezers) use about 10% of household electricity. The HEEP survey has found that 55% of the refrigerators, 50% of the refrigerator/freezer combinations and 80% of the freezers

[iv] For further information see: www.ecobulb.co.nz

are more than 10 years old (i.e. manufactured before 1994). This age is significant, as ozone depleting CFC refrigerants and blowing agents were phased out in 1994.

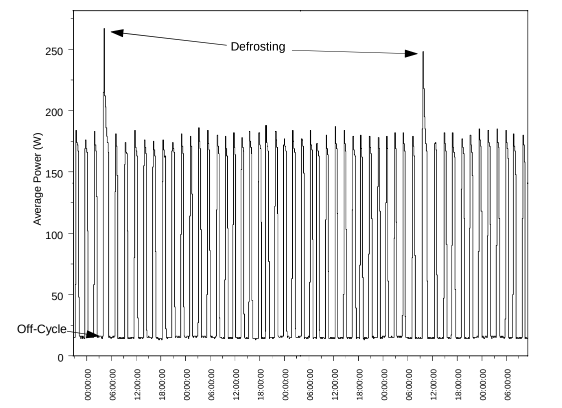

Figure 1: Fridge – normal operation

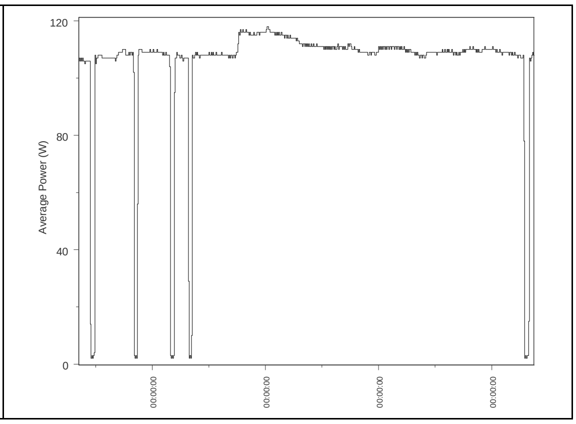

Figure 2: Freezer – faulty operation

What happens when refrigeration appliances fail? HEEP monitoring has found that nearly one in five refrigeration appliances have a problem – approximately 10% are faulty, with a further 8% marginal. Nationwide, this is equivalent to over 400,000 appliances.

A typical example of the electricity use of a refrigeration appliance in normal operation is given in Figure 1. In this case, the compressor power is approximately 170 W, the off-cycle (baseload) power consumption is about 15 W, and defrosting occurs about once every three days.

An example of a faulty freezer is given in Figure 2, in which the compressor stays on for long periods of time and occasionally switches off. Some faulty refrigeration appliances never switch off.

Without the HEEP monitoring this issue would not have been either identified or quantified. The number of refrigeration appliances with problems is so large that there is an opportunity for real benefits – not only to the individual household (through improved food storage and energy savings), but also to the nation (through reduced electricity demand) and to the wider world (through correct identification of failure and recovery of the CFC gas).

HEEP estimates that each faulty refrigeration appliance uses about 550 kWh per year more than they would if operating properly – a cost of about $90 a year per appliance. Taking into account the faulty and marginal refrigeration appliances, the unnecessary expenditure could easily reach $30 million per year. If these appliances were replaced by modern appliances using half the energy of a correctly operating old appliance, the benefits could easily double.

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 10 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 for HEEP results.

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

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1.3 Acknowledgements

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

- Building Research Association of New Zealand Inc (BRANZ Inc)
- Energy Efficiency and Conservation Authority (EECA)
- Foundation for Research, Science and Technology, Public Good Science & Technology Fund (PGST).

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

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- Lindsey Roke, Fisher & Paykel Ltd
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- Prof. Arthur Williamson, Thermocell Ltd
- Phillipa Howden-Chapman, Anna Matheson and Helen Viggers, Te Kainga Oranga – Housing and Health Research, Wellington School of Medicine.

2. WHERE DOES NEW ZEALAND'S ENERGY GO?

2.1 Introduction

> *"Another piece of advice, Copperfield," said Mr. Micawber, "you know. Annual income twenty pounds, annual expenditure nineteen nineteen six, result happiness.*
> *Annual income twenty pounds, annual expenditure twenty pounds ought, and six, result misery.*
> *The blossom is blighted, the leaf is withered, the God of the Day goes down upon the dreary scene, and – and in short you are forever floored. As I am!"* (Dickens, 1850)

Where would Mr Micawber be today? After visiting his local Citizen's Advice Bureau, he would be guided to a Budget Advice Service, where the first question would be to ask him to set out details of his income and expenditure.[v]

The problems that result from the need for ever-increasing demand (expenditure) to be matched by ever-increasing supply (income) can be seen in the energy sector as well as a household. For example, the past year has seen activity due to:

- a short-term crisis, as rain did not refill the hydro-lakes
- uncertainty that the Maui natural gas field may be reaching the end of its theoretical economic life
- increased international oil prices as demand growth does not appear to be matched by comparable short or long-term growth in oil supplies.

Now is an appropriate time to review the supply and demand of energy in New Zealand, starting with a budget review – what are the details of energy supply and demand?[vi]

2.2 New Zealand energy supply

The Ministry of Economic Development publishes twice a year the Energy Data File which provides official statistics on energy supply and consumption in New Zealand (MED, 2004a). It is based on an analysis of energy imports and production, plus mandatory reporting by energy supply companies of deliveries by sector. The following analysis is based on this publication.

Figure 3 illustrates the proportions of New Zealand's main fuel sources – including the use of oil and natural gas for 'non-energy' purposes (e.g. fertiliser, roading, etc). 'Other renewables' includes electricity generation from wind, biogas, industrial waste and wood.

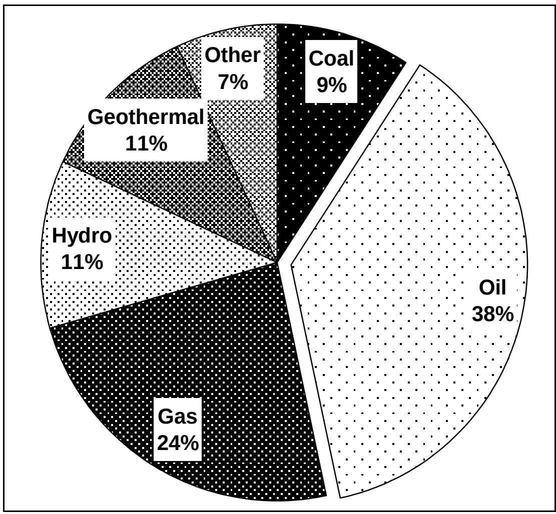
Figure 3 shows that New Zealand's single most important fuel source is the fossil fuel, oil. Over the past 30 years oil has decreased from just under half (48% in 1975) of the total primary energy supply, to over one-quarter (around 28% in the 1980s), but since then has steadily increased to the current 38% (2003 provisional data). In the same time, total annual primary oil use has increased from 185 PJ to 278 PJ – an increase of 50%.

[v] www.cab.org.nz is an excellent first step.

[vi] Note: percentages in tables or on charts may not add to 100 due to rounding.

2.3 New Zealand energy demand

But where does all this fuel go? Figure 4 re-evaluates the national energy data from a consumer demand perspective. Not surprisingly, the largest fuel supply (oil) feeds into the largest consumer demand (domestic transport). The importance of oil is at variance with the reports in our general and business news media, which are largely focused on electricity.



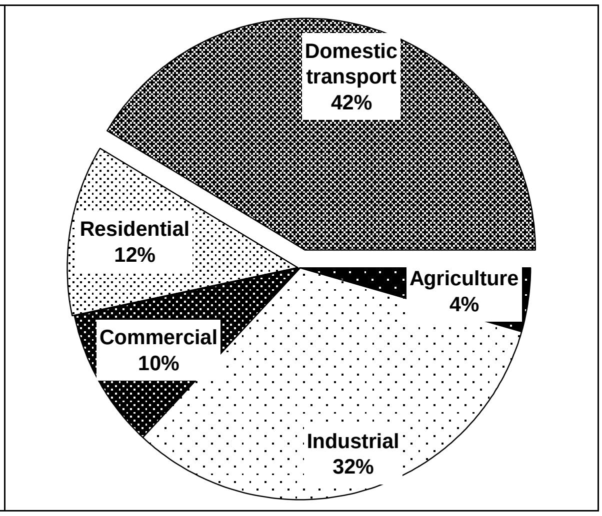


Figure 3: NZ 2003 primary energy by fuel **Figure 4: NZ 2003 consumer energy by sector**

Figure 5 compares the fuel types used in the different sectors of the New Zealand economy, with the total demand by sector provided at the top of the graph.

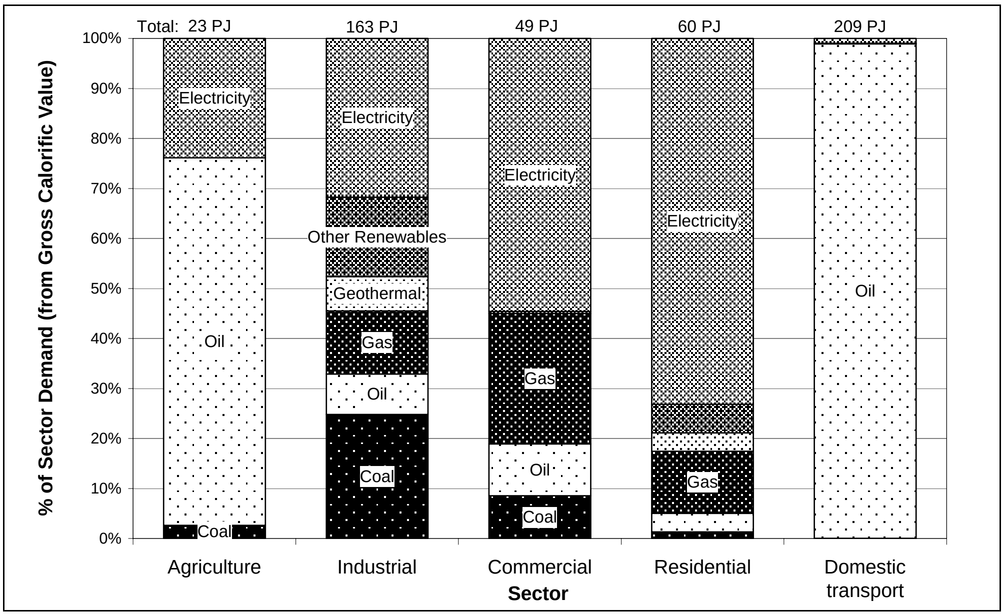


Figure 5: NZ consumer energy demand (2003) by sector and fuel

Agriculture and domestic transport are the most oil intensive sectors, but it is worth noting that all sectors of the economy make use of the 'transport' sector – in the main, apart from a relatively small fuel use for motor sports, transport is a service sector. It should also be noted that the 'commercial' sector includes public lighting, rail and urban traction.

Examining only residential sector fuel, Figure 6 shows that electricity is just under three-quarters (73%) of the energy used in the residential sector, with natural gas second at 12%.

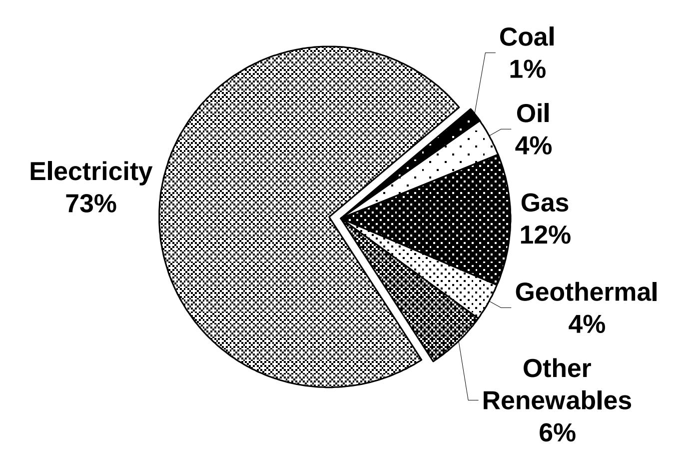


Figure 6: Residential sector energy use by fuel 2003

'Other renewables' at 6% is followed in order of importance by oil and geothermal at 4% and coal at 1%.

Currently the residential sector consumes about one-third (34%) of consumer electricity, but just under 30 years ago this was close to one-half (48% in 1976). Thus, although electricity is so critical to the residential sector, other sectors now play a more significant demand role.

2.4 Have there been any changes in residential energy demand?

> *The relative energy intensity of an average household today is not much different from what it was 30 years ago – and yet we are using far more convenience devices and appliances today.* (Doug Heffernan, CEO Mighty River Power – quoted in Schäffler, 2004)

There are two parts of this statement to be considered – whether energy intensity has changed, and the importance of the convenience devices and appliances.

The first part of this statement does not seem unreasonable. Based on the number of *occupied permanent private dwellings* recorded in quinquennial Censuses and the Energy Data File (MED, 2004a), residential energy use per household has increased by only 6% over the period 1971 to 2001. In the same time, the population has increased by 34% and the number of households by 61%, so there are less people per house. The result – total residential sector energy use has increased by 70%, and energy use per person has increased by 27%.

The most recent decade shows a slightly different picture. Figure 7 (data from MED, 2004a and Statistics NZ, 2004) plots total residential energy consumption (PJ), consumption per household (GJ/household)[vii] and per person (GJ/person) from 1990 to 2004. Figure 7 shows increases over the period 1993 to 2004:

- total residential sector energy use by 8%
- the number of households by 17%
- the number of people by 15%.

The consequence of these changes is that the average energy use per household has fallen by 8% and the residential energy use per person by 6%.

[vii] Note: the 'Permanent dwelling' series previously used are no longer available, so the results presented here are based on 'estimated households' and thus differ from the HEEP Year 6 report.

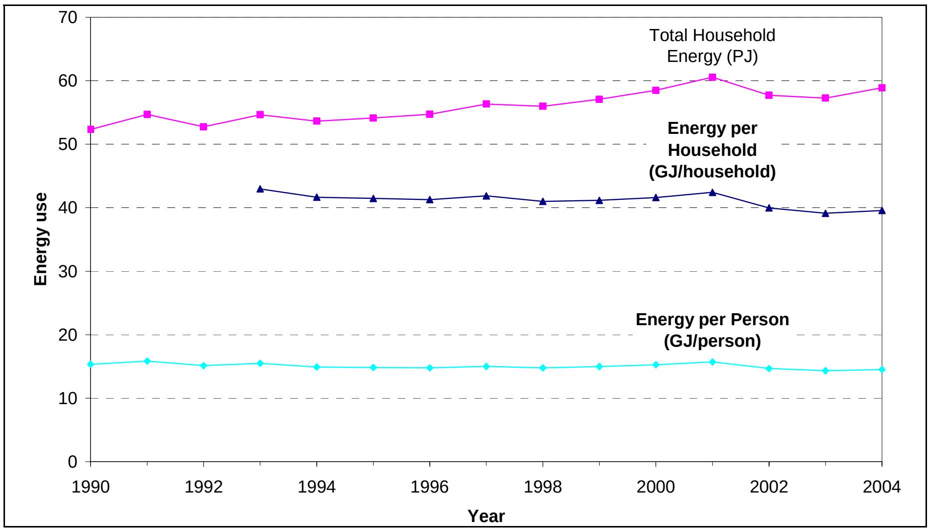


Figure 7: Residential energy consumption 1990–2004

The patterns shown in Figure 7 are related to more than just energy use. For example, New Zealand households show a long-term trend of falling occupancy rates – reducing from 2.8 people per household in 1991 to 2.7 people in 2001 (Statistics NZ, 2002). Structural changes in households (e.g. number of people per household) need to be considered as much as structural change in technology.

But what about the last part of the statement – *yet we are using far more convenience devices and appliances today*. Where does energy use go in New Zealand homes? Are convenience devices and appliances so important in their energy use, or do other uses drive the residential sector energy use? This information is not available from the supply data used to prepare the Energy Data File (MED, 2004a), so it is necessary to find other sources.

2.5 Investing in energy demand knowledge?

Before committing any funds, the wise investor looks carefully at all possible investments – noting the different risks and opportunities. The first step is careful research for the necessary data. Data are not collected without funding, so who is funding the search for data?

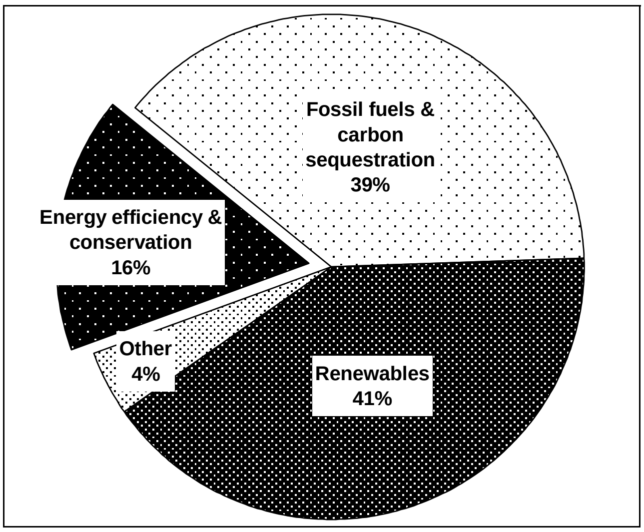


Figure 8: FRST energy research budget 2003/04

Figure 8 summarises the Foundation for Research Science and Technology 2003/04 budget for energy research (MED, 2004b). The total budget was $12.2 million, of which $2 million was invested in 'energy efficiency and conservation'. No comparable data is available for private sector investment.

The majority of Government 'energy' research is concerned with supply. Apart from the HEEP, there is only limited research being carried out into understanding energy end-uses in other sectors of the economy. It is thus necessary to look to historical data.

2.6 What uses household energy?

For the past 30 years, almost all knowledge of household energy use has been based on the 1971/72 Household Electricity Study, conducted by the then New Zealand Electricity Department and the Department of Statistics (Statistics NZ, 1973). As the title would suggest, it was concerned solely with electricity use – the use of other fuels (e.g. for water heating, cooking or heating) was recorded, but no estimate was made of that fuel use.

Figure 9 illustrates electricity breakdown by end-use from the 1971/72 study – the three largest uses of electricity being water heating (44%), other appliances including lighting (28%) and home heating (15%) (Statistics NZ,1976). The data used in Figure 9 is subject to a number of caveats in the original report:

- the winter of 1971 was exceptionally mild, suggesting less heating was used than for a more normal (i.e. colder) winter
- the majority of houses used 'electricity and other fuels' as their main means of home heating (74% of the insulated houses and 68% of the uninsulated houses), but no estimate was made of the non-electricity heating fuel use
- 19% of the houses used electricity and some other fuel for the provision of hot water, but again no estimate was made of the non-electricity fuel use
- the sample included 315 'insulated' (19%) and 1,336 'uninsulated' (81%) houses, but the presence of insulation was associated more with higher income groups and a more widespread use of electric heaters
- the insulated houses in the matched sample were not only warmer, but also consumed 40% more heating electricity (1,632 kWh vs 1,158 kWh).

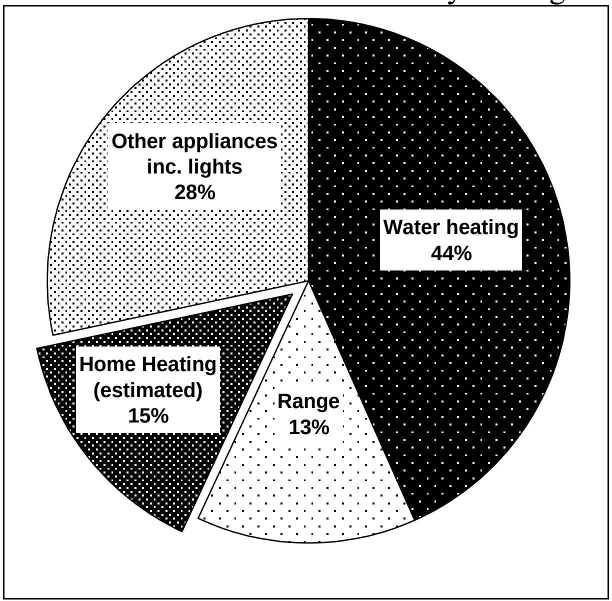


Figure 9: 1971/72 NZ electricity end-uses

By the end of the 1970s, natural gas was becoming available in major locations throughout the North Island, an oil crisis had shifted residential interest away from oil as a form of space heating, and improved solid fuel burners were replacing the open fire.

There were also changes in both technical and social aspects of the way houses were built and used, with largely unknown energy consequences. There have, for instance, been significant changes in:

- **materials** (e.g. large sheet particleboard for flooring has replaced strip flooring)
- **the NZ Building Code** (e.g. thermal insulation has been required since 1978)
- **appliances** (e.g. microwave ovens widely available from the late 1970s)
- **electronic controls** (e.g. remote controls require 'standby' electricity)
- **work practices** (e.g. retailing is now a seven-day-a-week operation)

- **house layout** (e.g. greater use of open plan living spaces)
- **home energy consumption** such as home offices (e.g. home computers)
- **household characteristics** including household ethnicity, size and age composition.

Although the need to understand these changes has been publicly discussed since the early 1980s (e.g. N.Z. Parliament, 1984), it was not until late 1995 that the Building Research Association of New Zealand Inc (BRANZ Inc) started the Household Energy End-use Project (HEEP) with a pilot study of 10 houses in Wanganui (Stoecklein et al, 1997).

Figure 10 provides preliminary HEEP estimates of electricity end-uses for Auckland houses.

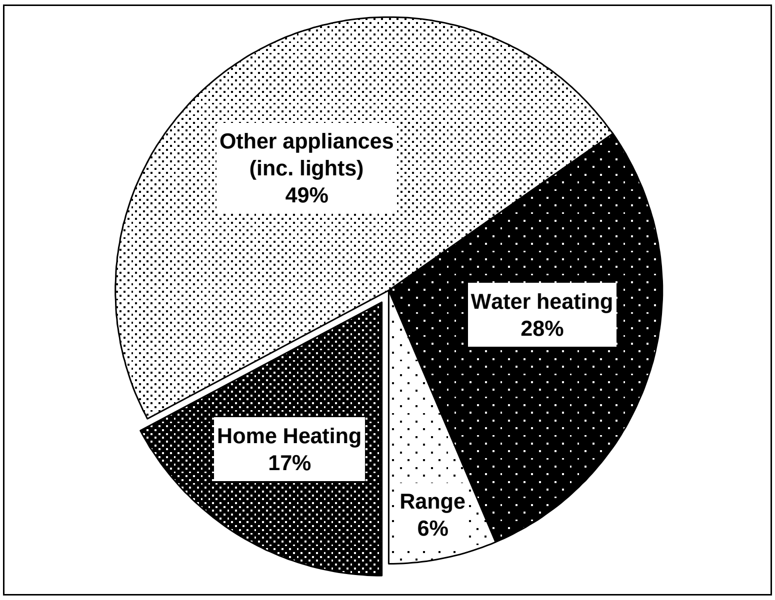


Figure 10: HEEP estimate of Auckland electricity end-uses

Whilst the household electricity use is similar (8,400 kWh/yr in 1971/72 New Zealand average compared with 7,900 kWh/yr for the Auckland HEEP houses), the main three end-uses of electricity have shifted considerably from the pattern found in 1971/72 (see Figure 9):

- appliances (including lights) have increased from 28% to 49%
- home heating remains about the same at 15% in 1971/72 and 17% in HEEP
- water heating has reduced from 44% to 28% of electricity use
- range (oven and hobs) has reduced from 13% to 7% of electricity use.

A closer examination of the HEEP data finds that lighting (about 15%) and refrigeration (about 10%) each account for a sizable portion of the electricity use. The importance of these uses have not previously been recognised, possibly due to a lack of end-use data or perhaps because each is only a small power load. However, a small load turned on and used for a long time (e.g. a heated towel rail operating all day, all year) uses as much energy as a large load turned on for a comparatively short time (e.g. electric clothes dryer used 90 minutes daily).

Understanding electricity use does not provide an adequate understanding of household energy use. Although it is possible to use electricity for all household uses, very few houses use only electricity. In particular, most households use more than one fuel for space heating.

The results of the most recent HEEP energy analysis are reported in Figure 11 and Figure 12. They provide preliminary energy estimates based on the 300 randomly selected houses in the HEEP sample in Auckland, Wellington, Christchurch, Dunedin, Invercargill, Whangarei and Tauranga, and in locations on the Kapiti Coast, Otago, Northland and Waikato. The estimates will be subject to change as wet-back water heating and solar water heating are included. The completed results of this work will be reported in the next available HEEP report.

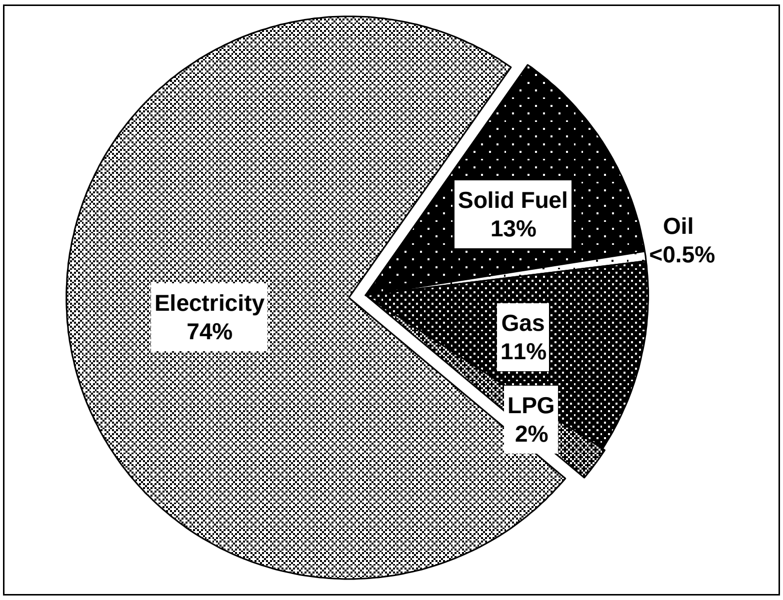


Figure 11: Residential fuel use – preliminary HEEP estimate

Figure 11 shows a preliminary estimate of the relative importance of the main residential fuels. Comparing the HEEP analysis in Figure 11 with the residential sector fuel use from the Energy Data File (Figure 6) shows a similar importance of electricity, but differences in that:

- no household geothermal energy use has been measured by HEEP (although this may relate to the specific sampling areas)
- HEEP monitored use of oil is lower than that suggested in the Energy Data File
- solid fuel (coal and wood) and LPG are a higher proportion in the HEEP fuel use than in the Energy Data File (assuming 'Other renewables' includes wood).

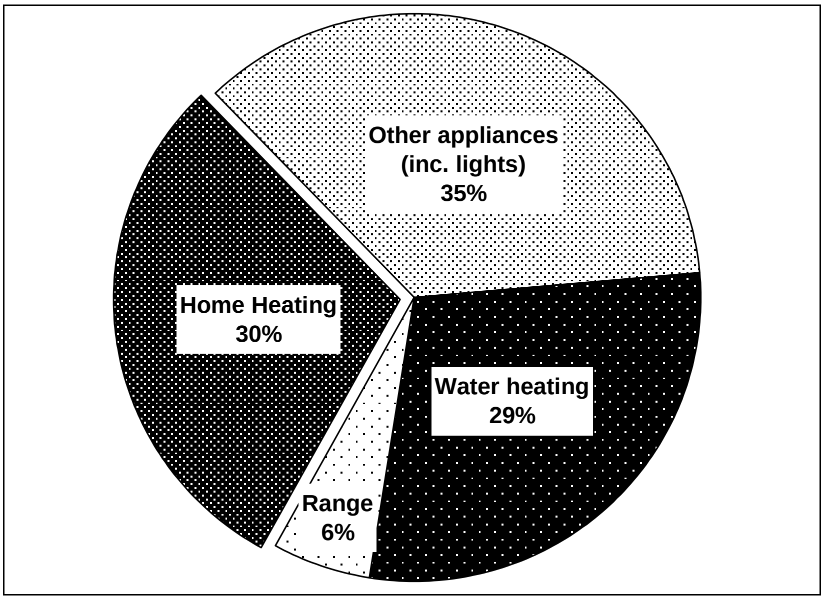


Figure 12: Residential end-uses – preliminary HEEP estimate

Figure 12 provides a preliminary estimate of residential energy use by end-use for the fuels in Figure 11. The proportion differences from electricity end-uses in Figure 10 reflect the role of LPG, reticulated gas and solid fuels in providing space heating and domestic hot water.

Although it is possible to use different fuels for water and space heating, the shift is likely to occur over a long time period and be associated with consequential structural change. For example, 'portable kerosene heaters' were found in 11% of households in 1984, but over the following 17 years have all but disappeared – only 0.6% of households had one in 2001. Similarly, 'portable electric heaters' were found in 89% of houses in 1984, but by 2001 were only in 71% of households (Statistics NZ, 2001). In most cases (as evidenced by the HEEP house appliance inspections), these heaters are no longer available for use. This would suggest that there are long-term energy supply planning implications of such shifts in energy end-uses.

These four figures illustrate how household energy end-use has changed over 30 years:

- Figure 9 (1971/72 Household Electricity Study) demonstrated for the first time that hot water heating, appliances and space heating were the major uses of electricity
- Figure 10 (HEEP 2004 estimate based on the electricity use in 100 Auckland houses), illustrates how electricity use has changed over the past 30 years, particularly the increased importance of appliances
- Figure 11 (HEEP 2004 estimate – based on 300 mainly urban and suburban houses) illustrates the important role played by solid fuel (wood and coal) and LPG
- Figure 12 (HEEP 2004) – provides for the first time a preliminary understanding of all the energy end-uses in New Zealand houses.

The common theme in all of the end-use analyses is that heating fuels (space and water heating) are the drivers of household energy use, not the suggested 'convenience appliances'.

2.7 Discussion

Over 150 years ago, Charles Dickens' Mr Micawber neatly summed up the consequences of a mismatch between income and expenditure. We now must question whether today's society has learnt the consequences of an ever-increasing energy demand.

This paper has reviewed the availability of energy supply and demand data, and found that official statistics provide information on energy supply and sectoral energy demand. At the more detailed energy demand level, except for the residential sector as reported in this paper, the end-use data is out-of-date and inadequate.

Liquid transport fuel (in the main oil) was identified in the 1970s as New Zealand's main energy problem (e.g. Harris et al, 1977). Today, as the world looks towards a future with increasingly expensive petroleum-based transport fuels, we hold confidence in our abilities to deal with this, but based on a lack of knowledge of demand and a belief that investment in supply will be sufficient.

Can a society built on the assumption of readily available, low-cost oil continue without major change? For example, 'just-in-time' manufacturing expects a flexible, responsive transport system to be able to deliver any required component within a well-defined timeframe. Such a transport system, in turn, is supported by low-cost fuel which can allow trucks (or cars) to travel with less than full loads

In the main, sectoral energy demand changes slowly. Apart from step increases, for example due to the construction of a major base metals processing facility, changes in energy demand tend to be composed of a large number of small shifts. For example, the effect of more energy-efficient new houses and new appliances will take time to impact on the national averages. In the year end August 2004, consents were issued for a total of 32,169 dwelling units (including 5,942 apartments) (Statistics NZ, 2004a). The average over five years (2000–2004) is 25,534 dwelling units per year – which would take 62 years to completely replace the estimated 1.58 million private dwellings in New Zealand at 30 September 2004 (Statistics NZ, 2004b).

The HEEP research is changing our understanding of household energy use. The preliminary analysis reported here shows that there have been critical changes in the demand for fuels over the past 30 years. For example, although total electricity use per household has not changed greatly, houses, households and the patterns of electricity use by these households have. The consequences of this shift have yet to be understood.

This lack of understanding can be traced to a lack of data, which in turn traces to a lack of investment in understanding energy demand. The majority of current New Zealand energy research is directed towards energy supply and conversion, and even energy demand statistics are in limited supply.

The HEEP work is providing new knowledge on the use of energy in the residential sector, and this in turn will provide significant opportunities – not only for energy supply but also for a wide range of other businesses involved in the provision of energy using and conserving products and appliances.

The examples presented here resulting from the HEEP improved understanding of household energy end-use include:

- possibilities of time-of-use profiles for different consumer groups
- different importance of standing losses for different types of hot water cylinders
- impact on energy and water costs of low-flow shower heads
- patterns of heating and actual winter temperatures in New Zealand houses
- impact of thermal insulation on living room and bedroom temperatures
- importance of lighting on peak power demand
- appliance 'standby' power
- importance of faulty refrigeration appliances.

In some cases these results come within the initial research goals, while in others they are a serendipitous discovery. The paper has provided examples of how the results of the HEEP research can lead to significant opportunities. How many other opportunities remain to be discovered is unknown, but then that is the objective of scientific research.

2.8 Conclusions

A budget advisor attempting to review New Zealand's energy income (supply) and expenditure (demand) would be faced with major difficulties – far more difficulties than faced by Mr Micawber with his detailed understanding of his pitiful situation.

There is a considerable knowledge of energy supply, but this is not the case for energy demand; although as a result of the research reported here we are beginning to better understand the residential sector. Although the residential sector only directly accounts for 12% of consumer energy, changes in the performance of this sector reflect throughout the economy.

The HEEP work, even though far from complete, has already identified a range of important energy demand issues in the residential sector that have important implications for national energy supply. These issues create new opportunities for science and business to create innovative solutions:

- what energy demand issues exist for other sectors in the economy?
- could these energy demand issues result in improved or even in sustainable energy supplies?
- what are the opportunities to reduce the energy-related greenhouse gas emissions?

There are no answers to these and many other questions, as we as a society lack the basic knowledge. This lack of knowledge does not seem to be an appropriate basis on which to build a national energy policy.

3. EMERGING SOCIAL DATA FROM HEEP

HEEP currently provides us with socio-demographic information for 399 households in dwellings that can be analysed in relation to indoor temperatures, energy use, energy consumption behaviours and, eventually, in relation to the energy performance of dwellings and relevant dwelling characteristics. Of those dwellings, the 296 for which monitoring has been completed at this point can also be analysed in relation to total energy consumed across all fuels.

In this section we investigate the socio-demographic characteristics of those 399 households. We then analyse the associations between key socio-demographic characteristics and indoor temperatures. The fuel use in each dwelling in relation to those socio-demographic characteristics is then considered. Finally, we comment on they way in which this data illuminates the connections between energy and social policy in New Zealand.

3.1 Socio-demographic characteristics of the HEEP households

The predominant household composition type in the 399 dwellings is the couple-with-children household. Those households make up 35.5 percent of the households, followed by couple-only households (31 percent), with one-person households at 13.1 percent.

Figure 13 compares the household composition profile of the HEEP households with New Zealand households as recorded in the 2001 Census.

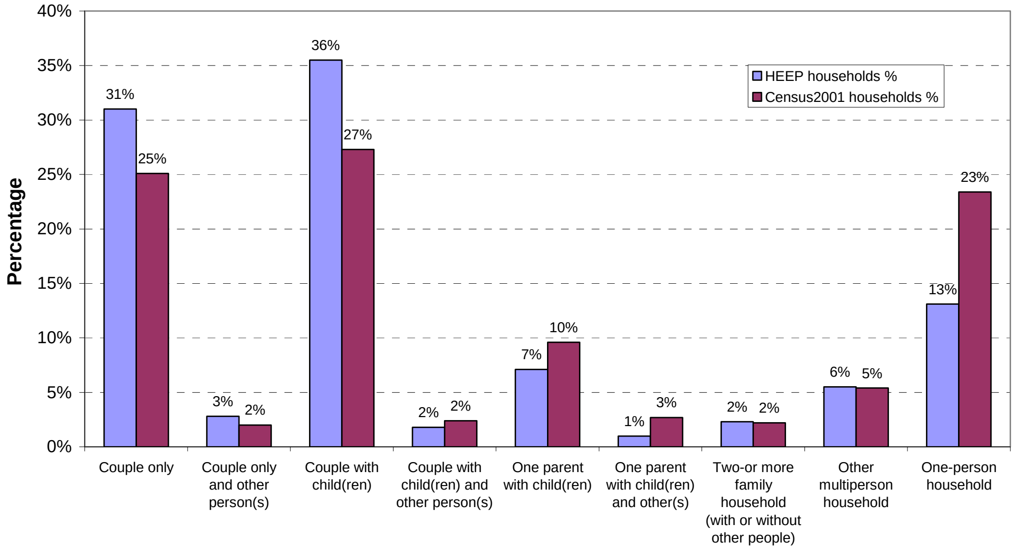


Figure 13: HEEP household composition and NZ 2001 household composition

Similar proportions of the HEEP households had members under five years of age (15.4 percent) or members 65 years or older (15.9 percent). Figure 14 sets out the profile of households in relation to critical life stages associated with the youngest household member.

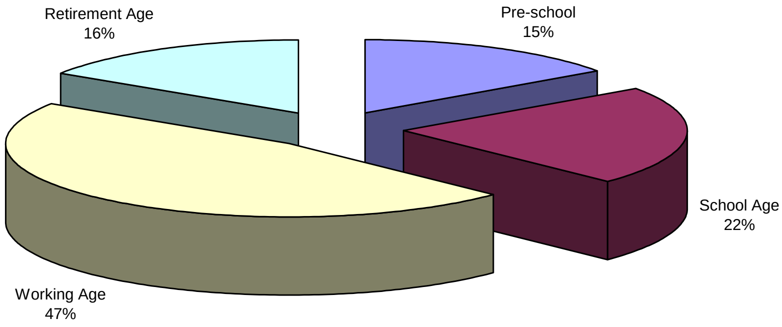


Figure 14: Age of youngest household member HEEP households

Just over a quarter of the households had no adult member of the household in employment (25.2 percent), while 17.4 percent 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.

Using the Luxemburg method (Atkinson et al, 1995) for calculating equivalised household income to control for household size effects, the quintile boundaries are:

- Quintile 1 – $1,118–$15,000
- Quintile 2 – $15,653–$24,597
- Quintile 3 – $24,749–$33,333
- Quintile 4 – $35,000–$45,000
- Quintile 5 – $49,498–$90,001.

Preliminary analysis suggests that the following household types are over-represented among the lowest household income quintiles:

- one-person households
- other undefined multi-person households
- one-parent with children households
- multiple family households with children households
- couple-with-children plus others households
- couples with others households.

The latter are also over-represented in the highest income quintile. 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 15 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 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 quintile 5.

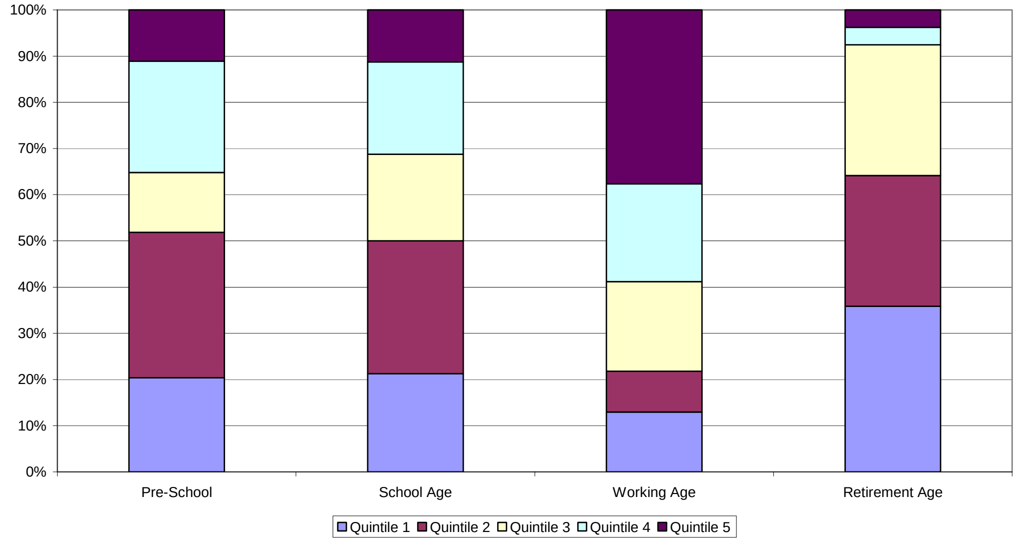


Figure 15: Equivalised HEEP household income by youngest household member

3.2 Indoor temperatures and socio-demographics

The emerging data from an analysis of equivalised household income appears to show some connection between household income and indoor temperature differentiations. This analysis is very preliminary and should not be regarded as definitive and may be subject to change. Nevertheless, when considering mean temperatures in living rooms in the evening, it does appear that low quintile groups are over-represented in those dwellings which might be described in comparison to other HEEP dwellings as cold or below average. Conversely quintiles 3 and 4 tend to be over-represented in dwellings which are hot by comparison to other living room mean evening temperatures. In relation to average evening living room temperatures, both quintile 4 and quintile 5 are over-represented (Figure 16).

By contrast, similar but very preliminary analysis suggests little association between mean evening living room temperatures and household life stage. Households with the youngest member in retirement appear to be slightly under-represented in the dwellings that are relatively cold and somewhat over-represented in the dwellings that are relatively warmer. Similarly, households with the youngest member being a pre-school child tend to be slightly over-represented in relatively cold households and in households with above average mean evening living temperatures. They are, however, under-represented in dwellings that could be categorised as having relatively hot mean living room evening temperatures.

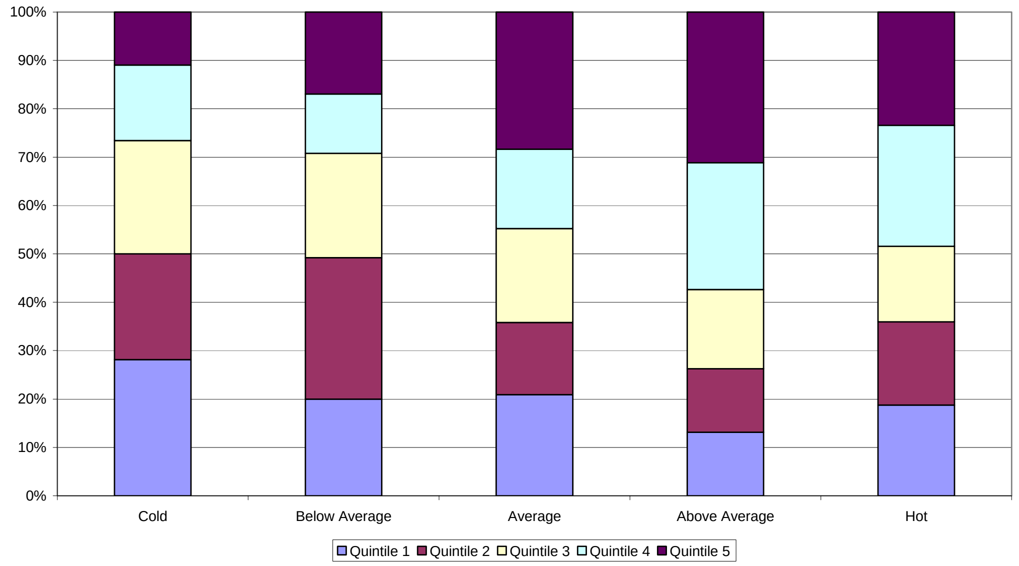


Figure 16: Equivalised household income by evening mean living room temperature

While that analysis is preliminary, the HEEP data provides some tantalising insights into temperature outcomes. The opportunity now is to explore the way in which household behaviours and energy inputs and dwelling characteristics dynamically contribute to what might be broadly described as comfort outcomes for households with different life chances.

3.3 Total fuel and socio-demographics

The total fuel consumed by households when analysed according to quintiles* does show some variation according to household composition and life stage characteristics. In relation to household size, there is a strong over-representation of larger households among the higher total fuel consumption households and a converse over-representation of one-person households among low household fuel consumption. This is expressed in Figure 17.

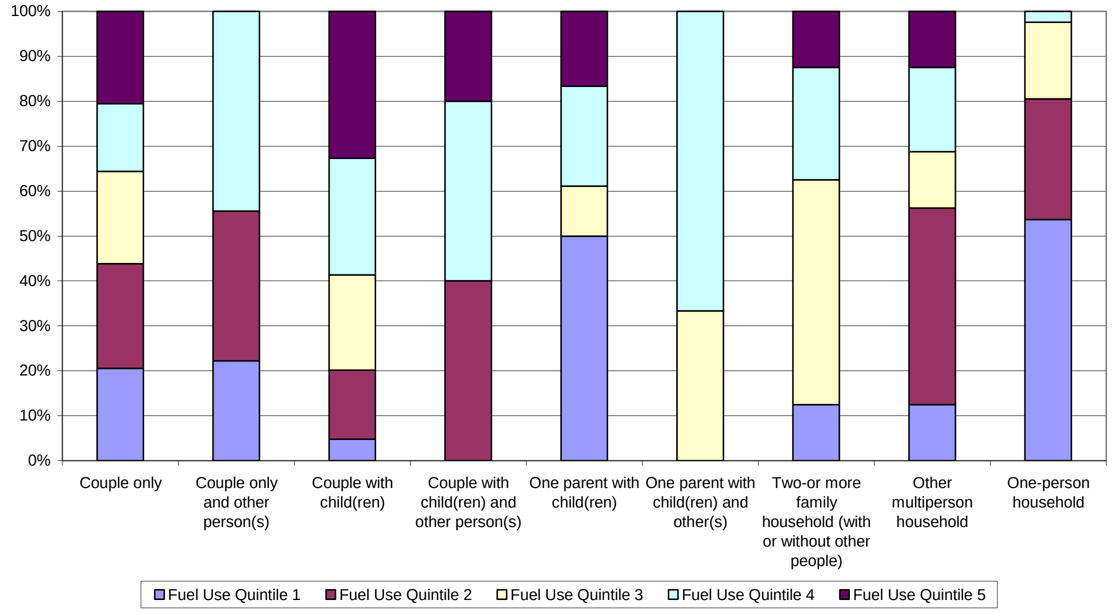


Figure 17: Total fuel use by household composition

* Quintile 1 – lowest 20% to Quintile 5 – highest 20% of total fuel energy consumption.

The association between life event and total fuel use is marked for households in two life stages. First, households whose youngest member is aged between 5–14 years tend to be over-represented among the higher total fuel use quantities. By way of contrast, households whose members are all in excess of retirement years are over-represented among the 20 percent of households who make up the lowest quintile of total fuel users (Figure 18).

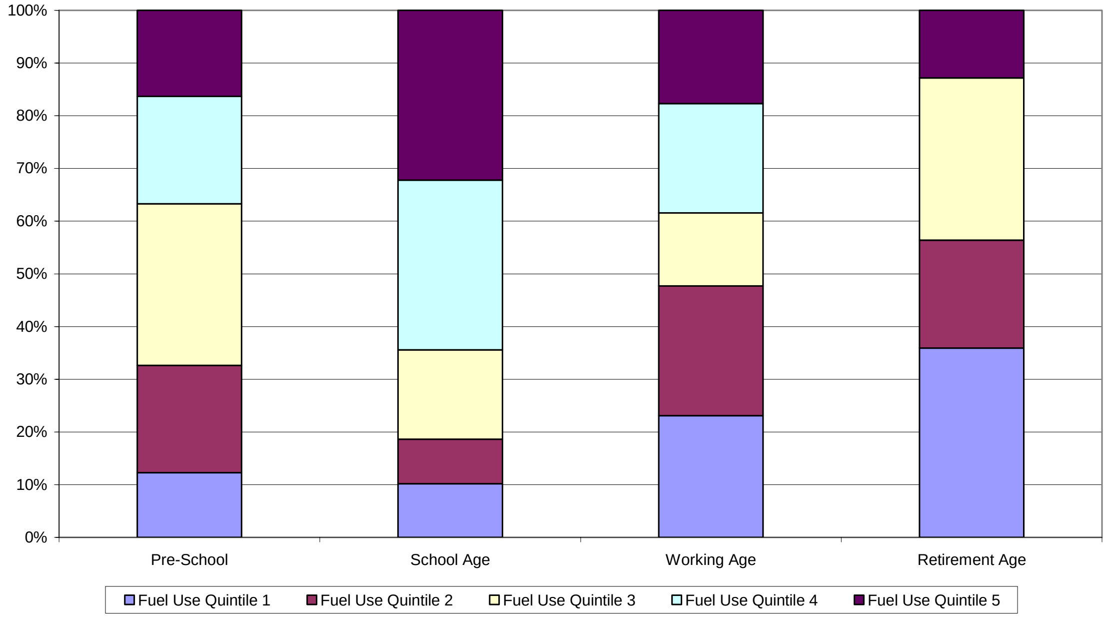


Figure 18: Total fuel use by age of youngest household member HEEP households

Considerable over-representation of households in the lowest equivalised income group is also found among the lowest quintile of total fuel users. Conversely, households within the top equivalised income quintiles are also over-represented among the 40 percent of households with the highest total fuel consumption (Figure 19).

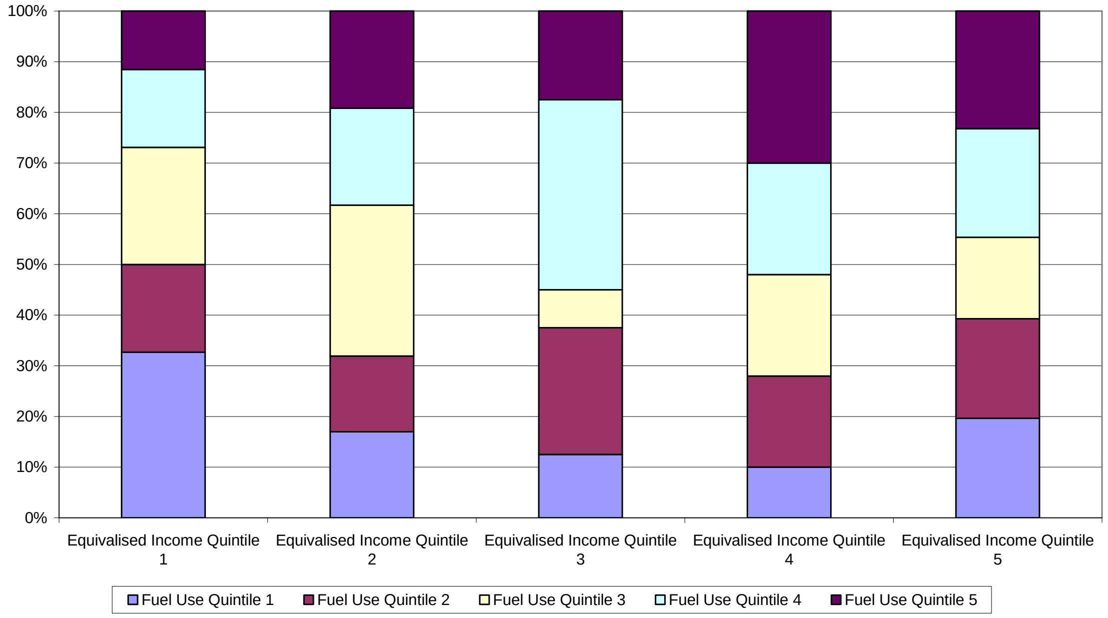


Figure 19: Total fuel use by equivalised household income

While this analysis of the social data is very preliminary, it is already generating a better understanding of the way in which the characteristics of dwellings moderate, or are moderated by, the social characteristics of households and their dynamic interface with the labour market, life events and lifestyles. Most importantly, the emerging HEEP data on the social aspects of energy consumption within domestic dwellings reads directly to a critical but largely ignored interface between energy policy and social policy.

3.4 Energy and social policy: a neglected interface

The connection between energy policy and social policy has been largely ignored. Neither social policy outcomes nor the energy policy outcomes have incorporated mutually reinforcing success measures. Nor, indeed, has there been a critical analysis of the extent to which energy policy outcomes and social policy outcomes are consistent or in tension with each other.

There are two examples in New Zealand of programmes in which the connection between social policy and energy policy is actively expressed. The first is the retrofit insulation programmes partially subsidised by central Government through the Energy Efficiency and Conservation Authority (EECA) which in some regions uses the Community Services Card as a targeting mechanism. The second is in the income support system in which beneficiary families facing extraordinary circumstances can apply for welfare assistance to meet household expenses. One of those household expenses is the cost of energy.

In the United Kingdom the interface between energy policy and social policy has been played out in public and there are political concerns around fuel poverty. The concept of fuel poverty has not to date shown much traction in New Zealand. The United Kingdom and New Zealand have very different built stocks but, more importantly, New Zealand's temperatures are considerably more moderate than those found in the United Kingdom. This is not to suggest that fuel poverty does not exist in New Zealand. There are some indications that the pre-conditions at least exist for fuel poverty. There are, for instance, inequalities in relation to fuel access between low income and high income groups, with low income groups tending to be exposed to higher proportions of their income on energy than high income groups. Similarly, within the beneficiary population the inability to cope with additional financial pressure associated with periodic increases in energy bills (either through price increases for electricity supply or unit price or consumption increases within the household) are typically cited as reasons for requiring additional benefit assistance or help from food banks. In addition, it is also clear that fire deaths, in rural areas at least, have been associated with households using flame-based heating and lighting, either because they cannot bear the costs of reticulating electrical energy to a dwelling or because a household has not been able to maintain supply. Information related to fuel poverty is, however, fragmentary and unsystematic.

The fragmentary nature of information around fuel poverty and other social dimensions of energy reflects, among other things, three key tendencies:

- First, because energy is a universally consumed good in which the market is the primary mechanism of distribution, there has been little analysis of the differential access of households to energy. In effect, the interface between the social and energy policy has been too pervasive to become defined as problematic and incorporated into the rubric of social policy.

- Second, and connected to the first reason, social policy has had a history in New Zealand of being reduced to a focus on welfare policy. While there are, as we will see, strong connections between energy policy and welfare policy, to date these have been largely marginalised in the income adequacy debates which have seen adjustments in benefit levels as being the primary mechanisms to deal with deficient energy access among beneficiary households.
- Third, energy policy has been preoccupied by supply issues and management, rather than issues of demand and demand management or the issue of household access to energy and the implications for households of their energy consumption.

While energy is seen as a fundamental requirement of our society, energy policy has principally focused on the supply of energy from a capital-intensive energy sector with a small number of major suppliers and usually large industry-based consumers. Energy supply is, thus, well understood, but the same cannot be said for energy demand, which is simply viewed as ever-increasing. Much of that demand for energy is within homes and represents a complex interaction between a dwelling and the households living in them.

We believe that there are four critical questions around energy that can be illuminated by the HEEP data and connect energy policy to social policy. They are:

i. To what extent are well-being outcomes associated with differentials in access to and the efficient use of energy?
ii. What are the determinants of differential household energy use and energy efficiencies?
iii. 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?
iv. To what extent can the optimisation of low income households' incomes be pursued through energy efficiency?

The first and second questions are intimately connected. In relation to well-being, the most obvious domain of well-being concern relates to temperatures. Compared to similar societies overseas, New Zealand households use relatively little energy. One important reason for this is that New Zealanders appear unwilling to heat their houses to the levels considered comfortable and healthy by the World Health Organisation. However, cold indoor temperatures are associated with damp and mould. Cold, damp and mould have been associated in the international literature with a wide range of health risks. While preliminary analysis of household income and temperature did not reveal a significant relationship between the two, the initial data analysis did not equivalise household incomes in any way. Consequently, the income effects tend to be masked by household size effects. As we have shown using equivalised incomes and income quintiles, there does appear to be an over-representation of low income quintiles among colder dwellings.

There are also safety concerns around energy use. Exposure to gases in domestic spaces due to unflued LPG heating, exposure to open flames, and exposure to highly energy inefficient hot water temperatures are all risks associated with poor health and safety outcomes.

A variety of analyses are being undertaken in relation to temperatures and energy use to ascertain the extent to which household differentials account for differentials that may affect life chances and to tease out the complex relationship between dwelling, household characteristics and behaviours. These include analysis of the:

- relationship between equivalised household income and temperature
- total energy use by households according to:
  - equivalised household income
  - dwelling characteristics
  - life event stage
  - labour market positioning
  - temperature outcomes
- dwelling characteristics and appliance profiles by household characteristics to establish the extent to which lower socio-economic status households tend to:
  - access dwellings with lower levels of energy performance
  - use appliances with lower energy efficiencies
- differential exposure of households to health and safety risks associated with energy use.

In connecting social policy and energy policy it is important that the two separate preoccupations of each sector are recognised. For the energy sector the question is the extent to which the nation's 'energy efficiency' may be increased and energy consumption minimised through the targeting of households with different socio-economic and demographic characteristics. For the social policy sector, especially but not only in the welfare context, the question is the extent to which income maximisation for low income households may be pursued through energy efficiency. In the context of cross-sectoral policy responses within a whole-of-government approach, the issue is to identify where there are levers which can generate both energy outcomes and income maximisation/well-being outcomes.

While we still have a long way to go analytically on these issues, the analysis so far would suggest that the more appliances a household has the more energy they use and the more heating they do. If those consumption patterns transpire to be connected with income in what we might expect, given the consumption patterns evident in the Household Economic Survey, then it might be wise to target general energy reduction interventions to high user households. Moreover, it may be that we need different measures for energy programmes which recognise the needs of all households as well as the nation's energy conservation requirements. Retrofit insulation, for instance, might be an example in which the achievement of outcome is not only measured through energy use reductions but also by relative increases in comfort and income optimisation.

There are, of course, some appliances that low income households use which are high energy use appliances or, in some cases, expose households to high levels of expensive energy use when there are cheaper alternatives. Old refrigerators and freezers are a case in point. Indeed, it might be argued that in general appliances at similar levels of functionality are becoming increasingly energy efficient. Some 18% of refrigeration appliances (refrigerators, combined fridge/freezers, freezers) appear to have some form of problem. In about 10 percent the wastage is so large that there would be real benefits from replacement of the appliance.

This has implications for both subsidised programmes directed at reducing energy consumption, as well as practices around benefit assistance, and even for the way in which our non-governmental support agencies assist households in need. The relative energy benefits, as well as the relative income optimisation benefits, might be greater if EECA subsidised the purchase of new efficient appliances for low income households along with, or may be instead of, increasing the insulation of their dwelling. The tendency for beneficiaries or households in need to be ‘sent off’ to replace appliances such as refrigerators and washing machines through the local second hand appliance dealer may be a less sustainable option both environmentally and for income maintenance than ensuring that high energy performance appliances are purchased. Within the framework of the whole-of-government approach, there does seem opportunity for the energy and welfare agencies to come together to facilitate the outcomes they all want.

4. LPG HEATERS

This section of the report discusses the ownership and usage of portable unflued LPG cabinet heaters, more commonly called LPG heaters. This analysis does not include the use of LPG appliances attached to fixed gas piping in the house (usually fed from one or more externally mounted 45 kg home gas cylinders). This section provides an update of the material presented in the HEEP Year 7 (Isaacs et al, 2003), HEEP Year 6 (Isaacs et al, 2002) and HEEP Year 4 (Camilleri et al, 2000) reports.

4.1 Heater numbers

The monitoring for HEEP in 2003 and 2004 has seen a large increase in the number of LPG heaters encountered in the sample households. The selection process commenced with the major population centres followed by minor centres, leaving minor urban and rural areas to the last two years of monitoring.

Figure 20 provides a comparison of the observed number of LPG heaters per household for city (the urban level is either major urban or secondary urban) or small town/rural (the urban level is minor urban or rural).While there is a noticeable difference in the means, the wide range of variation in the numbers of LPG heaters per household suggests that additional factors need to be considered.

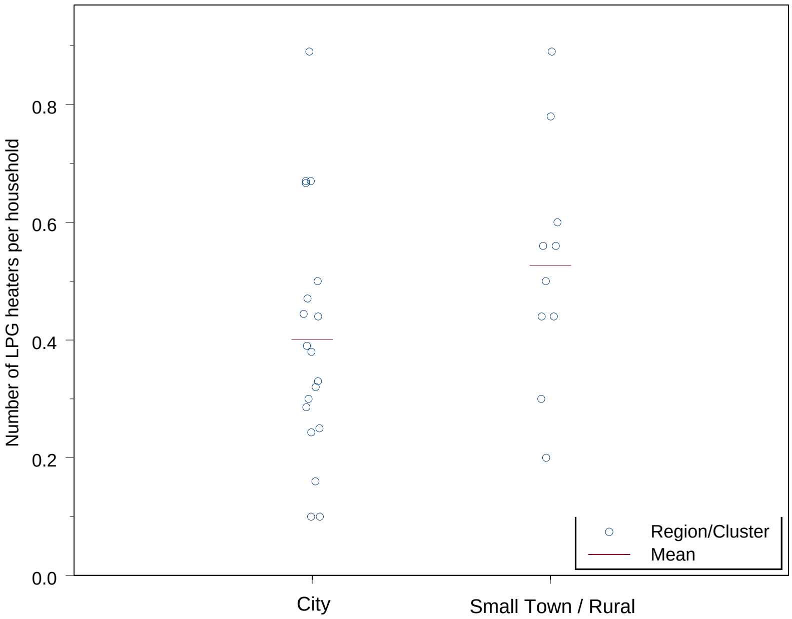


Figure 20: LPG heaters per household in city and small town/rural areas

Table 1 shows that the preliminary total number of LPG heaters in the HEEP random sample is 157 with approximately 58 being currently monitored. A further 17 heaters were also encountered in the non-random HEEP dataset comprising replacement households, special sample houses (Hamilton pensioner houses) and pilot study houses (Wanganui).

HEEP monitoring period	Households in random HEEP sample: Number	With portable LPG heaters	With portable LPG heaters (%)	LPG heaters in random HEEP sample: Number	Average number per household
1999 †	41	16	39%	16	0.39
2000	17	7	41%	8	0.47
2001/02	97	27	28%	28	0.29
2002 †	47	10	21%	10	0.21
2003	99	36	36%	37	0.37
2004 ‡	98	54	55%	58	0.59
TOTAL	399	150	38%	157	0.39

Table 1: Ownership of LPG heaters in the current HEEP sample

† Figures for Wellington and Christchurch have been revised from previous HEEP reports
‡ LPG heater count for currently monitored regions is preliminary and subject to change.

The HEEP Year 7 report (Isaacs et al, 2003) reported on average 0.31 LPG heaters in use per household. Table 1 shows that a preliminary figure for the total number of the LPG heaters per household in the complete random HEEP sample is 0.39. Taking the number of private dwellings in New Zealand as approximately 1.3 million (2001 Census) the HEEP sample would infer that there are approximately 500,000 LPG heaters in New Zealand households.

The regular Household Economic Survey (HES) undertaken by Statistics NZ (1984–2001) provides information on the ownership of a number of appliances types, including gas heaters. It categorises gas heaters as either 'fixed gas heaters' or 'portable gas heaters'. The portable gas heater category would include portable unflued LPG cabinet heaters, as well as any portable unflued gas heaters that are attached to the houses' piped gas supply via a bayonet plug.

The HEEP database has not distinguished between fixed and portable gas heaters, but instead has records whether the gas heater was flued (and therefore fixed) or unflued which could be either fixed (such as a hallway panel heater) or portable (via a bayonet plug). From an examination of the available photos of unflued gas heaters in HEEP, half of these were fixed with the remaining half being portable. With a total of 35 unflued gas heaters in the HEEP sample, this would take the ownership of portable gas heaters per household to 0.43 (equivalent to 560,000 extrapolated to all New Zealand households), 90% of which are portable unflued LPG cabinet heaters.

The HES survey reports on the proportion of households with a particular type of heater and not the number of heaters per household. From the 35 additional unflued heaters in the HEEP sample, it is estimated that an additional 10 households had portable gas heaters, giving a total 40% of households (520,000 over all New Zealand) with portable gas heaters. The HEEP Year 6 report (Isaacs et al, 2002) states that the 2001 HES survey reported that 33% of houses owned a portable gas heater (430,000) but that there was a growing trend over the years for this type of heater. The next HES survey for 2004 (now on a three-yearly cycle) will be released in 2004 and further comparisons will be undertaken.

4.2 LPG heater and dehumidifier ownership

Table 2 provides a preliminary cross-tabulation of the total ownership of LPG heaters and dehumidifiers in the HEEP random sample. There has been a small narrowing of the difference in the proportion of households with dehumidifiers in LPG owning and non-LPG heater owning households since this result was presented in the HEEP Year 7 report (Isaacs et al, 2003). Households without an LPG heater now have a 22% chance of having a dehumidifier, whereas those with an LPG heater are approximately 40% more likely to have a dehumidifier with 31% of LPG heater owning households also owning a dehumidifier.

	No LPG	LPG	Total
No dehumidifier	194	104	298
Dehumidifier	55	46	101
	249	150	399

Table 2: Ownership of LPG heater and dehumidifier

4.3 Heater types

The properties of an LPG heater were only recorded if the heater was stated as used and available for instrumentation at the time of the installation visit. The properties recorded were the make and model of the heater, whether the heater had discrete settings or a thermostat, whether the heater had radiant panels or was a convective heater, the number of settings and the gas consumption rates for each of these settings. From the completed monitoring of 99 heaters, 66 had these details recorded (no details were recorded for the Wellington houses).

Ninety-seven percent (64) of the heaters with information recorded were of a radiant panel design with the remaining two being of a convective 'blanket' design. Seventy-nine percent (52) of the heaters examined had three settings (low, medium, high) with 11% (7) having an additional economy setting. Three percent (2) of the heaters were of a compact two setting design, with these settings comparable to low and medium settings on the other systems.

Figure 21 provides histograms of the gas consumption rates for each of the settings of each of the heaters, with Table 3 providing details on the number, mean and standard deviations of the levels of each of the heaters.

Setting	Number	Gas flow (mean)	Gas flow (std deviation)
Economy	7	840 W	140 W
Low	61	1410 W	290 W
Medium	61	2520 W	380 W
High	59	3770 W	360 W

Table 3: Mean gas flow rates for each setting

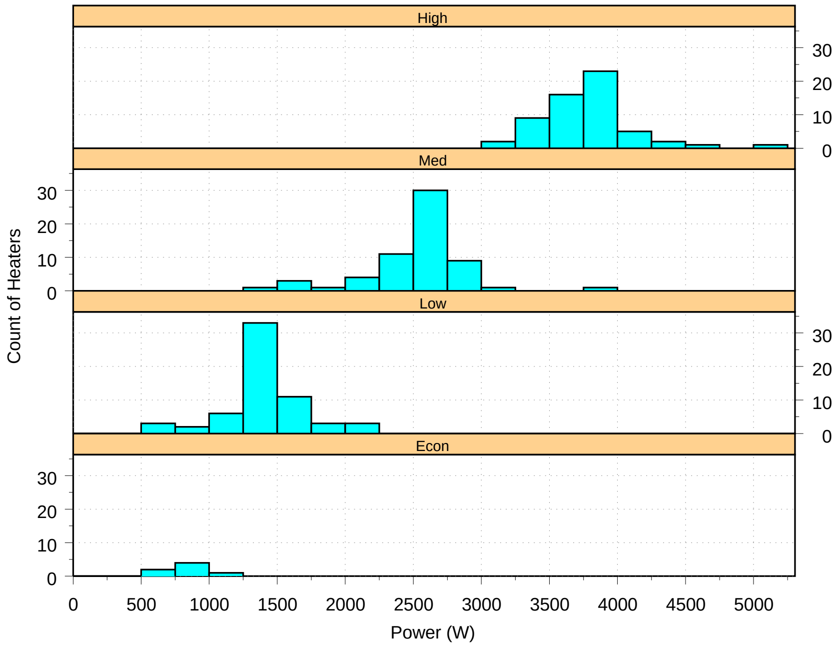


Figure 21: Gas consumption rates for radiant non-thermostat LPG heaters

4.4 Data availability

The number of LPG heaters available for analysis since the HEEP Year 7 report (Isaacs et al, 2003) has more than doubled, with data from 54 heaters being recorded over the June to August period (the comparable figure from last year was 22). The currently monitored households have an estimated 57 additional heaters, so the number of heaters able to be analysed next year will approximately double. Table 4 gives a breakdown of the number of heaters available for analysis broken down by region.

Normally only heaters reported during the occupant survey as being used were instrumented. Overall, 84% of heaters owned were reported as being used.

The reliability of the occupant response was accidentally tested in two houses. In one household the survey respondent reported that the heater was not used, but the heater was monitored. Data from this 'not used' heater shows that it was used on average for nine hours per week over winter. In another house, a second heater was monitored despite the survey response indicating it was not used, although in this case the recorded data confirms that the heater was not used

The column in Table 4 *With data (no monitoring issues)* gives the number of heaters in each region that were present and could have been operated over the monitoring period. A typical reason for heaters that were reported as being used, but not appearing in this list, is the heater being sold or an occupant moving out.

The column *With data (monitoring issues)* gives the number of heaters from the *With data (no monitoring issues)* column that have not had complete data loss over the winter period due to thermocouple wiring faults or logger faults. This column also includes LPG heaters that were not instrumented, particularly 13 houses in Wellington when the monitoring technique was not available, and the occasional household where the installation team did not realise an LPG heater was in use in the household.

Finally, the last column of Table 4 *Winter use recorded* gives the number of heaters that had non-zero energy use recorded over the winter. The remaining eight of the 54 heaters with data had only zero energy use recorded (heater not used) over the June to August period.

4.5 Patterns of use

In order to examine length of use and energy consumption of the LPG heaters it will be assumed that the heaters surveyed as 'not being used' had zero usage and zero energy consumption. The LPG heaters from the Wellington region are excluded from this analysis (due to biasing the 'not used' category), resulting in a current sample size of 65 heaters.

It is interesting to note that 30% (19) of these 65 heaters were either surveyed as not used or had no usage recorded over the winter period.

	Number of LPG heaters				
Monitoring period	***Owned***	***Reported as used***	***With data (no monitoring issues)***	***With data (monitoring issues)***	***Winter use recorded***
1999	16	13 (81%)	13	0	0
2000	8	6 (75%)	5	5	4
2001/02	28	24 (86%)	20	18	13
2002	10	8 (80%)	6	4	4
2003	37	32 (86%)	33	27	25
Total	99	83 (84%)	77	54	46

Table 4: Usage of LPG heaters from the processed HEEP LPG sample

Both the histograms of hours of use (hours per week) and gas consumption (kWh per week) from the 65 heaters seen in Figure 22 and Figure 23, show high positively skewed distributions with the first bin of data (0–5 hours per week and 0–15 kWh per week) accounting for over 40% of the heaters. Note that Figure 22 and Figure 23 count the heaters surveyed as not used as using zero hours or energy per week.

Table 5 provides the mean and standard deviations of the on-time and the energy consumption for all the 65 heaters, and also those that recorded non-zero consumption (46).

		Heater on-time (hours per week)		Energy consumption (kWh per week)	
	Number	**Mean**	**Std Dev**	**Mean**	**Std Dev**
All heaters	65	12	15	25	30
Heaters that were used	46	18	15	36	34

Table 5: Mean LPG heater duration and energy consumption

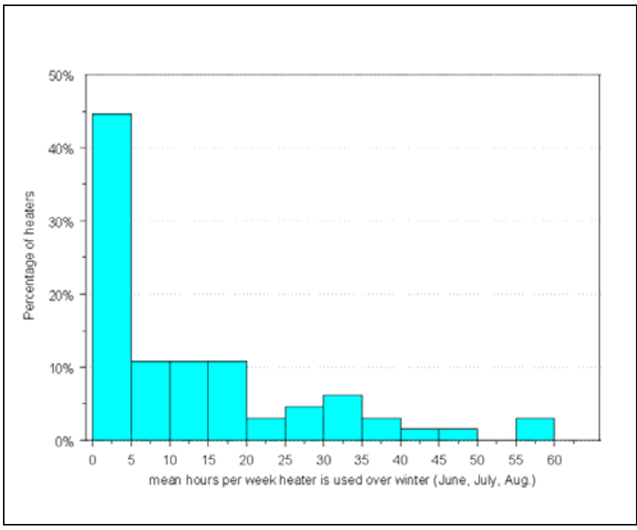


Figure 22: Histogram of hours of use LPG heaters (winter months)

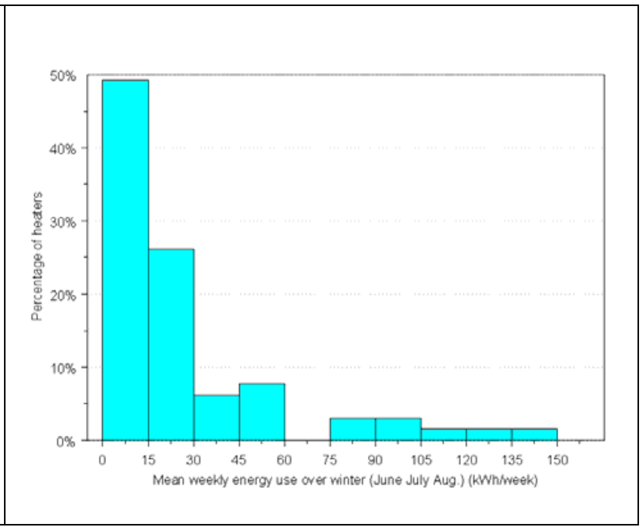


Figure 23: Histogram of the energy use for LPG heaters (winter months)

Figure 24 shows a histogram of the portion of the time each of the 46 LPG heaters in the sample that had recorded winter usage is operated in its primary setting. Half of the heaters in the sample spend more than 88% percent of the time they are on in their primary setting.

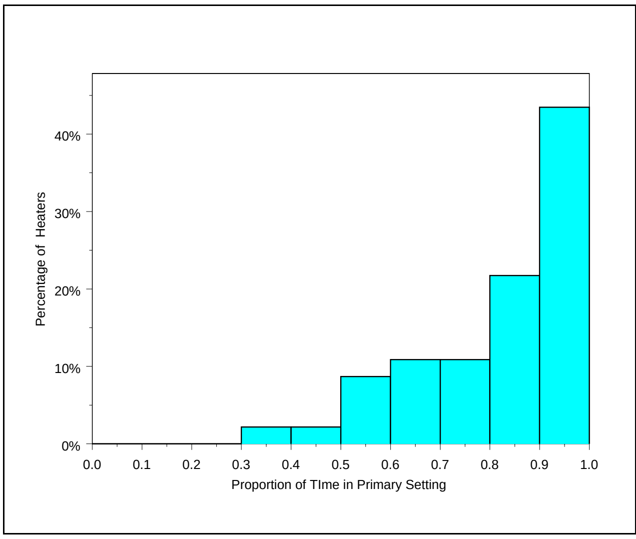


Figure 24: Proportion of the time spent in the primary settings for LPG heater

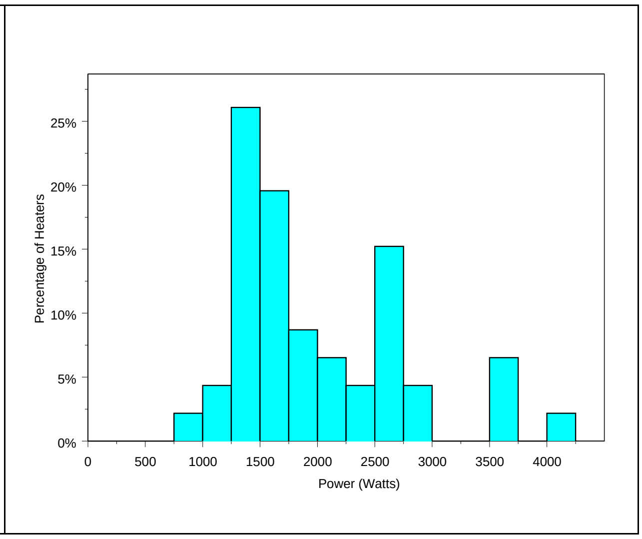


Figure 25: Expected gas consumption for the 'on' setting for each LPG heater

For these 46 heaters; 67% (31 heaters) had either a low (29) or economy (2) setting as the most preferred setting, 22% (10) operated their heater on medium most frequently, while 11% (5) had a preference for the high setting. Figure 25 provides a histogram of expected gas consumption rate for operating LPG heaters showing increases in the number of heaters around the 1500 W, 2500 W and 3500 W levels corresponding to low, medium and high settings respectively.

Figure 26, Figure 27 and Table 6 provide information on the amount of energy used and time spent in each of the settings for the 46 used LPG heaters. These again show the popularity of the low and medium settings, with the hours of use for each setting decreasing as the power of the setting is increased. In terms of energy consumption, both the low and medium settings have a similar average which is over twice that for the high setting.

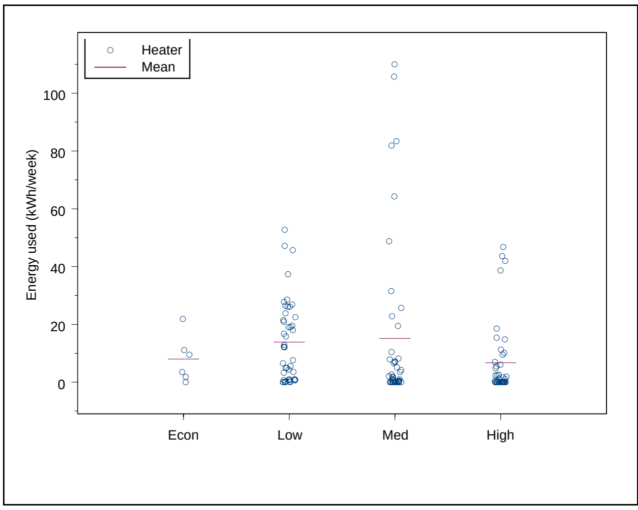


Figure 26: Energy used by each setting for heaters with winter usage

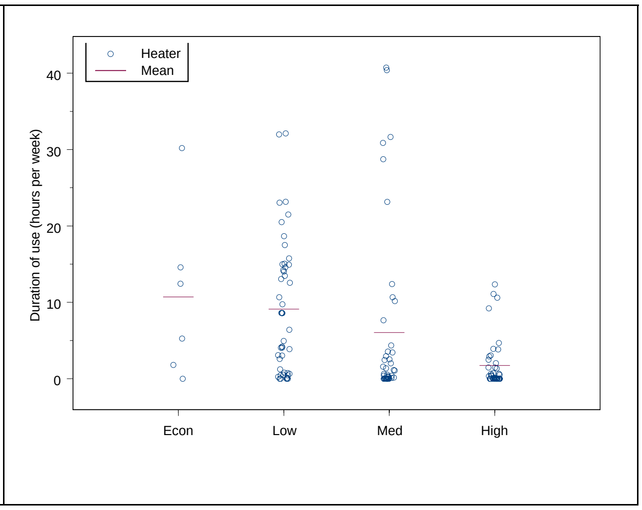


Figure 27: Time in each setting for heaters with winter usage

Setting	Heater on-time (hours per week) Mean	Heater on-time (hours per week) Std Dev	Energy consumption (kWh per week) Mean	Energy consumption (kWh per week) Std Dev
Economy	11	11	8	8
Low	9	9	14	14
Medium	6	11	15	29
High	2	3	7	13

Table 6: Mean energy consumptions for each setting

As was the case with the total energy and total time in use, the variations in the time and energy use of each setting are large.

5. INDOOR TEMPERATURES

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

The indoor temperatures and heating seasons reported here are based on final HEEP monitored data (399 houses). This is possible, even though the final year of monitoring will not be completed until 2005, as monitoring for the winter period is over for the final houses and all the household surveys are complete.

5.1 Historical comparison

What temperatures are found inside New Zealand houses, and what are the drivers? Earlier HEEP reports have investigated this area and have found indoor temperatures to be somewhat lower than would be expected. Table 7 compares the results of the HEEP monitoring with the 'lounge' temperatures for the August-September months by region from the 1971/72 Household Electricity Survey (Statistics NZ,1976).

Aug-Sep temperatures °C	**Northern North Island**		**Southern North Island**		**Christchurch**		**Southern South Island**	
	HEEP 2001-2004	**1971**	**HEEP 1999, 2002-2004**	**1971**	**HEEP 2002**	**1971**	**HEEP 2003**	**1971**
Living room:								
Mean temperature	16.5	17.7	16.1	16.6	16.1	15.2	14.7	13.6
Standard deviation	0.1	-	0.2	-	0.3	-	0.5	-
95% Confidence interval	16.2-16.8	-	15.8-16.5	-	15.4 – 16.7	-	13.7-15.8	-
External:								
Mean temperature	11.9	12.0	9.3	11.0	10.3	9.3	7.3	8.6
Mean temperature difference	4.6	***5.7***	6.9	***5.6***	5.7	***5.9***	7.4	***5.0***
Sample size	112	98	74	64	34	69	30	64

Table 7: HEEP and 1971 descriptive temperatures by region

The 1971/72 temperature study found a strong consistency in the differences between inside and outside temperatures (in ***bold italics*** in Table 7), and concluded that this indicated that "in homes throughout New Zealand, rooms tend to be heated to certain levels above the surrounding outside air temperature, rather than to a universal absolute temperature level."

This would not appear to be the case for the HEEP sample, with the temperature differences shown in Table 7 ranging from 4.6°C in the Northern North Island to 7.4°C in the Southern South Island. Table 7 would suggest that excluding the Southern South Island, average living room temperatures are close to 16°C.

5.2 Heating patterns

The first step to evaluating winter evening temperatures was to determine the most common heating season based on the occupant survey response to questions about the first and the last month when heating is used. Table 8 and Figure 28 give the number of houses reporting the given start or finish month. Note that the six households that heat all year round are given a January start and December finish month. The majority of houses (72%) report starting in April or May and finishing in September or October.

	Month	Number start	Number end
1	January	6	
2	February		
3	March	18	
4	April	131	
5	May	131	1
6	June	58	1
7	July	14	8
8	August	3	51
9	September	1	142
10	October		116
11	November		32
12	December		9

Table 8: Reported heating season

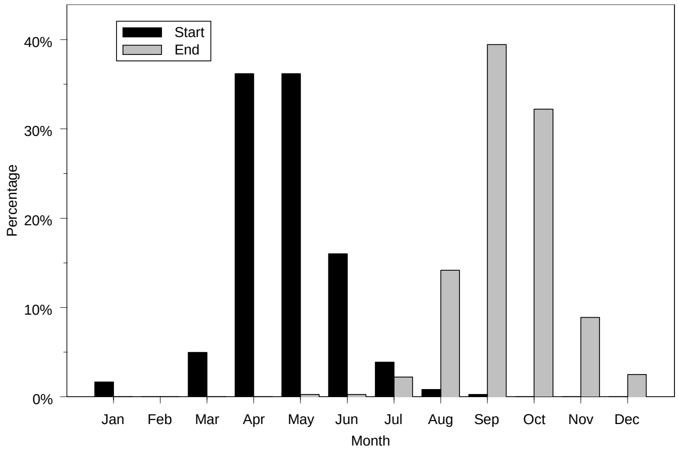


Figure 28: Reported heating season start and finish

Figure 29 (also based on survey data) gives the length of the reported heating session, with the number of houses in each band given in brackets on the y-axis. It shows that households that start heating early in the season also finish later in the season.

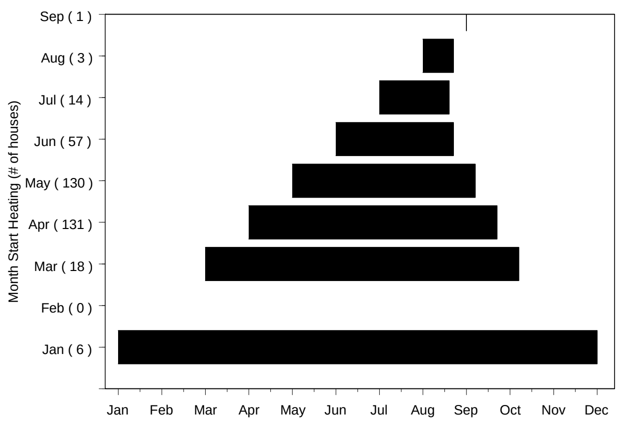


Figure 29: Length of reported heating season

Table 9 shows that the average starting and finishing heating seasons show statistically significant variations by region – households in cooler climates, on average, start heating earlier and finish heating later than those in warmer climates.

Month 1 in Table 9 is January through to month 12 which is December. The nearest month is given based on the rounded average.

On average, heating commences in late-April (4.7) and on average finishes in mid-September (9.4).

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

Region	Group	Start		Finish		Length	SD	Count
Kaikohe	Northland	6.4	June	8.4	August	2.0	0.4	8
Kamo West		5.4	May	9.1	September	3.7	0.5	10
Sherwood Rise		6.2	June	7.8	July	1.5	0.3	4
Orewa		5.7	May	9.2	September	3.5	0.9	6
North Shore	Auckland	4.9	April	9.5	September	4.5	0.4	15
Waitakere		5.2	May	9.2	September	4.0	0.4	13
Auckland		5.0	May	9.2	September	4.3	0.4	25
Manukau		5.3	May	9.1	September	3.7	0.4	18
Awhitu	Waikato/BOP	4.5	April	9.5	September	5.0	0.4	6
Parawai		4.7	April	9.6	September	4.9	0.6	9
Minden		4.7	April	9.3	September	4.6	0.9	10
Tauranga		5.8	May	8.6	August	2.8	0.9	5
Hamilton		5.2	May	9.8	September	4.6	0.3	12
Arapuni	Central NI	4.5	April	9.5	September	5.0	0.4	10
Western Heights		4.5	April	9.3	September	4.8	0.7	6
Ngakuru		4.4	April	9.4	September	5.0	0.4	8
Mangapapa	East Coast	4.2	April	8.7	August	4.4	0.2	9
Rangatira	Central NI	4.0	April	10.0	October	6.0	0.4	6
Wairoa	East Coast	4.8	April	9.2	September	4.4	0.3	9
Tamatea North	East Coast	4.8	April	8.8	August	4.0	0.6	8
Foxton Beach	Lower NI	4.4	April	9.7	September	5.2	1.0	9
Waikanae		5.2	May	9	September	3.8	0.2	6
Wellington	Wellington	4.7	April	9.5	September	4.7	0.3	22
Wai-iti	Upper SI	4.0	April	10.1	October	6.1	0.8	8
Seddon		4.0	April	8.9	August	4.9	0.3	7
Christchurch	Christchurch	4.5	April	9.3	September	4.8	0.3	31
Oamaru	Otago/Southland	3.8	March	9.9	September	6.1	1.1	8
Dunedin		3.8	March	10.2	October	6.4	0.7	12
Invercargill		4.0	April	10.2	October	6.2	0.2	6

Table 9: Average heating season by region (from North to South)

The period between June and August (inclusive) continues to be used as the winter heating season for HEEP analysis. The evening period was taken to be the time between 17:00 and immediately before 23:00. The average winter evening temperatures were then calculated for each household using the winter season and the evening periods. If multiple loggers were present in the family room, then the averages of the logger readings were calculated, although no account was taken of logger heights or consistency between different households. As loggers are generally installed at two different heights, i.e. at about 0.4 m and about 2.0 m, the average temperature should be representative of temperatures at around 1.2 m height.

5.3 Heating schedules

Heating schedules were reported by the occupant when surveyed. Differences between region and weekday/weekend for daytime heating can be seen in Figure 30 which shows the percent of houses in each region that heat the living room for that part of the week. Not surprisingly, houses in the colder climates (Southland/Otago, Central North Island etc) heat more during the day than houses in the warmer climates, with more heating being done on the weekends when occupants are more likely to be at home. A reason for the decrease in heating during the day for the Lower North Island and Wellington has yet been determined. Preliminary comparisons of the daytime house occupancy and the heating schedule show no significant relationship.

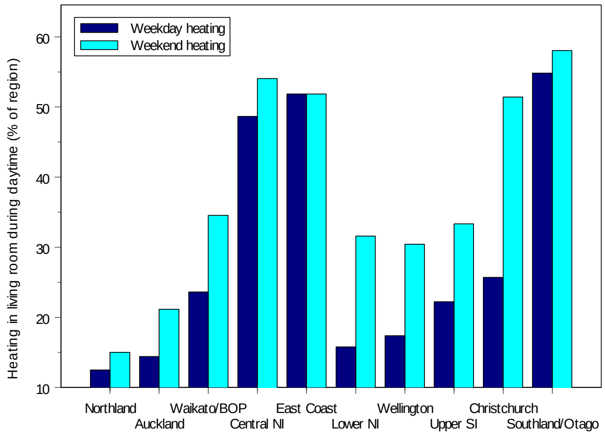


Figure 30: Living room daytime heating by region and weekday/weekend

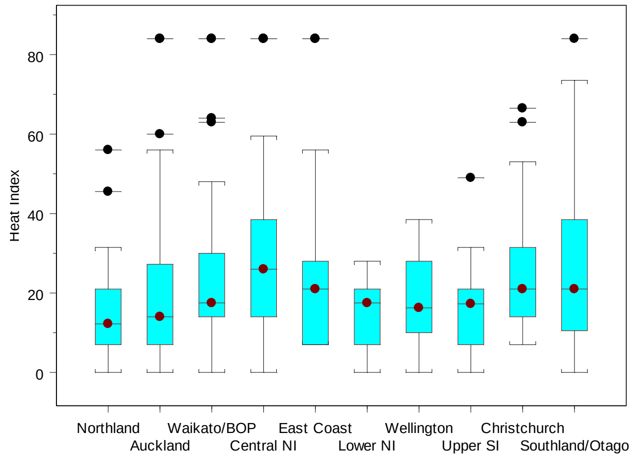


Figure 31: Heating index by region

The HEEP Year 7 report introduced the HEEP 'heating index' (Isaacs et al, 2003). In brief, the HEEP occupant survey asks for information on the times of heating (time of day and day of week) for three locations – the bedrooms, living and utility rooms. The weighted sum then forms the whole house heating index.

Figure 31 shows the heating index by region. The five houses at the maximum heating index of 84 reported heating the whole house 24 hours a day. A relationship can be seen between climate and the use of heating – unsurprisingly, the colder the climate the greater the use of heating.

Figure 32 shows that the houses in the South Island report that they are typically less likely to heat bedrooms than the North Island houses. This could explain why in Figure 31 the mean South Island heating index is not as high as that for the Central North Island. Only about 5% of HEEP houses heat bedrooms on a 24 hour schedule.

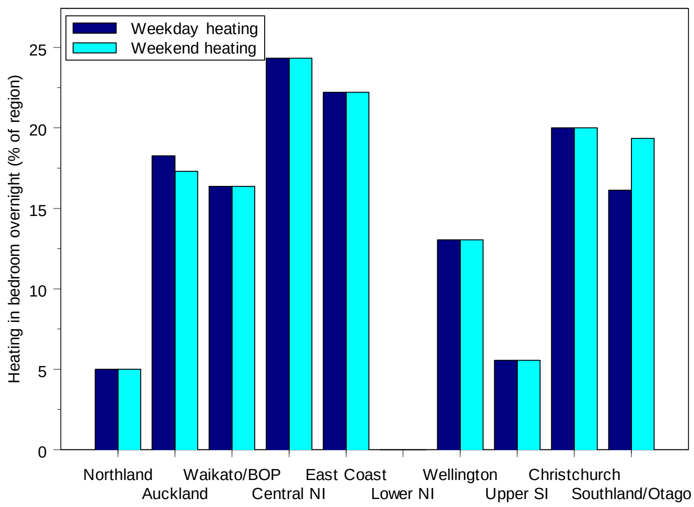


Figure 32: Bedroom overnight heating by region and weekday/weekend

Overall there is constant heating in the living rooms of approximately 10% of the HEEP houses. Figure 33 and Table 10 shows the majority of these houses are in Southland/Otago, the Central North Island and the East Coast of the North Island. These areas also have a higher proportion of houses with solid fuel burners than the other areas.

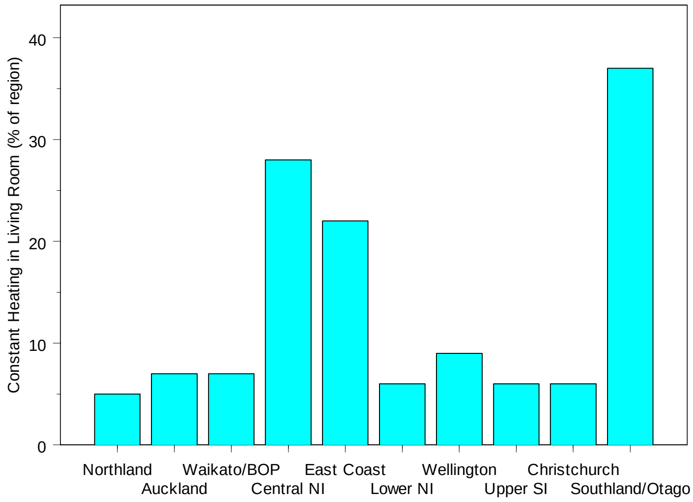


Figure 33: Living room 24 hour heating by region

Region	No heating	Evening heating	Constant heating	Sample count
Northland	13%	55%	5%	40
Auckland	14%	49%	7%	102
Waikato/BOP	4%	44%	7%	54
Central North Island	3% (1 house)	36%	28%	36
East Coast	0%	41%	22%	27
Lower North Island	0%	71%	6%	17
Wellington	0%	53%	9%	45
Upper South Island	6%	53%	6%	17
Christchurch	0%	40%	6%	35
Southland/Otago	16% (3 houses)	21%	37%	19

Table 10: Reported evening, all day and no heating by region

Table 11 provides statistics from the occupant self-reported heating schedules. The living room is the most common room to be heated and most often this is in the evening, with approximately 85% of occupants heating. Under half (45.5%) only heat their living room in the evening on weekdays and 37.2% in the weekends. Utility rooms are seldom heated, with 67.3% on weekdays and 69.2% of houses on weekends not heating utility rooms. Approximately 50% of the houses heat their bedrooms on weekdays, with slightly less heating their bedrooms in weekends. The most common time for heating bedrooms is in the evening (~20%) followed by overnight (~6%). Constant heating is done in ~10% in the living room and ~5% in the bedrooms and utility rooms.

Room Weekday/Weekend	Living Weekday	 Weekend	Bedroom Weekday	 Weekend	Utility Weekday	 Weekend
Morning	1.5%	1.8%	3.2%	2.6%	3.0%	2.5%
All day	0.7%	1.6%	0.3%	0.7%	0.7%	1.0%
Evening	45.5%	37.2%	21.8%	19.7%	11.4%	9.0%
Night	1.7%	1.8%	6.7%	6.5%	1.2%	1.3%
Morning/day	0.0%	0.0%	0.2%	0.0%	0.2%	0.3%
Morning/evening	13.9%	11.3%	6.0%	4.7%	4.0%	3.0%
Morning/night	1.0%	1.0%	0.2%	0.3%	0.0%	0.0%
Morning/day/evening	9.3%	12.3%	1.4%	2.3%	3.0%	4.2%
Morning/evening/night	0.3%	0.3%	0.0%	0.3%	0.7%	0.5%
Daytime/evening	5.0%	10.3%	1.0%	2.0%	2.5%	3.0%
Evening/night	3.2%	2.8%	4.0%	4.0%	1.0%	0.7%
Daytime/evening/night	0.5%	0.8%	0.0%	0.0%	0.3%	0.5%
24 hours	10.9%	10.8%	5.0%	4.7%	4.7%	4.8%
No heating	6.5%	8.0%	50.2%	52.2%	67.3%	69.2%

Table 11: Percentage of houses on various heating schedules

5.3.1 Pre- and post-1978 houses

A minimum standard of insulation was introduced for all new houses from April 1978 onwards. There is a clear difference in temperatures between pre- and post-1978 houses (see Section 5.4.4). It is unknown if this is due to just the insulation requirements or a combination of factors such as the occupants' behaviour. A cross-tabulation was prepared between the heating schedule and house age (pre- or post-1978), but no significant relationship was found (p-value 0.33). It would appear that occupants in the pre-1978 houses do not use different heating schedules to post-1978 houses. There is a reversal in the percent of houses that heat constantly and those that heat only in the morning, daytime and evening between pre- and post- 1978 houses, as seen in Table 12.

House age	Constant heating	Morning, day and evening heating
Pre-1978	13%	8%
Post-1978	8%	13%

Table 12: Pre- and post-1978 heating schedule

5.4 Temperatures

As discussed in earlier HEEP reports, few New Zealand households maintain constant indoor temperatures 24 hours a day. For the purpose of the following analysis, the 'winter evening' (between 17:00 and 23:00 from June to August inclusive) is used as the baseline. Unless otherwise specified, the temperatures reported are for the living room (the part of the house most commonly heated).

Figure 34 provides an overview of the winter (June through August) evening (17:00to 23:00) living room average temperatures in all 399 houses. The curve follows the normal (bell shaped) distribution, with an average temperature of 17.8°C and a standard deviation of 0.12°C. Figure 34 shows that nearly 25% of the average winter evening living room temperatures are below the WHO recommended healthy minimum of 16°C (WHO, 1987).

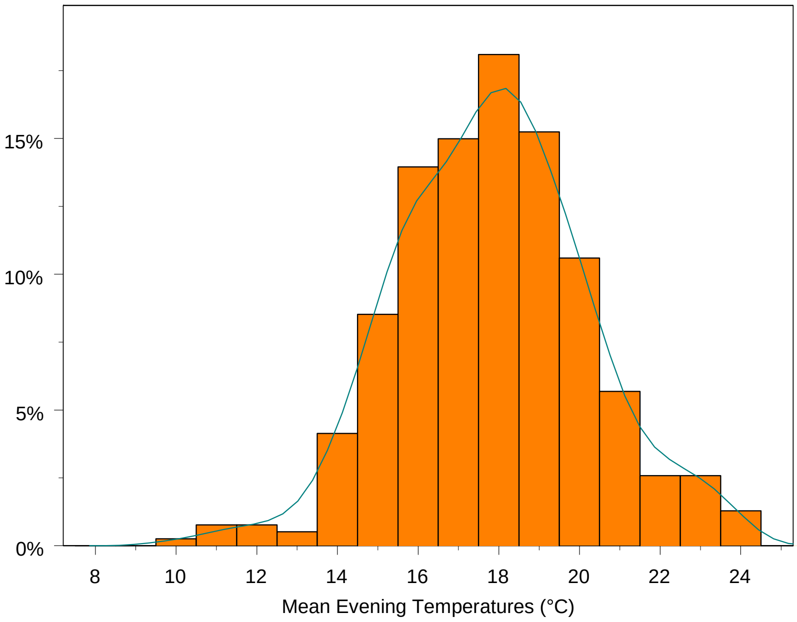


Figure 34: Winter evening living room average temperature distribution

5.4.1 Region

Figure 35 provides a box plot of the average winter evening temperatures, ordered by region from the far North to the far South. It shows a trend in temperatures from North to South, though it is not straightforward. The trend appears to have cooler temperatures in the North, warmer temperatures in the middle and lower North Island (except Wellington) and the upper South Island, and then cooler temperatures again in the lower South Island. This behaviour does not appear to be solely related to climate, but is perhaps related to occupant behaviour, heating systems, and house physical characteristics.

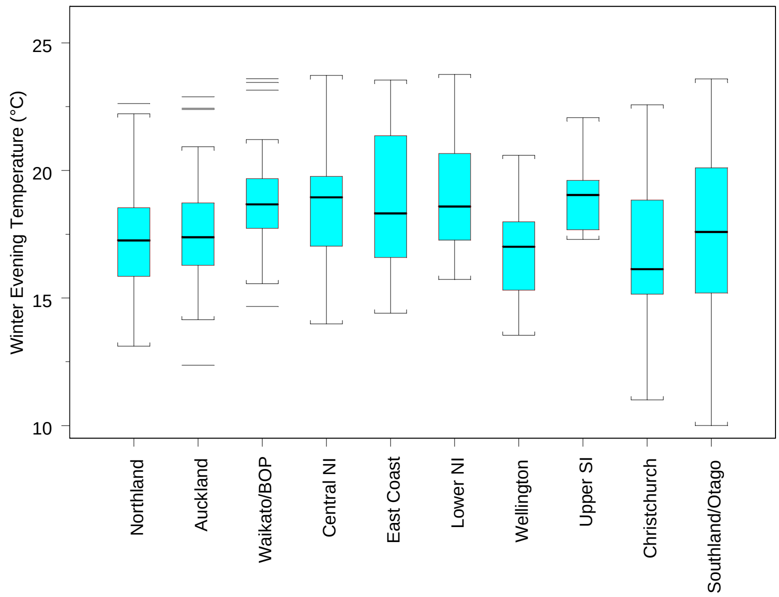


Figure 35: Mean winter evening living room temperatures by region

There is a significant difference between the regional groups at the 95% confidence level (ANOVA model: F statistic 5.5 on 9 and 377 degrees of freedom, Pr (F) = 0.0000004).

There is also a general trend, shown in Figure 36, of decreasing overnight bedroom temperatures from North to South. This is expected as most households do not heat bedrooms overnight, so the temperatures inside bedrooms would be expected to only be a few degrees above the external temperature for unheated bedrooms.

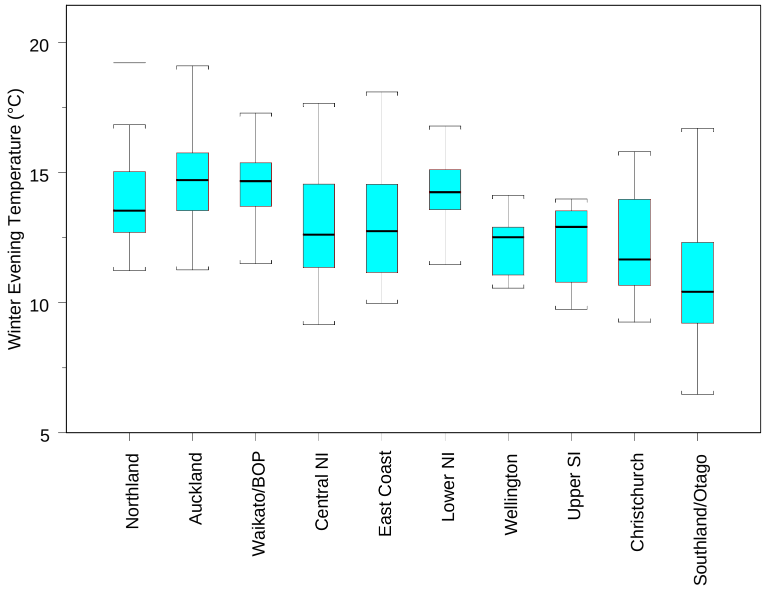


Figure 36: Mean winter overnight bedroom temperatures by region

5.4.2 Heater type and heater fuel

There are major variations in space temperature with different main heater types and/or main heater fuels.

Table 13 and Figure 37 illustrate that houses heated with gas or solid fuel are significantly warmer than electric and LPG-heated houses. Note that 'gas' includes reticulated gas and the large home gas (LPG) cylinders. The LPG in the tables represents only the portable cabinet type LPG heaters, generally with a 9 kg gas bottle.

Fuel	Temperature °C	Standard deviation	Sample count
LPG	17.1	0.2	54
Electricity	17.2	0.2	108
Gas	18.0	0.4	33
Solid Fuel	18.7	0.2	152

Table 13: Winter living room evening temperatures by heating fuel

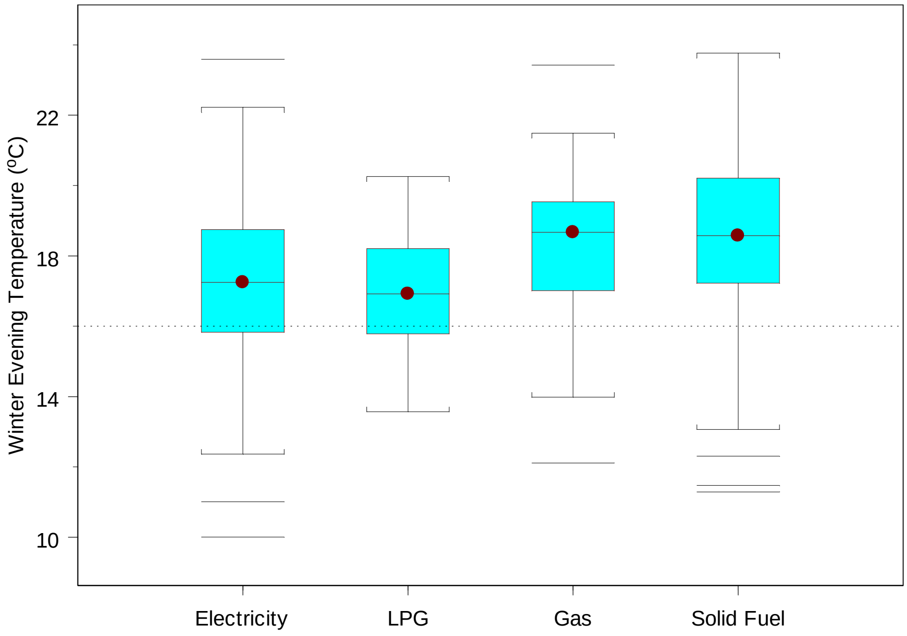


Figure 37: Living room winter evening temperatures by heating fuel

Table 14 and Figure 38 show that houses with gas central heating or enclosed solid fuel burners are the warmest group with an average evening temperature of 18.3°C and 18.9°C. There is a notable difference in temperatures between homes heated with enclosed solid fuel burners and open fires of 2.9°C. It should be noted that with the increased sample, the mean living room temperatures for all fuel types have increased from previous reports. The drivers for these differences have yet to be established.

Heater type	Temperature (°C)	Standard deviation	Sample count
Open solid fuel	16.0	0.5	12
Electric	16.9	0.3	83
LPG	17.1	0.2	54
Fixed electric	17.8	0.3	19
Solid or liquid fuel central	17.9	0.2	2
Gas	18.0	0.5	26
Heat pump	18.0	0.4	4
Gas central	18.3	0.7	7
Enclosed solid fuel	18.9	0.2	138

Table 14: Winter living room evening temperatures by heater type

Gas, solid fuel and solid/liquid fuel centrally heated houses are the only heater types that have a mean winter evening temperature of above 16°C, shown as the dotted line in Figure 37 and Figure 38.

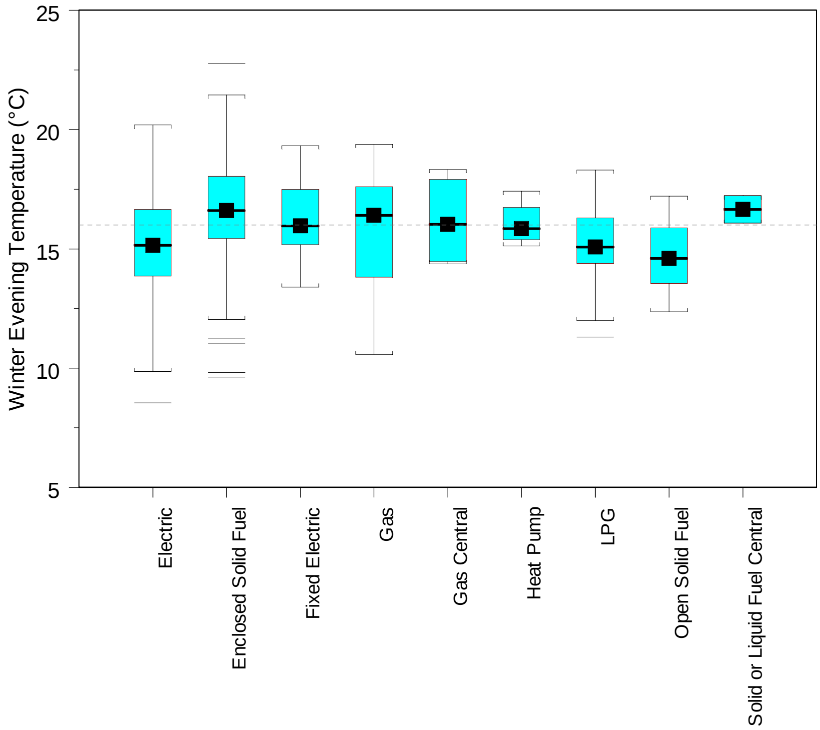


Figure 38: Living room winter temperatures by heater type

Figure 39 shows there is little difference in temperatures between regions for electricity and LPG-heated houses. There are higher numbers of solid fuel burners in the colder regions, and with their higher outputs they are able to achieve higher temperatures. It should be noted that there are low numbers of houses heated with gas in some regions (see national sample counts in Table 13 and Table14).

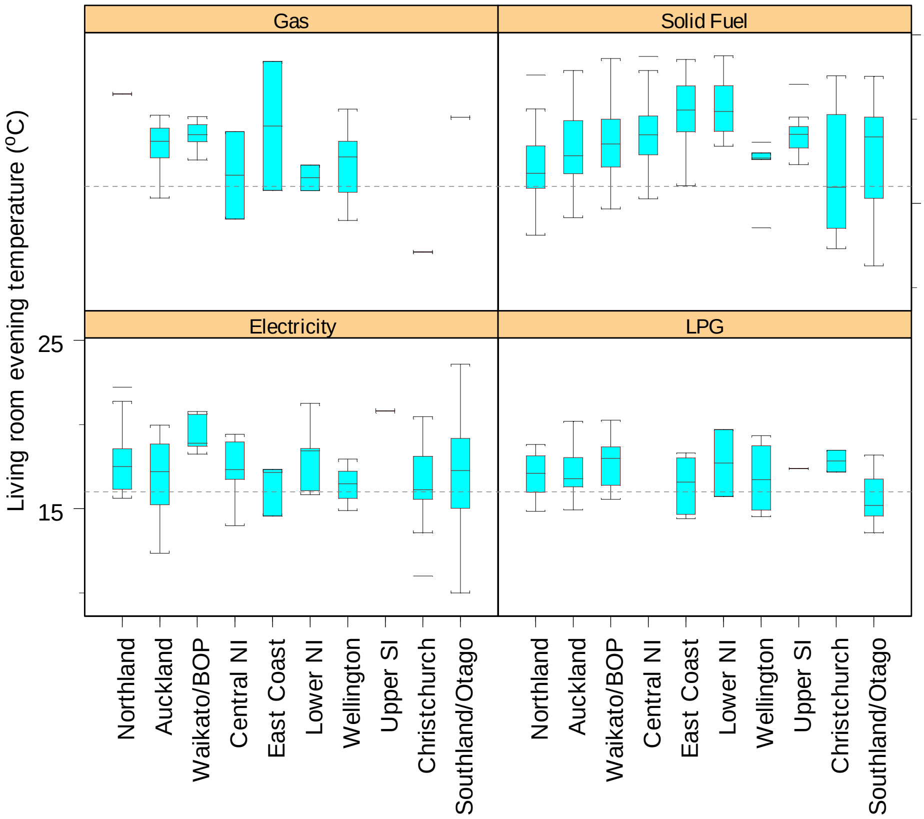


Figure 39: Living room evening temperature by location and most used heating fuel

5.4.3 House age

There is a strong relationship between the age of the house and the winter evening temperatures. On average post-1978 houses are 1.0°C warmer than pre-1978 houses. In previous years it has also been reported than energy use between the pre- and post-1978 are not significantly different. Although winter temperature data is available for all 399 houses, this is not yet the case for energy data which will not be available until completion of monitoring.

Figure 40 plots the relationship between living room evening temperature and the decade the house was built. This plot shows a steady increase in temperature as the houses become younger – i.e. the older houses tend to be colder. There is an average rate of fall 0.20 ± 0.05°C per decade. This result has a very high statistical significance (ANOVA F-statistic: 17.1 on 1 and 347 DOF, p-value 0.000045). This is without considering retrofitting of the house, the heating fuel, region or occupants' heating patterns.

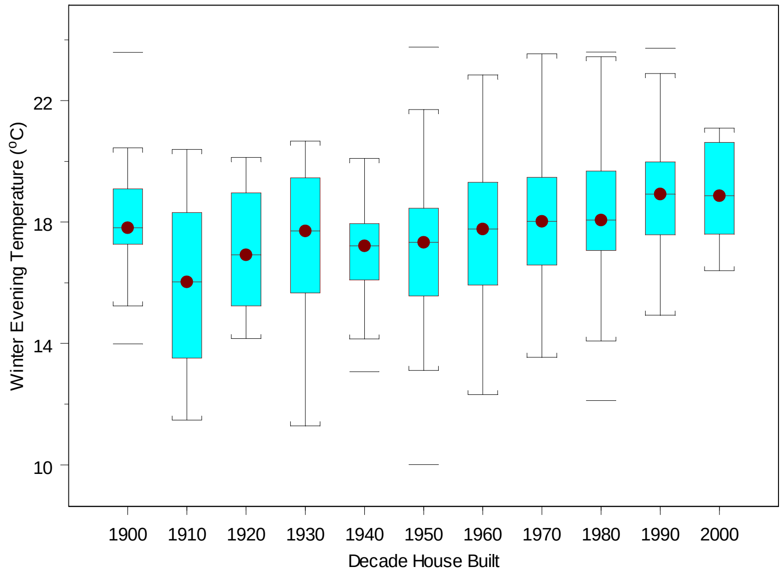


Figure 40: Winter evening living room temperatures by year built

5.4.4 Thermal insulation requirements

Houses built after 1 April 1978 were required to include a minimum level of insulation, while insulation was not required in older houses. As seen in Table 15, there is a 1.0°C difference in living room evening temperatures between pre- and post-1978 houses. This temperature difference remains consistent with that reported in previous HEEP reports, although average temperatures have risen from the numbers in the HEEP Year 7 report of 17°C (pre-1978) and 18°C (post-1978) to 17.6°C and 18.6°C. This increase in average temperature could be due to the large number of solid fuel burners in the current monitoring, and this will be further explored.

House age group	Average winter evening living room (°C)	Standard deviation (°C)	Sample count	Bedroom overnight (°C)	SD (°C)	Count
Pre-1978	17.6	0.1	265	13.2	0.1	243
Post-1978	18.6	0.2	99	14.5	0.2	95

Table 15: Winter temperatures by insulation level

The same pattern can be seen in bedrooms as living rooms in the pre- and post-1978 houses, although bedrooms are seldom heated (see Figure 41 and Figure 42).

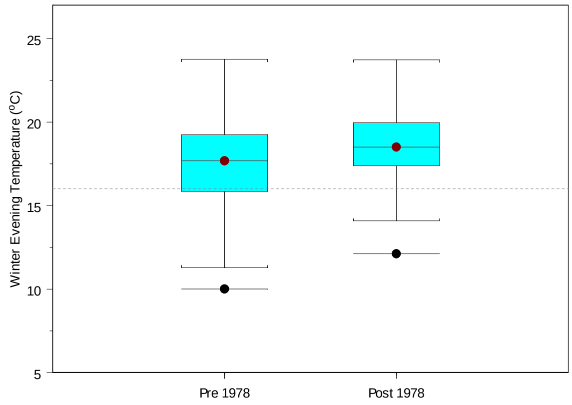


Figure 41: Living room winter evening temperature by insulation requirements

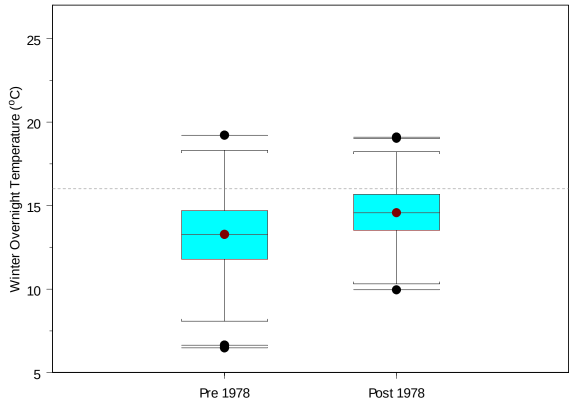


Figure 42: Bedroom overnight winter temperature by insulation requirements

This pattern continues regionally (Figure 43) with all post-1978 houses being warmer than pre-1978 houses. In Christchurch and Wellington there does look to be little difference; this is possibly due to the heater type used in some of these houses. There is a disproportionate number of gas centrally heated houses in the pre-1978 Wellington houses resulting in warmer temperatures in the older houses. In Christchurch there is a very cold post-1978 gas house, and nine enclosed solid fuel houses that are pre-1978, with only one post-1978. It is possible that the differences in heating appliances between the pre- and post-1978 groups are over-riding the tendency for post-1978 houses to be warmer.

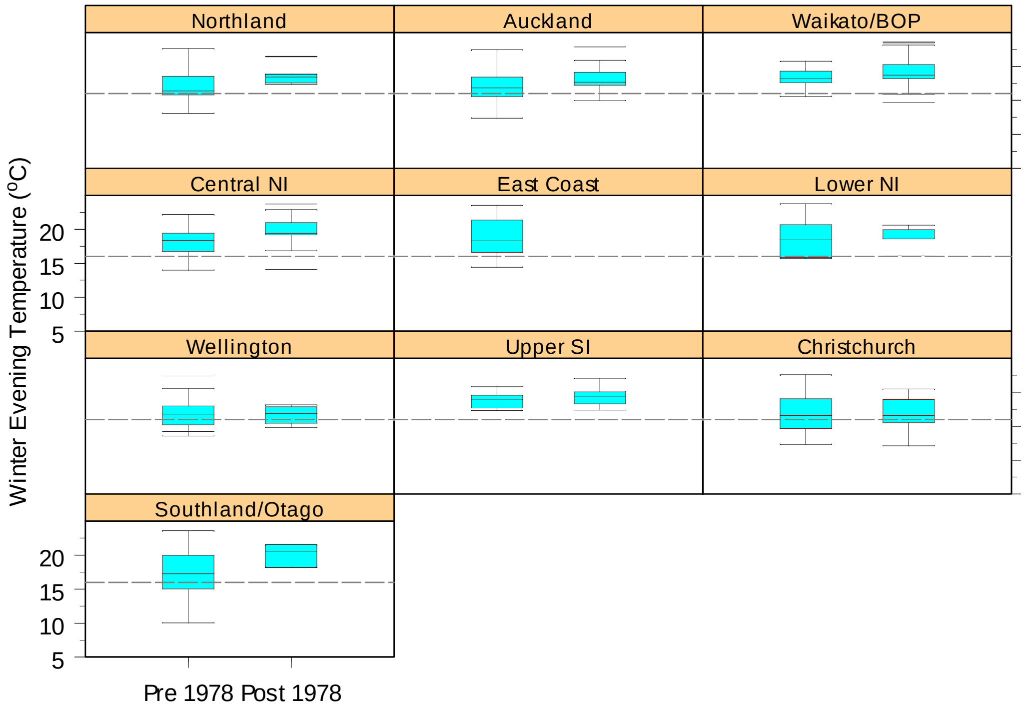


Figure 43: Regional living room temperature differences by insulation requirements

Again the same pattern occurs with the bedroom temperatures. Even though the lack of bedroom heating leads to lower average temperatures, the post-1978 houses are now warmer than the pre-1978 houses. Bedroom temperatures were not monitored for all the Wellington houses, so there is not enough information to make a good comparison in this location.

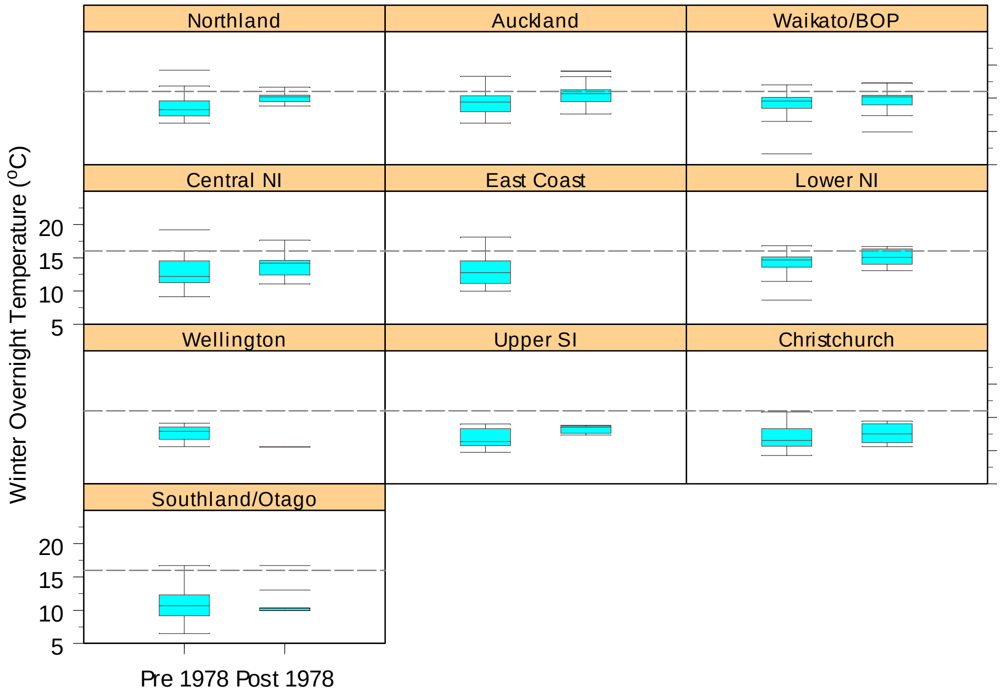


Figure 44: Regional bedroom temperature differences by insulation requirements

Table 16 shows the counts in each region by pre- and post-1978 houses and the mean living room temperatures. There are no post-1978 houses in the East Coast region

Regional group	House age	Living room °C	Standard deviation	Sub-sample count	Total count
Northland	Pre-1978	17.1	0.4	27	36
	Post-1978	18.8	0.5	9	
Auckland	Pre-1978	17.1	0.3	62	89
	Post-1978	18.2	0.3	27	
Waikato/BOP	Pre-1978	18.3	0.3	29	54
	Post-1978	19.1	0.4	25	
Central NI	Pre-1978	18.2	0.4	23	36
	Post-1978	19.6	0.7	13	
East Coast	Pre-1978	18.8	0.5	27	27
Lower NI	Pre-1978	18.8	0.8	11	16
	Post-1978	18.8	0.8	5	
Wellington	Pre-1978	16.8	0.4	26	30
	Post-1978	16.7	0.8	4	
Upper SI	Pre-1978	18.7	0.3	13	18
	Post-1978	19.4	0.8	5	
Christchurch	Pre-1978	16.9	0.6	21	29
	Post-1978	16.8	0.9	8	
Southland/Otago	Pre-1978	17.1	0.7	26	29
	Post-1978	20.1	1.0	3	

Table 16: Regional living room temperatures by insulation requirements

6. ENERGY USE OF HEEP HOUSES COMPARED TO ALF3

This section explains the method and results from a comparison study between heating energy use from a modelling program and an energy monitoring project on occupied houses. HEEP produces estimates of annual heating energy use in the monitored houses, while the Annual Loss Factor, 3rd edition (ALF3) (Stoecklein and Bassett, 2000) estimates the annual heating energy required for a residential building based on the house physical location and construction, and a selected heating schedule.

6.1 Selection criteria

Houses were selected from the HEEP data base of 472 houses, of which 98 are part way through the monitoring. As solid fuel energy estimates were not available when this work commenced, the selection was limited to the houses which do not use solid fuel. Ultimately all HEEP houses, regardless of heating fuels, will be examined using ALF3.

Table 17 shows the sample in terms of houses that do not heat, houses that are still being monitored and solid fuel houses. The majority of the houses in the HEEP databases have been selected randomly from predetermined locations to give a nationally representative sample.

There are also 52 non-randomly selected houses which have varying amounts of monitored and survey information collected. There were 12 pensioner flats with sufficient information and four houses from the pilot study in Wellington that had sufficient information and met the criteria for selection. Non-random houses are not normally used in general HEEP analysis, but have been used for this analysis.

The number of HEEP houses available was also reduced due to missing data, e.g. no information on the insulation, or for some of the non-random houses the monitoring period was too brief to give a good indication of the annual heating energy use. There were three houses that were considered too complex to model in ALF3.

Sample		Count
All houses		472
less	Houses currently being monitored	-98
Houses that have completed being monitoring		374
less	Solid fuel burners (excluding houses not completed)	-183
	Houses with no heating appliances	-10
Number available for study (including houses where insufficient data available to model or estimate heating energy)		181

Table 17: Houses available for study

Houses with electricity, natural gas and LPG heating were included from Kaikohe to Invercargill. No limits were placed on occupants, locations or any other house characteristics. During the modelling, some houses some were found to be unsuitable due to missing data on physical characteristics such as window dimensions, orientation, insulation details etc. Houses that had no heating appliances (all in Northland or Auckland) were also considered unsuitable for the comparison. Because of the higher population of solid fuel burners in rural and southern regions, fewer houses were available in these areas than hoped.

6.2 ALF3 energy estimates

Each house was entered into ALF3 using the physical dimensions and occupant data held in the HEEP databases. The most appropriate ALF3 heating schedule was selected based mainly on the survey responses. In some cases, house energy data was checked for situations where the heating was not used in the reported manner. The heating seasons are also based on self-reported survey responses, which previous study found to be reasonably accurate.

Figure 45 provides an illustration of an ALF3 input screen. The left side is used for data input – in this case the house location, the heating schedule and the heating temperature level. The right side provides a summary of the specific losses for each component of the building, the energy balance, and whether the house complies with one of the three possible compliance routes for NZBC Clause H1: Energy Efficiency.

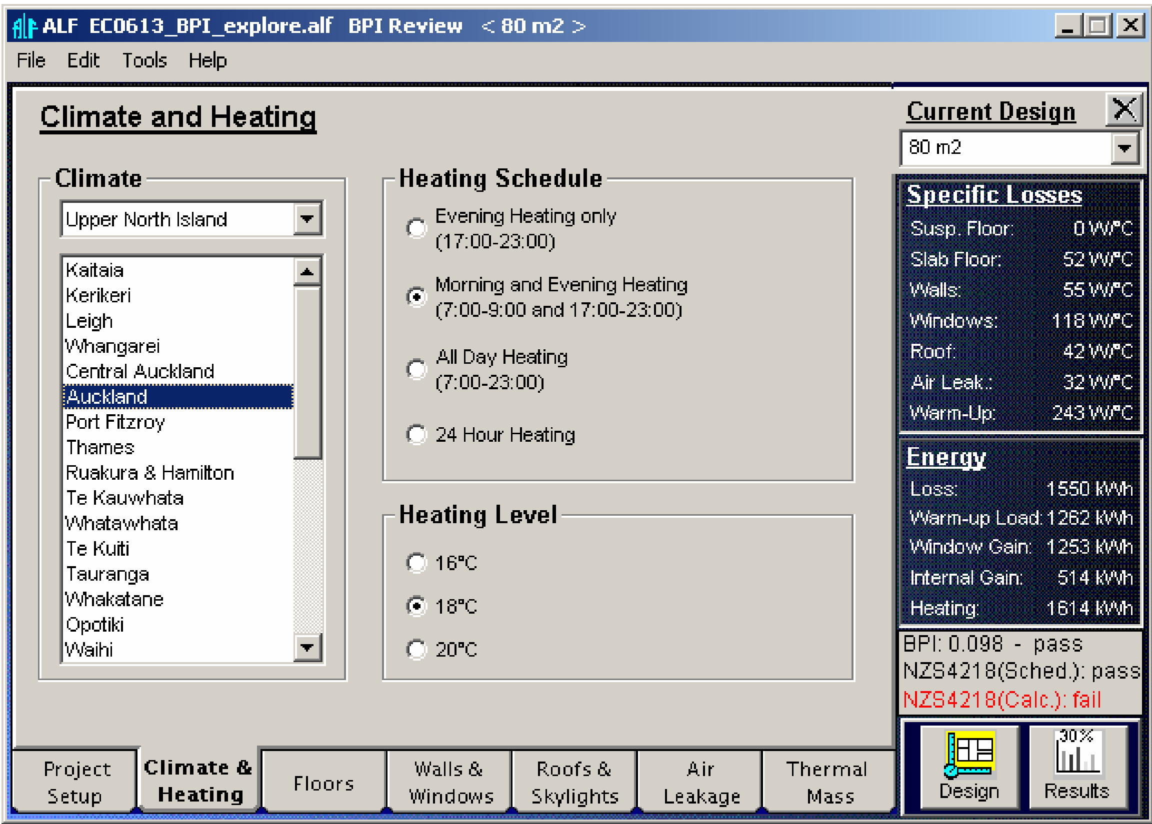


Figure 45: ALF3 screen image

Figure 45 illustrates how ALF3 provides annual energy balances (in kWh) for the total house on the right side of the input screen:

- energy **Loss** through the building envelope
- **Warm-up Load** after the house has been allowed to cool
- **Window Gain** from utilisable solar energy
- **Internal Gain** from occupants and appliances
- **Heating** energy required to maintain the various heating levels.

The ALF3 reported **heating** energy is the difference between the utilisable energy gains (solar, occupants and appliances), the energy losses (through roof, wall, floor, windows and due to infiltration) and includes the warm-up energy.

This section compares the calculated ALF3 heating energy use with the estimated HEEP heating energy use. However, the assumptions used by ALF3 to calculate the energy loss, warm-up load and internal gains will affect the validity of the calculation of the total house heating energy use. The two most important assumptions concern the length of heating and the maintained indoor temperatures.

6.2.1 Heating season length

ALF3 bases the heating months on a survey of BRANZ staff carried out during the development of ALF3 (Stoecklein and Bassett, 2000 – Section 5.3). The results of that survey suggested occupants start heating when the long-term average temperature for the month was below 11.5°C.

Using the self-reported heating months from the HEEP occupants (see Table 9), the long-term average temperature at which heating starts can be determined for the HEEP locations (given in Table 18 below). This table uses data from the entire HEEP sample, excluding the houses that do not heat.

Location	Average external heating start temperature (°C)		Heating season (months)	
	HEEP	ALF3	HEEP	ALF3
Kaikohe	12.5	11.5	3	1
Whangarei	12.5	11.5	3	1
Auckland	13	11.5	5	3
Hamilton	13	11.5	5	4
Minden	13.3	11.5	5	3
Tauranga	13.3	11.5	5	3
Foxton Beach	***11.5***	***11.5***	***5***	***5***
Waikanae	***11.5***	***11.5***	***5***	***5***
Wellington	***11.5***	***11.5***	***5***	***5***
Christchurch	12.5	11.5	6	5
Oamaru	12.2	11.5	7	6
Dunedin	12	11.5	7	6
Invercargill	11	11.5	7	8

Table 18: Heating months – HEEP and ALF3

The HEEP houses in the home areas of BRANZ staff – Wellington, Waikanae and Foxton Beach (highlighted in ***bold italics***) – commence heating when the long-term average temperature for the month is below 11.5°C. This matches the results of the ALF3 survey, but other areas have different temperature trigger points.

It was thus necessary to modify the ALF3 heating season. This is achieved by modifying the relevant climate file in order to adapt the length of the heating season to the occupant reported heating season.

6.2.2 Heating temperature

ALF3 models the heating period at one of four pre-set schedules and the temperature at one of three pre-set levels (see Figure 45), e.g. between 17:00 and 23:00 the temperature is maintained at a constant 18°C. In reality, New Zealand living rooms are not kept at a fixed temperature. The heating level for use with ALF3 was determined by calculating the mean temperature of the HEEP house during the heating period.

To examine the importance of assuming a constant (mean) temperature rather than a dynamic (changing) temperature, a house was modelled using SUNREL.[viii] Two heating schedules were tested – one with dynamic temperatures (a house with a warm-up and cool-down period) and one with a set heating level (an ALF3 model), on both a high mass and lightweight construction house. The heating energy use (June to August inclusive) for the two house constructions were within 4% of each other, supporting the use of this simplification.

[viii] SUNREL website: www.nrel.gov/buildings/highperformance/sunrel/

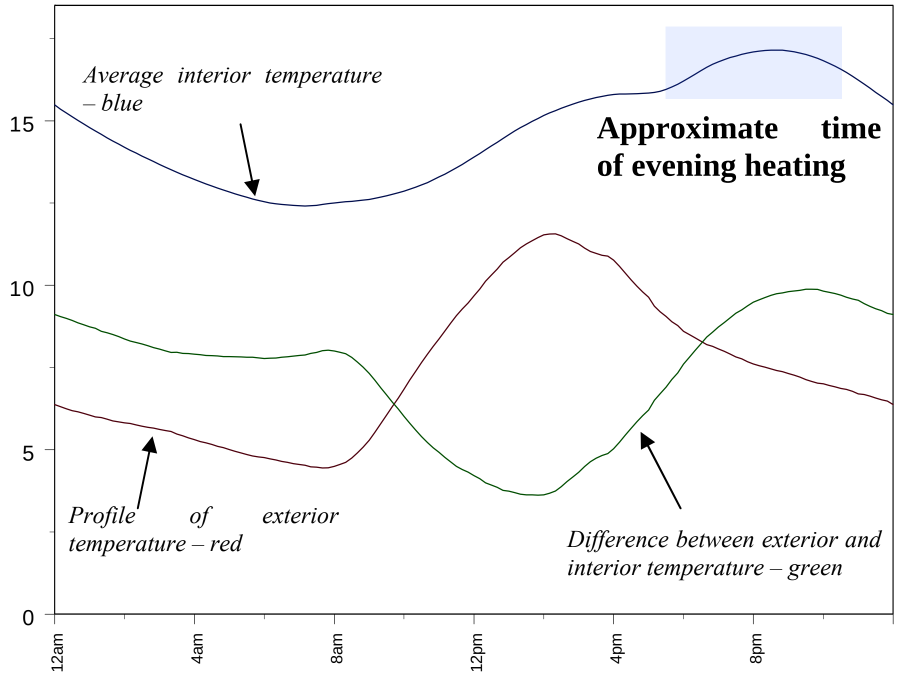


Figure 46: Winter temperature profiles for Christchurch HEEP houses

The main heating period was during the evening for the majority of the HEEP houses. The start of heating can be determined from a daily average temperature profile. The time at which a sharp rise in temperature is coupled with a falling exterior temperature is defined as the start of heating. This heating period is highlighted in Figure 46. An average evening start and finish time was calculated for each location, and then the mean temperature calculated for each house during this period.

The maximum temperature is reached some time into the heat period, and at this point the occupants reduce, but do not stop, heating. The end of heating was determined by finding the point in the daily average temperature profile at which the difference between the outside and inside temperature decreases.

Location	Start	Finish	Hours
Auckland	6:00	10:00	4 hr
Hamilton	5:10	9:20	4 hr10 m
Tauranga	5:30	9:30	4 hr
Wellington	5:00	10:10	5 hr10 m
Christchurch	5:20	9:40	4 hr 20 m
Dunedin	5:00	10:00	5 hr
Invercargill	4:00	10:00	6 hr
Clusters	4:10	9:30	5hr 20 m
ALF3 evening heating	5:00	11:00	6 hr

Table 19: Mean heating times on winter evenings

Evening heating times for the selected locations are given in Table 19, and range from 2 hours to 6 hours. One of the standard ALF3 heating regimes is for evening heating of 6 hours – 17:00to 23:00 (see Figure 45).

Once the evening heating times were established, the mean temperatures could be calculated from the monitored family room temperatures for the months of June, July and August.

Four houses in the selected sample claimed not to heat during the evening period; when the temperature and energy records were investigated it was found that possibly the question was incorrectly interpreted by the occupant in two houses. These two houses claimed to heat during the night (which they may do, although it does not clearly show), but the monitored temperatures do show evening heating. The other houses appear to heat only in the morning.

For the selected HEEP houses, 11 houses heat in the morning rather than the evening, with one house occupied by a shift worker who tends to heat during the night.

Heating levels range from 9.6°C to 25.3°C during the periods mentioned in Table 19 for the entire HEEP sample, and from 12.9°C to 25.3°C in the selected sub-sample. The range of heating levels can be seen in Figure 47 for the entire HEEP sample.

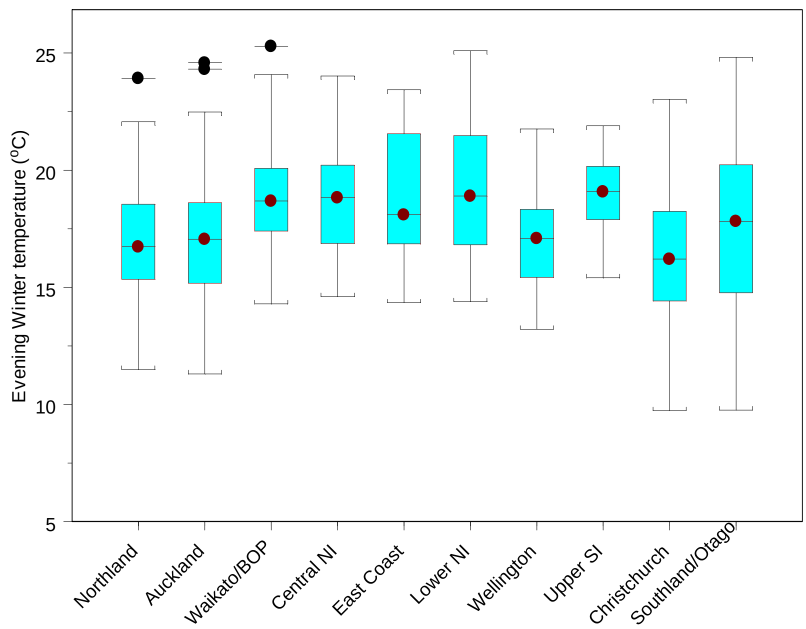


Figure 47: HEEP sample mean average winter evening temperatures

There are three temperature options in ALF3 as seen in Figure 45 – 16°C, 18°C and 20°C. The ALF3 heating levels used to estimate the heating energy use for a given house are determined by calculating the mean temperature as described above, and then selecting the ALF3 heating temperature based on the ranges shown in Table 20.

ALF3 heating temperature (°C)	**16°C**	**18°C**	**20°C**	**Total**
Calculated average temperature	< 16 – 17°C	17.1 – 19°C	Above 19.1°C	
Count	31	33	25	89
% of sample	35%	37%	28%	100%

Table 20: Average heating temperatures in selected houses

In cases where the average evening temperatures differ from the options available in ALF3, then extrapolation or interpolation as set out in the ALF3 manual, Section 5.3 can be used. Albrecht Stoecklein (an author of ALF3) suggests that extrapolation can only be reliably carried out from 14°C to 22°C. The ALF3 model becomes very sensitive to small changes in temperature in a warm climate when the heating temperature is set below 16°C, so it is not recommended to use the model in this situation (ALF3 Manual, Section 5.3). Approximately 75% of the houses in the HEEP database have a mean winter evening living room temperature of between 14°C and 22°C.

The interpolation or extrapolation method as suggested in the ALF Manual, Section 5.3 was not used for this analysis. A degree hour correlation was developed (Section 6.5.1) which also takes into account the different heating hours used in the HEEP houses compared to the ALF heating hours.

The range of temperatures in the selected sub-sample can be seen in Table 20 and Figure 47. Of the 31 houses in the <16–17°C range, 17 houses were below 16°C and in the upper range 16 houses were above 20°C. These are houses that are outside of the range of options in ALF3.

Figure 48 and Figure 49 provide frequency information on the living room winter evening temperatures for the selected sample.

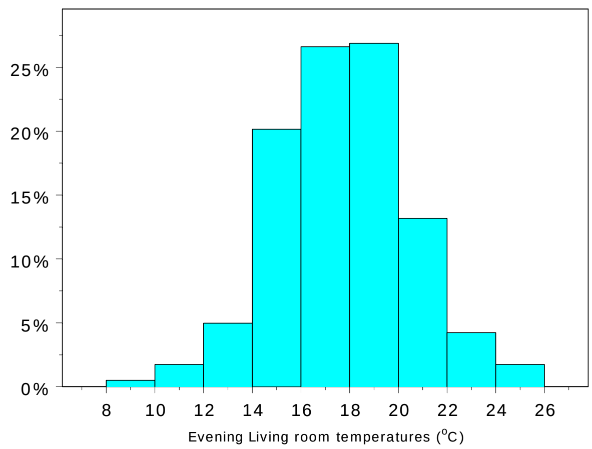


Figure 48: Histogram of living room evening temperatures in selected sample

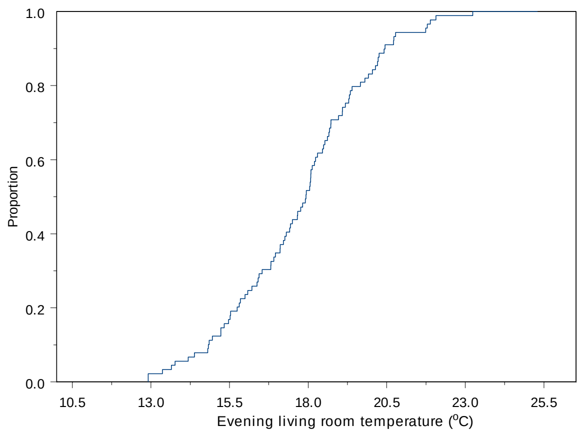


Figure 49: Cumulative frequency of living room temperatures in selected sample

6.3 Modelling issues

It should be noted that houses that have no heaters, or where the owners claimed not to heat, are not included in the sample selection.

6.3.1 Missing information from HEEP material

The ALF3 model requires information in greater detail on house construction and use in some areas than available in the HEEP databases. Details that are often lacking include the spacing between studs in a wall, the insulation thickness inside that wall and the materials and construction method. These issues will often be a problem when establishing component R-values in order to model existing houses with little or no information on their construction. The areas where assumptions have been made are explained below.

6.3.1.1 Simplification of construction types for walls and roof

Modelling in ALF3 required simplification of construction types for walls and roof as often many details of construction were unknown. A table of wall and roof types was developed by Roman Jaques and Ian Cox-Smith (Jaques et al, 2003), and is reproduced as Table 21.

Insulation R-value (m²°C/W)	Wall EIFS	WALLS Timber Framed Weatherboard	Sheet cladding	ROOF Battens	Dwangs
1.3	1.5				
1.8	2.0	2.0	1.7	2.1	1.7
2.2	2.4	2.1	1.9	2.5	1.9
2.6	2.8	2.3	2.1	2.8	2.1
3.0		2.5	2.2	3.2	2.3
3.4				3.6	2.5
3.6				3.8	2.6
4.0				4.2	2.7
5.0				5.2	

Table 21: Wall and roof construction

Components that have no added insulation are not covered in Table 21. For these components the R-values in Table 22 were developed based on the *BRANZ Insulation Guide* (Van der Werff, 1995).

(m²°C/W)	Weatherboard	Sheet cladding	Brick veneer	Roof
Construction R-value	0.6	0.4	0.5	0.4

Table 22: Construction R-value with no insulation

6.3.1.2 Insulation thickness

The thickness of insulation in walls was particularly hard to assess, as it is hidden by the wall cladding. Wall insulation thickness was taken to be between 90 and 95 mm thick, unless records reported a 150 mm wide wall where the insulation would be thicker.

The depth of ceiling insulation was recorded for the HEEP houses where the ceiling space was accessible. When the ceiling insulation R-value was estimated, the age of the house was considered as changing regulations have seen a required increase in the thickness of insulation. It is also expected that there will be some deterioration of thermal performance over time.

Information on the insulation is not complete, with 17 houses missing information on floor insulation, 22 houses on ceiling insulation and 20 houses wall insulation.

6.3.1.3 Slab insulation

Slab insulation was unknown in most cases, so unless the owner knew about the construction of the house it was assumed that no insulation was under the slab. Two house owners knew their house to have under-slab insulation.

6.3.1.4 Dwangs or battens in the roof

Information on the house having battens or dwangs in the roof is not recorded in the HEEP databases. For the purposes of this study, houses from 1980 onwards have been modelled with battens and houses before 1980 with dwangs.

6.3.1.5 Sheltered/exposed perimeter wall

ALF3 requires information on the shelter of the perimeter wall – whether it is exposed or protected from the wind. The HEEP survey does not record the degree of shelter at the perimeter wall. As each house has an extensive photographic record, the shelter of the perimeter wall could be determined. This was used for the 47 houses with suspended floors.

6.3.1.6 Thermal breaks in windows

Dimensions, single or double glazing and window covering were recorded at the time of installation for windows, but there was no information recorded on presence or absence of thermal breaks in aluminium window frames. Thermal breaks in New Zealand are considered to be rare due to the price compared to standard frames. For all houses with aluminium windows the 'no thermal break aluminium frame' was selected.

6.3.1.7 Varying stud height/sloping ceiling

When the ceiling is of varying height, an average stud height was calculated. This was then used as the ceiling and wall height when modelling in ALF3 (used for five houses).

6.3.2 ALF3 modelling issues

In addition to assumptions of the physical construction, it was also necessary to deal with other design issues.

6.3.2.1 Common walls between flats

Thirteen houses of the selected dwellings are apartments with one or more common wall(s). Common walls can not be treated as external walls, as often the adjacent space (the next-door neighbour) is heated or at least protected from the elements. If the neighbouring flat is heated to the same temperature there would be no heat transfer, but this cannot be assumed at all times. As a coarse adjustment for the higher thermal resistance between heated and unheated zones, the common wall R-value is increased by a factor of 0.5, as suggested in Section 5.4.1.1 of the ALF3 manual.

6.3.2.2 Conservatories

Conservatories can greatly affect the thermal performance of a building. There are two types of conservatories:

- Where the conservatory is separated from the rest of the house by a door, wall or window.
- Where the conservatory has a direct opening to the rest of the house.

The ALF3 Manual, Section 5.5.2 suggests suitable methods:

- When the conservatory is open to the rest of the house, it is treated as a large window. The insulation value of the components separating the conservatory from the house is increased by the conservatory glass R-value. This approach generally underestimates the solar gains, but also underestimates the losses.
- Where the conservatory is open to the house, it is treated as a large window. Solar gains and window losses are calculated as for a normal window.

There are five houses with conservatories that can be separated from the rest of the house, and two conservatories which are open to the house.

6.3.2.3 Frosted glass

The effect of frosted glass or net curtains on solar shading differs for the many types. BRANZ Senior Scientist, John Burgess, suggested 20% as a realistic average.

6.3.2.4 Height of sub-floor perimeter wall

The height of sub-floor perimeter walls often vary, especially on a sloped site. The HEEP site inspection recorded either an average height or a range of heights. If a range was given, the average was taken, and the house photos were used to assist the process. The height of the perimeter wall was used for the 47 houses with suspended floors.

6.3.2.5 Floor covering R-value

In most houses floor coverings vary between rooms, with low R-value vinyl or tiles mainly in service areas and higher R-value carpet in living areas. The percentage of the floor covered in carpet was calculated and the carpet R-value of 0.4 multiplied to give the house average, e.g. if 50% of the house is carpeted, the overall floor R-value increased by 0.2.

6.3.2.6 Wind exposure

ALF3 has four classes for wind exposure – sheltered, medium sheltered, medium exposed and exposed, as shown in Figure 50, which is also used in the HEEP survey. If the occupant reported wind exposure was thought to be too high, it was checked against the ALF3 wind exposure map (ALF3 Manual, Section 1.2) and modified to a lower level.

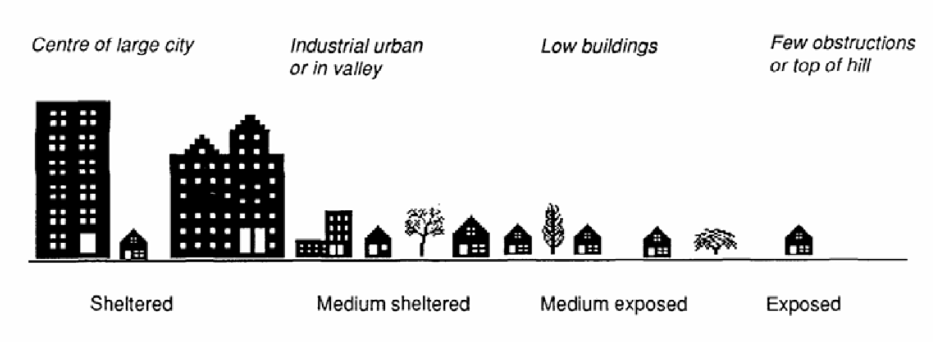


Figure 50: Wind exposure classes

6.3.2.7 House air leakage

The survey asks for an assessment of the air leakage of the house. The ALF3 Manual gives a guide for calculating air leakage based on the design and age of the house (Table 23). As some occupants were thought to be too extreme in their assessment, the air leakage was based on the occupant opinion, house plan and photographic evidence.

	Base air leakage (air change per hour)	Typical example
Airtight	0.25	simple, small rectangular, airtight joinery, all windows with gaskets
Average	0.50	larger than 120 m²
Leaky	0.75	complex shape, some match lining materials, generally over 200 m²
Draughty	1.00	pre-1960, match lining, match flooring, often high stud

Table 23: Air leakage rates

6.3.2.8 Climate and location

Four of the smaller localities – Waikanae, Foxton Beach, Kaikohe and Minden do not have climate files in ALF3. For these locations, a neighbouring town with a climate file was used. The four locations affected and the ALF3 climates are given in Table 24.

HEEP location	ALF3 climate location
Kaikohe	***Kerikeri***
Whangarei	Whangarei
Auckland	Auckland
Hamilton	Ruakura and Hamilton
Minden	***Tauranga***
Tauranga	Tauranga
Foxton Beach	***Levin***
Waikanae	***Paraparaumu***
Wellington	Wellington
Christchurch	Christchurch
Oamaru	Oamaru
Dunedin	Dunedin
Invercargill	Invercargill

Table 24: Climate locations

With the development from ALF2 to ALF3, interpolations functions were developed to allow any New Zealand location to be modelled if the monthly average temperatures and monthly number of sunshine hours are known (see ALF3 Manual, Section 6.1). This was not considered necessary for this study, as the climate file mainly affects the length of the heating season, which was manually changed in the climate file to match the occupants' heating patterns.

For the Auckland houses, there was the option of the Auckland central or the Auckland region climate file. The Auckland central file was significantly warmer, with heating only for one month of the year. This was considered unsuitable, as the Auckland HEEP houses heat on average for three months. The Auckland region climate was considered more realistic in terms of temperatures and was thus used in the Auckland ALF3 models.

6.3.2.9 House heating zones

Earlier work found the majority of the HEEP houses heat only a portion of their homes – generally the living room (Isaacs et al, 2003). For the selected houses, only 28% heat the bedrooms and living room on a regular basis, with only 5% regularly heating the whole house. In the total HEEP sample, 46% of houses heat their bedrooms and living rooms on a regular basis.

ALF3 assumes the entire house is heated. It is possible to use other modelling tools (e.g. SUNREL) to model a multi-zoned house, but in order to provide the simplicity wanted from ALF3 it was not possible to make this into a multi-zone model. A method was therefore needed to use ALF3 to model only the heated areas of the house. The ALF3 manual suggests modelling the heated areas of the house and increasing the R-value of the internal walls (which then effectively become the external walls) by a factor of 0.5 of the construction R-value of the exterior walls, as they have a conditioned space on the adjacent side.

With the house being considered one zone, internal floors/ceilings are not considered for heat losses. The ALF3 Manual suggests that the whole house be modelled except where it is clear a part of the building is not heated and not insulated, e.g. most garages (ALF3 Manual, Section 5.4.1.1). For this comparison, attached garages were not modelled and conservatories were also excluded unless open to the house.

The excerpt below is from the ALF3 Manual, Section 5.5.2 and is a suggested method of dealing with the one zone model. The Manual notes that this is a very coarse adjustment, which does not take into consideration gains and thermal mass in the unheated zones or the area of external walls in the unheated zone:

- *For all the area calculations (floors, walls and roofs) use only the area of the heated and insulated building zones.*
- *Adjust the R-value of the internal walls between heated and unheated zones by adding half of the average R-values of the envelope of the unheated zone.*

Two methods were then tested to determine a possible way of adapting ALF3 to treat the heated zone of the house:

1. The method suggested in the ALF3 Manual, Section 5.4.1.1 was to model the heated zone of the house only and increase the R-value of the internal walls in zone (as mentioned above).
2. The proportion of the house that is heated was determined, and then heating energy calculated using that percentage of the ALF3 heating output for the whole house.

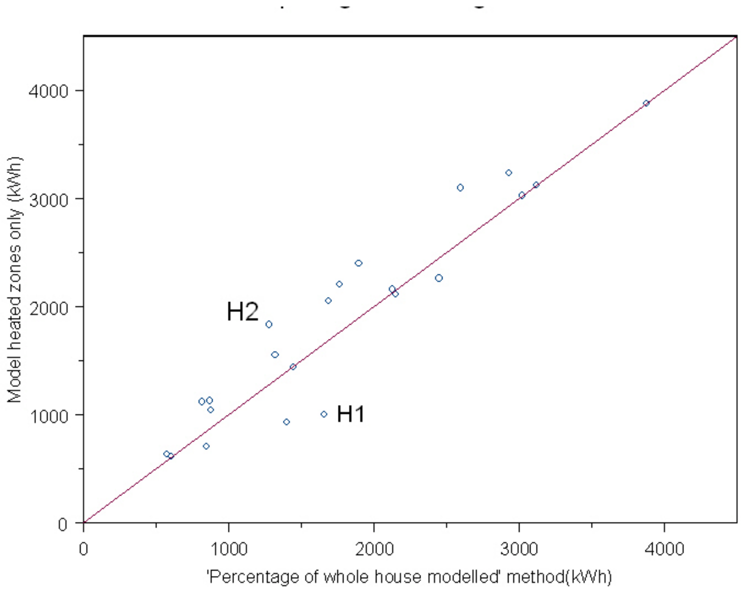


Figure 51: Percentage versus modelled heated zone methods

When comparing the two methods (Figure 51), a strong relationship was found (r^2=0.9). It was decided, after trying both methods on 22 houses, that the percentage method was more simplistic and likely to be just as accurate as the approach suggested in the ALF3 Manual. The energy use by the remaining houses was then assessed using the percentage method.

The two concerns with simplifying the heating to a percentage of the house are with the mass and solar gains. All of the houses in the ALF3 sub-sample are relatively low mass, with those that have concrete slab floors often covering the majority of the concrete with carpet.

This suggests that the differences that occur between the two methods are from the differing amounts of useful solar gains in the heated space of the house.

Two houses were looked at in closer detail – H1 and H2 as shown in Figure 51. These two houses were selected as the two methods results give results that differ by a factor of about 1½. The heating energy use for house H1 from the percentage method is higher, and but for house H2 the modelling method gives a higher energy user. The main difference between these two houses is the direction the heated areas of the house are facing for solar gains. The living spaces in H1 face west, while in H2 they face north. Both H1 and H2 are lightweight, rectangular houses with similar insulation and the heated spaces on one corner of the building. No obvious reasons for the difference have been identified, and further work will be carried out on a larger sample in the coming year.

6.3.2.10 No schedule for overnight heating in ALF3

In ALF3 there is no schedule for heating overnight. The four that are included are:

- morning only
- morning and evening
- daytime
- 24 hour heating.

Five out of the 89 selected houses (5.6%) regularly heat their bedrooms overnight. The entire HEEP database has 43 out of 346 (12.4%) of houses heating overnight, as the majority of houses that are heated overnight have solid fuel burners.

Five of the selected houses that report overnight heating also report heating during the day or evening, but no clear heating pattern can be seen in the overnight temperature profiles. This suggests overnight heating may be irregular or heating only to low temperatures. In these cases an ALF3 schedule appropriate to another period when occupants reporting heating was used.

6.4 House heating energy

Houses in the HEEP study have natural gas, electricity, LPG and solid fuel use monitored, but only in the one quarter of 'end-use' houses are individual appliances monitored. It is difficult to determine space heating energy due to a number of issues including the:

- variety of different fuel sources – electricity, gas, LPG, etc
- varying outputs of different heating appliances
- differing occupant heating habits
- lack of stable heating regimes.

Thus it has not been possible to use analysis tools based on stable 'average' indoor temperatures. Instead it has been necessary to develop tools to extract heating energy use from the detailed energy monitoring.

The only previous New Zealand investigation investigating energy and temperatures in a range of houses and locations was the *1971-72 Household Electricity Survey* (Statistics NZ, 1973). That study was undertaken when monitoring equipment was far simpler (e.g. manual weekly readings of electricity use were taken from conventional spinning disk kWh hour meters), compared to the HEEP study which can record energy use at one minute increments.

The 1971-72 study evaluated heating energy use based on the assumption that no significant amount of energy was used for heating during the summer months. It assumed that any increases in winter energy use were due to space heating, extra use of lights and, to a lesser extent, increased use of cooked meals. This approach allowed the upper limit of heating energy use to be calculated.

For the HEEP analysis, two different methods for calculating electricity and natural gas energy use have been used, one using both temperature and energy data, and the other using only energy data.

As HEEP always separately monitors hot water fuel use, the total electricity and natural gas energy use can have this hot water energy removed. This can then be averaged by weeks, and a linear model fitted for energy use versus 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 highest energy use in this period could be taken as the base.

Winter months energy use over this base was considered to be for heating, and this in turn was related to temperature data from either HEEP monitoring or the National Climate

Database (CLIMDB).[ix] This method has the advantage that missing data from either the energy monitored or the temperatures does not significantly affect the accuracy of the result.

The second method works on the same principle, but specifically looks at winter months (June, July, August) versus summer months (January, February, March). This approach requires more complete data for these periods than when the external temperature is taken into account.

Although the HEEP electric and natural gas fuel analysis has been completed, solid fuel and LPG energy use are evaluated using different methodologies. The monitored LPG use has now been converted into energy use (Section 4). The methodology for solid fuel burners is now complete, but this was not the case when the analysis reported here was undertaken. Further analysis is being undertaken, and will be reported in later HEEP reports.

6.5 Examination of models

The models were examined to determine differences that may be occurring between reality and the model.

6.5.1 Correction for different heating schedules and heating levels

The daily heating schedules in ALF3 are typically for longer periods than those found in the HEEP houses. ALF3 also does not deal with the different heating schedules found in various locations (Table 19).

The method described below was used for each individual house to modify the ALF3 heating hours to better match those reported by the occupants and the difference in monitored temperatures. All houses in the selected sample have been included – including the four houses with a heating level below 14°C and the three above 22°C. According to ALF3 author, Albrecht Stoecklein, ALF3 reliability will decrease below 14°C and above 22°C.

The method first calculates a ratio using the difference between the actual heating hours and the ALF3 option of six heating hours. It then calculates the heating degree hours for both external and 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 temperature difference between inside and outside 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).

6.5.2 Investigation of individual houses

The correction for heating periods and heating levels in the previous section improved the relationship between the ALF3 model and energy estimates from HEEP. Grouping together houses by location was possibly an over-generalisation, as individually examining each house and making heating hour adjustments further improved the relationship between ALF3 and the HEEP heating energy.

The heating hours were modified for 82 out of 89 houses to better reflect the occupants' heating schedules. There were seven houses in the sample that heated for the same period as

[ix] Accessible electronically www.niwa.co.nz/services/clidb/

ALF3 in the evening. This was determined by looking at both the daily average profiles for the winter months and the occupant information in the surveys.

Particular improvements in matching ALF3 to the HEEP energy use were found in those houses that had been simplified to just an evening heating period, but in practice were also heated during the morning or daytime. The heating period in many of these houses was only changed for an hour or two (72 houses), but overall 10 houses were subject to changes larger than this.

Other changes made to individual house heating energy were due to:

- **externally located instant hot water systems** (three houses) – removal of hot water cylinder gains from the ALF3 heating model
- **efficiency of gas space heating** (two houses) –where houses relied on gas heating the efficiency of the gas was taken into consideration
- **longer heating seasons** (two houses) – some houses clearly had longer heating seasons that the location average and were increased.

The following issues are noted as affecting the accuracy of estimating heating energy use from HEEP monitored data:

- **missing data** – missing energy and/or temperature data at times of the year which could affect the results – e.g. peak summer (used as the base energy use for calculating heating energy) or peak heating season (21 houses affected to differing extents)
- **changed lifestyle** – changes in occupants or their behaviour, e.g. a new baby resulting in more intensive use of heating (two houses)
- **holidays** – holidays or other absences during heating season resulting in overestimates of energy use (two houses)
- **heating season** – heating seasons were changed for all but three regions to the HEEP average; in some cases individual houses were changed as their heating season was noticeably different from the region average (two houses).

This study initially intended to undertake comparisons of 100 houses. 115 houses were initially modelled in ALF3, but 26 were removed from the sample due to:

- insufficient data to accurately estimate the heating energy use from HEEP data:
  - missing data through the year
  - pilot study houses were monitored for a shorter time than the current houses
- insufficient data to model the house in ALF3
  - missing plans or vital information such as a north direction
  - missing information on the physical building
- no heating reported by the occupant.

6.6 Comparison of ALF3 and HEEP heating energy

Figure 52 and Figure 53 compare, for each house in the sample, the ALF3 heating energy use with the HEEP energy use. Figure 52 uses the temperature method, and Figure 53 the energy method (see Section 6.4).

The "Y=X" line represent the case when the ALF3 and HEEP energy use are exactly equal. Below this line ALF3 suggests greater heating energy use than found by HEEP monitoring, and above the line suggests less. The majority of houses have the HEEP and ALF3 energy use matched within ±2000 kWh.

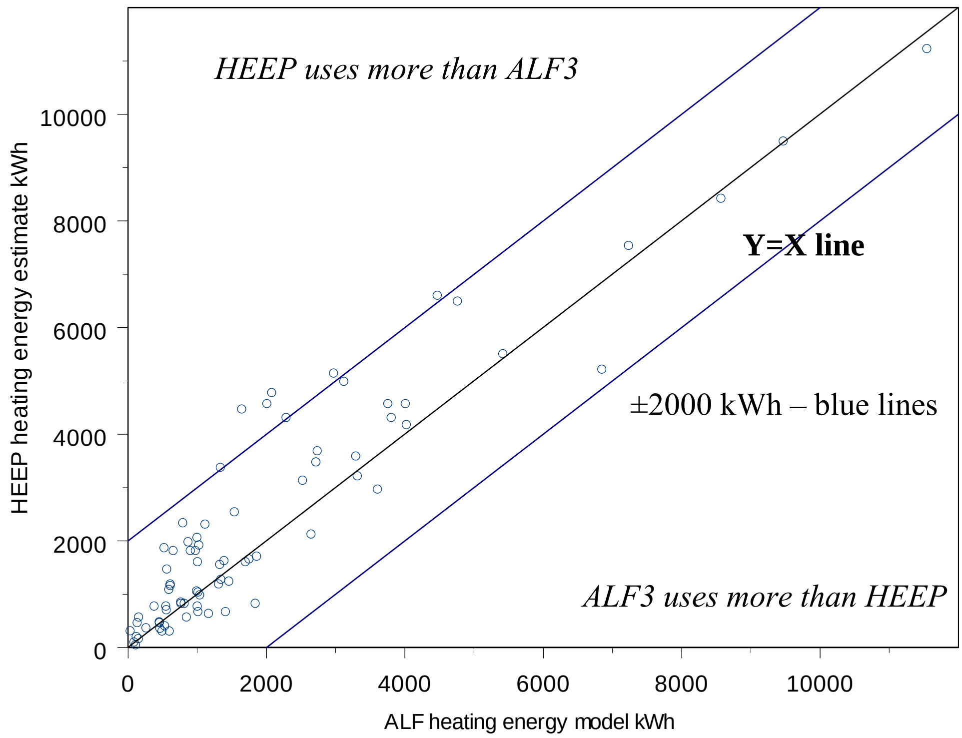


Figure 52: ALF3 heating model versus HEEP estimate – temperature method

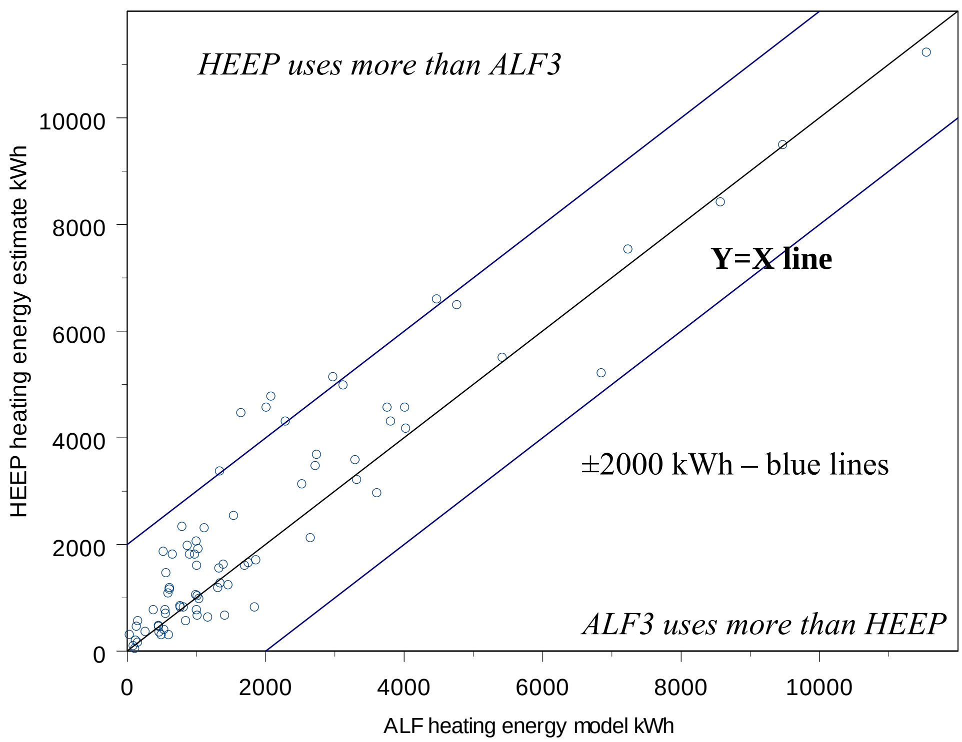


Figure 53: ALF3 heating energy model versus HEEP estimates – energy method

Figure 52 and Figure 53 show reasonable correlation between the HEEP and ALF3 heating energy over the selected houses. Neither HEEP estimation method would appear to be more accurate than the other; in addition both are dependant on different data.

In the case of high heating energy use houses, the HEEP and ALF3 heating energy are mainly within 20% of each other. These houses use mainly fixed heating appliances which were separately monitored by HEEP. This allows heating patterns to be more closely investigated.

6.7 Examination of heating energy differences HEEP and ALF3

Areas identified as potentially causing differences between the HEEP estimate and the ALF3 model includes:

- accuracy of HEEP space heating estimate methods
- internal gains
  - appliances
  - changes in human behaviour
  - changes in the number of occupants
- zoning method
- over-generalised
  - heating months may need to be personalised per house.

6.7.1 HEEP space heating estimates

A comparison between the two HEEP space heating estimation methods is given in Figure 54. The "Y=X" line represent the case where both estimate method give the same value. Below this line the temperature method suggests greater heating energy use than the energy method, and above the line suggests less.

There are a few houses outside ±20%, but overall the correlation is strong at $r^2 = 0.959$. Examination of the data for houses outside the ±20% boundaries in Figure 54 found that in most cases this was due to inadequate data to accurately estimate the heating energy. The houses that use higher amounts of heating energy typically have a fixed heating source (e.g. hard-wired night store or fixed natural gas heater). HEEP separately monitored these heaters, and thus the energy use estimates can be considered more accurate.

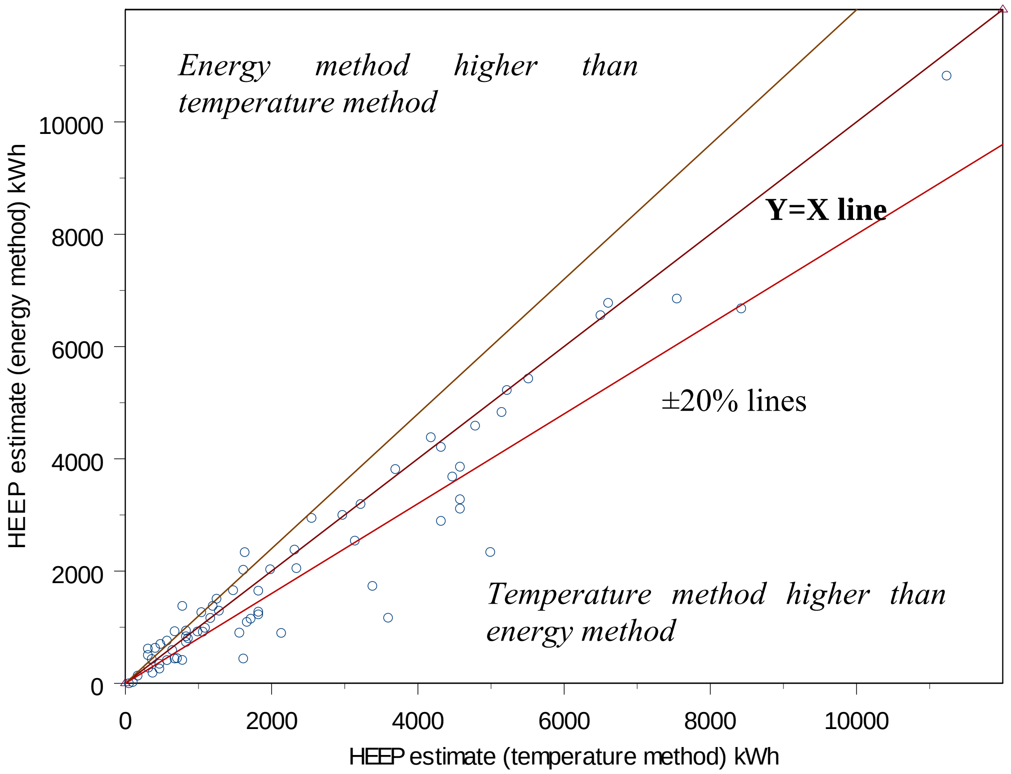


Figure 54: Comparison of the two HEEP estimating methods

In some cases the hot water data was not removed when calculating the temperature method; this occurred when there was insufficient hot water data to see the increase over the winter months. When the hot water energy use was taken away from the total energy use, it was found that the temperature method is more likely to overestimate the heating energy use.

6.7.2 Internal gains

ALF3 calculates internal gains from appliances based on house size – for each m^2 of building there is 5.3 W of waste heat from appliances and lighting (ALF Manual, Section 2.3.2). However, in reality, the number and location of appliances also affects internal gains, with some houses having a higher number of appliances in their heated zone than others. There is potential for further analysis of the HEEP data on appliances and their locations to better incorporate internal gains. For example, the number (e.g. high, medium and low numbers) of appliances may relate to the resulting internal gains.

Over the one year monitoring period, approximately one third of the HEEP closing surveys analysed to-date, reported changes in occupants. This includes new arrivals, changes in employment and household income. One person, indoors for half of the day, can generate approximately 100 kWh of internal gains in a three month heating season. Given the low levels of space heating in New Zealand houses, visitors staying for extended lengths of time, or a change in the number of members in the household, have an impact on the internal gains and hence space heating.

6.7.3 Zoning method

The selected percentage method (see Section 6.3.2.9) adjusts the reported ALF3 total heating energy use by the proportion of the house that is heated. A multi-zone model would separately calculate the energy use for two or more zones that are subject to individual space heating regimes (temperature and length of heating).

In particular, a multi-zone model may deal better with energy use in bedrooms, which seldom achieve the same degree of heating as living rooms (see Section 5.3).

6.7.4 Over-generalisation

The length of the heating season was averaged by location rather than calculated for each individual house. For two of the selected houses, the heating season was noticeably different from the location average. There was an improvement in the relationship between the HEEP and ALF3 heating estimates once this adjustment was made.

6.8 Conclusions

The energy used by households that are consistently heated is able to be estimated by ALF3 to within ±20% of the actual heating energy use.

In order to achieve this estimate, it was necessary to closely examine the household space heating use and make appropriate adjustments to the ALF3 assumptions. Three key differences have been identified between the HEEP monitoring and ALF3 assumptions:

- ALF3 predicts space heating energy use for the whole house, where most HEEP households only heat part of their house
- length of heating season (months) – most houses monitored in HEEP appear to heat for a longer period of the year than the ALF3 model
- length of daily heating (hours) – the majority of the occupants in the HEEP sample heat for shorter periods than given in ALF3.

Further work could also be done on the effect of appliance location and use as well as the effect of occupant schedules. These issues will be further investigated as part of the HEEP work, and recommendations will be made for the next edition of ALF.

There is also the potential for further analysis and comparison work to be carried out on further HEEP houses, and this will be reported in a later HEEP annual report.

7. RESIDENTIAL ENERGY-USE MODELS

This section reports on a literature survey of residential energy-use models, and evaluates their relevance to the development of the Household Energy Efficiency Resource Assessment (HEERA) residential energy-use model and database.

7.1 Background

To be of the greatest use, the energy end-use information collected by HEEP must be easily accessible in a form able to be used by a wide group of stakeholders, including:

- BRANZ for storing of residential energy-use information in a format that allows analysis of historic and projected energy use in New Zealand, and for quantifying the impact of energy efficiency and energy policy measures on energy use.
- Policy makers concerned with the National Energy Efficiency and Conservation Strategy (NEECS), EECA's Energy Saver Fund, and the Government as it implements Kyoto Climate Change greenhouse gas emission control strategies.
- Department of Building and Housing (formerly Building Industry Authority (BIA)) for continuing the development of the relevant clauses of the NZ Building Code (NZBC).
- BRANZ and other industry organisations for continuing the development of ALF, the Green Home Scheme and other energy or environmental design or assessment tools.
- Managers, operators and participants in the electricity marketplace interested in user time-of-day profiles.
- Suppliers and users of distributed generation technologies.
- Appliance developers, suppliers and Government regulators interested in either voluntarily improving the energy performance of their products, or the application of mandatory Minimum Energy Performance Standards (MEPS) or Energy Labelling.
- Researchers and policy developers working on health and housing.
- Suppliers of competing residential fuels.
- Individuals and organisations in need of data on residential energy use, temperatures and other properties of houses.
- Local and Central Government interested in reducing localised pollution due to residential energy use.

7.2 EERA

The potential users of the HEEP results represent a wide range of interests. Different databases and models are therefore required to store the HEEP results and to extract meaningful information for each type of user. One of these is the Energy Efficiency Resource Assessment (EERA) bottom-up stock model and database (Rossouw, 2001). The residential sector sub-model is being developed as part of HEEP, and will be named HEERA (Household Energy Efficiency Resource Assessment). Information regarding the EERA database, the model and its capabilities is provided in the Appendix.

EERA was developed with the support of a group of partners,[x] to be used on all sectors of the economy as a tool to:

- construct, analyse and compare end-use energy and greenhouse gas (GHG) emission scenarios for all economic sectors and energy types
- evaluate and quantify the impact of energy efficiency and energy-policy measures on the energy use and GHG emissions of scenarios through changes in:
  - equipment stock and efficiency
  - end-use energy type
  - supply energy type.

EERA highlights energy efficiency opportunities by quantifying and comparing the energy and GHG savings of efficiency improvements and their economic viability. The impact of energy efficiency and energy-policy measures are quantified by:

- establishing a reference scenario (Business-As-Usual (BAU), Frozen efficiency, etc)
- creating a modified scenario by implementing project measures relative to the reference scenario
- estimating and comparing the effect of project measures as the difference between the reference and modified scenarios.

The historic data for the residential BAU scenario covers the period from 1980 to 1997 and the projected data the period from 1998 to 2020. The data is based around the national stock of private residences as sector activities. This includes all occupied private houses or apartments in 12 geographic regions. Each residence is modelled as a thermal envelope surrounding a number of energy-using technology items.

Each type of energy-using technology item in a household is characterised by a:

- sector activity (stock of households of the specified household type)
- technology intensity (technology stock/household)
- energy intensity (TJ/yr/unit technology) for the region where it is located.

The delivered energy demand for a technology item is calculated as the product of the activity stock, technology intensity and energy intensity.

The historical sector activity, technology intensity and energy intensity data are derived from many sources. These are in some cases fragmentary and unreliable, requiring interpolation and normalisation. Normalisation involves adjustment of technology intensities to obtain correspondence between the calculated and known total electricity and fuel use for the residential sector as reported by the Energy Data File (MED, 2004a).

Future stocks and energy use are projected from historic trends, with consideration given to predictable future changes such as revision of the NZBC, and to market limits to growth. Unless disturbed by sudden external events or influences, economic development is assumed to proceed according to biological growth and decay cycles as described by logarithmic growth and exponential decay functions. The data are therefore interpolated and projected by

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[x] Joint venture partners from 1996 to 2002 included BRANZ, CRL Energy Ltd (CRL), Energy Efficiency and Conservation Authority (EECA), Natural Gas Corporation (NGC), Ministry for Economic Development (MED), Transpower New Zealand Ltd (Transpower) and the Electricity Corporation of New Zealand (ECNZ). The Joint Venture Agreement was discontinued in 2002 and further work was continued by CRL Energy Ltd.

logarithmic growth and exponential decay curves fitted to historic data points. The interpolations and projections are averages and the real values will fluctuate around these averages.

As with end-use models of this kind, EERA does not include a macroeconomic equilibrium module to provide an energy-price feedback to the demand-side. The effects of policy options which change the price of the fuels can therefore not be estimated, and neither is the interaction between energy efficiency and/or energy-policy measures possible. Such interaction is usually accomplished by means of price elasticities as exogenous model parameters. Disregarding this interaction can be justified by the observation that in the case of residential energy consumption by lights, appliance and water heating, there is normally little change in demand in response to changes in fuel price, especially in the short term (0–5 years). There may, however, be a more noticeable effect on space heating.

EERA has already been used to:

- analyse energy-use trends of residential, commercial, industrial and transport BAU scenarios
- develop Kyoto compliance scenarios
- evaluate energy efficiency projects
- compare the economic viability of residential energy efficiency measures
- evaluate the energy efficiency potential of the residential, commercial, industrial and transport sectors
- evaluate the National Energy Efficiency and Conservation Strategy measures for the building, environmental, and industrial sectors of New Zealand.

7.3 Literature survey

The purpose of this literature survey is to:

- compare the existing *residential* database and model of EERA with international energy-use databases and models with regard to purpose, capabilities and construction
- recommend how the HEERA model can be developed out of EERA, with HEEP requirements in mind.

In order to compare the capabilities of EERA with that of international models, it is important to be clear on what is required from the HEERA model in terms of HEEP outputs, how BRANZ intends to use HEERA, and stakeholder expectations. These requirements can be summarised as a HEERA model and database with the following features:

- **Framework:** The results of the HEEP data collection and monitoring, as well as additional residential information, are incorporated in a consistent framework. This enables the estimation of residential energy use, energy supply and greenhouse gas emissions through energy demand sub-models driven by basic demographic and socio-economic drivers. The sub-models calculate the space heating, water heating, cooking, lighting, refrigeration, laundry and electrical appliance energy use.
- **Content:** The space-heating sub-model simulates a building's space heating requirements by taking into account its physical features (construction, heating systems, location) and uses external inputs about the household operations (temperatures, hours used and patterns of appliance use). Water heating, cooking, lighting, refrigeration, laundry and electrical appliances contribute to the space-heating internal heat gains through their sub-models.

- **Data:** All the sub-models require:
  - dwelling stock from a dwelling vintage stock model
  - appliance stock from an appliance vintage stock model
  - the energy type involved
  - average power demand
  - household demographics and operation (temperatures, hours used, patterns of appliance use, family type and size, and income).
- **Time:** The dwelling and appliance vintage stock models allow for the time-related effects of new houses and appliances entering and old ones leaving the stock of houses and appliances. This enables an evaluation of the effect of policy options on energy consumption. This type of model is most useful for analysing the effect of changes in technology and usage, or ownership through time.
- **Economics:** Energy-use scenarios can be constructed that are capable of being analysed at the technology level from a range of viewpoints, including building construction, appliances and occupant socio-economic and demographic characteristics. No macroeconomic equilibrium mechanism is deemed necessary at this stage to provide an energy-price feedback to the demand-side. However, when the effects of policy options which change the price of the fuels need to be taken into account, such a feedback loop would be required if the end-use fuel-price elasticities justify its development.
- **Disaggregation:** The impact and uptake of energy efficiency and energy-policy measures aimed at the regional, building type, end-use, appliance, end-use energy, and occupant socio-economic and demographic characteristics can be quantified and analysed. This requires regional, building type, end-use, technology and end-use energy disaggregation of the database, with additional occupant socio-economic and demographic input to the energy efficiency and energy-policy measures. Since some of the stakeholders need to analyse and estimate the impact of measures at the local authority level, HEERA's database should ideally be disaggregated to this level.

7.4 Comparing residential databases and models

This literature survey has identified and compared the following types of databases and models that are used internationally for storing and utilising HEEP-type data and results.

7.4.1 The condition and occupancy of housing stock

Comparable surveys have been found for the United Kingdom, USA, Canada and New Zealand.

7.4.1.1 United Kingdom

Three house condition databases are maintained in the UK:

1. **English House Condition Survey** (EHCS) (e.g. Bates et al, 2002) is maintained by the UK Department of the Environment, Transport and the Regions (DETR). The EHCS information is collected from four component surveys:
   - main physical survey
   - household interview survey
   - postal survey of local authorities, housing associations and landlords
   - survey of market value of dwellings.

The EHCS information falls under the following categories: Property type, Household characteristics, Tenancy and occupancy characteristics, Value of housing stock, and Area description.

2. **General Household Survey** (GHS) (MIMAS et al, 2003) is a multi-purpose, continuous survey carried out by the Social Survey Division of the Office for National Statistics (ONS) which collects information on a range of topics from people living in private households in Great Britain. The survey has been carried out continuously since 1997.

   The GHS information is used by government departments and other organisations for planning, policy and monitoring purposes, and to present a picture of households, families and people in Great Britain. The main aim of the survey is to collect data on a range of core topics, comprising:
   - household and family information
   - housing tenure and household accommodation
   - consumer durables including vehicle ownership
   - employment
   - education
   - health and use of health services
   - smoking and drinking
   - family information including marriage, cohabitation and fertility
   - income
   - demographic information about household members including migration.

3. **Domestic Energy Fact Files** (Dunster et al, 1994a, Dunster et al, 1994b, Dunster et al, 1994c and Shorrock et al, 1998) prepared and supported by the Building Research Establishment (BRE) – these provide information on energy use trends and energy efficiency in four specific sectors of the UK housing stock between 1970 and 1998. They present tables, graphs and charts for all tenures and provide a full discussion. The four reports replace the three tenure-based Domestic Energy Fact Files produced in 1994.

7.4.1.2 United States of America

Residential Energy Consumption Survey (RECS) (EIA 2004) is conducted by the Energy Information Administration (EIA)[xi]. It provides information on energy-related data for occupied primary housing units in the USA. This information includes:
- the physical characteristics of the housing units
- the appliances utilised, including space heating and cooling equipment
- demographic characteristics of the household
- the types of fuels used, consumption and cost
- other information that relates to energy use.

The RECS fuels include natural gas, electricity, fuel oil, LPG and kerosene.

The RECS was first conducted in 1978. The eleventh survey was conducted in 2001 when data were collected from 4,822 households in housing units statistically selected to represent the 107 million housing units in the USA.

Data for the RECS are obtained from three different sources:

[xi] Accessible electronically www.eia.doe.gov/emeu/recs/contents.html

- on-site 40-minute personal interviews conducted in the housing unit
- telephone interviews with the rental agents of those rented housing units that have any of their energy use included in their rent
- mail questionnaires mailed to the housing units' energy suppliers asking them to provide the units' actual energy consumption amounts and expenditures.

7.4.1.3 Canada

Survey of Household Energy Use (NRCan, 1994, 2000a, 2000b) is carried out by the Special Surveys Division of Statistics Canada for the Office of Energy Efficiency (OEE) of Natural Resources Canada. The main results were reported in the 1997 Survey of Household Energy Use, and in the 1997 Survey of Household Energy Use – Detailed Statistical Report. The reports compare the results of the surveys conducted in 1993 and 1997, as well as other interim reports. These documents are used for existing energy efficiency programs, to analyse and understand the possible effects of measures being considered for the future and, finally, to estimate the energy efficiency potential in the residential sector.

7.4.1.4 New Zealand

New Zealand House Condition Survey (NZHCS) was carried out on more than 400 houses in New Zealand by BRANZ in 1994 (Page et al, 1995). This was followed up by a detailed inspection of 465 houses in Auckland, Wellington and Christchurch in 1999 and a telephonic socio-demographic and maintenance survey on 510 houses, leading to the database and report (Clark et al, 2000). A further NZHCS is currently (November 2004) underway, and will be reported in 2005.

The NZHCS contains essentially the same type of data as is collected by the EHCS in the UK, the RECS in the USA and the SHEU in Canada. The main difference is that the UK and USA databases may have more comprehensive social information than the NZHCS, and are annually updated instead of five-yearly.

7.4.2 Modelling house heating

In these models the estimation of the space heating requirement of a house is based on its energy balance, which is in turn 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.

The energy requirements for water heating, cooking, lighting and electrical appliances can be based on experimentally derived relationships between energy use and occupancy of the house. The temporal dimension is usually excluded from such models.

7.4.2.1 United Kingdom

Building Research Establishment's Domestic Energy Model (BREDEM) (Shorrock and Anderson, 1995, Anderson et al, 1985, 2002a, 2002b) is used for the purpose of rating houses or quantifying the effect of structural modifications. It has served as the basis for the development of UK housing energy rating schemes such as the Standard Assessment Procedure (SAP) and National Home Energy Rating (NHER).[xii]

These rating schemes measure slightly different factors:

[xii] National Home Energy Rating and Standard Assessment Procedure for houses: www.nher.co.uk/e.shtml

- SAP looks only at the fixed elements of the home and is the same wherever the property is located in the UK.
- NHER includes various location-specific elements (including whether the home is south facing or sheltered from wind by other buildings) and so better reflects actual running costs.

BREDEM traces its origins to the early 1980s, and is now available in annual (BREDEM-12) and monthly (BREDEM-8) versions. The BREDEM model considers the building's physical features (construction, heating systems, location) and uses external inputs about the household operations (temperatures, hours used, patterns of appliance use) in order to develop estimates of space heating, water heating, lighting, appliance and cooking energy use.

An analytical approach, involving the balancing of heat losses against gains in a two-zone building model, is used to calculate the space heating energy requirements. This incorporates empirical functions based on occupancy to estimate the utilisation of metabolic gains, demand for hot water and the energy use for cooking, lighting and appliances. These assumptions about the behaviour of the occupants determine the heating regime, temperatures and heating patterns.

The model is well-suited to quantifying the effect of various energy efficiency measures, and is the most widely used approach to modelling the space heating energy requirement of dwellings in the UK. BREDEM has been extensively validated against monitored data.

7.4.2.2 United States of America

A large number of mostly propriety computer building simulation programs are available in the USA. The best available public-domain, state-of-the-art, building energy simulation programs are reportedly:[xiii]

- **ENERGYPLUS**[xiv] combines the best features of two earlier programmes, **BLAST** and **DOE-2.1e**. EnergyPlus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation and input and output data structures tailored to facilitate third party interface development. Other planned simulation capabilities include solar thermal, multi-zone airflow, and electric power simulation including photovoltaic systems and fuel cells.

  EnergyPlus' two foundation programmes are:

  DOE-2[xv] has been the technical basis for a range of building energy codes and standards in the USA. A number of Home Energy Rating Systems (HERS) are also based on this programme. DOE-2 calculates the hourly energy use and energy cost of a building given information about the building's climate, construction, operation, utility rate schedule and heating, ventilation and air-conditioning (HVAC) equipment. DOE-2 is a portable FORTRAN program that can be used on a large variety of computers, including PCs. DOE-2 has been

[xiii] Building Energy Simulation Tools (BEST): http://arch.hku.hk/reserach/BEER/best.htm
[xiv] EnergyPlus support website: http://eere.energy.gov/buildings/energyplus/
[xv] DOE-2 website: http://gundog.lbl.gov/dirsoft/d2whatis.html

validated by comparing its results with thermal and energy-use measurements on actual buildings.

BUILDING LOADS ANALYSIS AND SYSTEM THERMODYNAMICS (BLAST)[xvi] was the program used by the USA Department of Defence for energy efficiency improvements to its buildings. The BLAST analysis program encompasses three major sub-programs which compute hourly requirements of the space loads, calculates demands (hot water, steam, gas, electrical, chilled water) of the building and air-handling systems, and computes the hourly annual fuel and electrical power consumptions. The heart of space loads prediction is the room heat balance. For each hour simulated, BLAST performs a complete radiant, convective and conductive heat balance for each surface of each zone described, and a heat balance on the room air. This heat balance includes transmission loads, solar loads, internal heat gains, infiltration loads, and the temperature control strategy used to maintain the space temperature.

- **SUNREL**[xvii] is an upgrade of SERI-RES (which in turn built on the programme SUNCODE), which was released in the early 1980s by the Solar Energy Research Institute (SERI) which has since been incorporated into the National Renewable Energy Laboratory (NREL). The program has been used by researchers around the world and has been proven to be accurate and reliable. SUNREL is an hourly building energy simulation program that aids in the design of small energy-efficient buildings where the loads are dominated by the dynamic interactions between the building's envelope, its environment, and its occupants. The program is based on fundamental models of physical behaviour and includes algorithms specifically for passive technologies, such as Trombe walls, programmable window shading, advanced glazings, and natural ventilation. In addition, a simple graphical interface aids in creating input files. It does not currently model HVAC equipment performance, but calculates the loads that an HVAC system would see.

7.4.2.3 Canada

HOT2000[xviii] is the Canadian energy analysis and design model for low-rise residential buildings. It utilises current heat loss/gain and system performance sub-models, and aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems. Reports on the house analysis, weather file, economic and financial conditions and fuel costs are available. The house analysis includes detailed monthly tables, annual heat loss and HVAC load results. Canada's home energy rating system, EnerGuide for Houses, provides an estimate of the energy consumption to operate a house and is based on HOT2000.

The Buildings Group in National Resources Canada has developed a suite of software tools to evaluate energy use in buildings – including residential and commercial buildings, lighting and daylighting, building envelope and windows. Many of these are available from their website.[xix]

[xvi] BLAST support website: http://bso.uiuc.edu/

[xvii] SUNREL website: www.nrel.gov/buildings/highperformance/sunrel/

[xviii] HOT2000 simulation model: www.buildingsgroup.nrcan.gc.ca/software/hot2000_e.html

[xix] Buildings Group software home page: www.buildingsgroup.nrcan.gc.ca/software/software_e.html

7.4.2.4 New Zealand

Annual Loss Factor, 3rd edition (ALF3)[xx] is the latest version of software which has been developed by BRANZ since 1980. It is designed to calculate the annual energy use and heating requirements in common New Zealand houses for rating or quantifying the effect of design or structural modifications for the New Zealand climate and conditions (Stoecklein and Bassett, 2000). Unlike the thermal simulation programmes discussed above, ALF3 is a not a general purpose thermal simulation tool. ALF3 is the result of using the thermal simulation programme SUNCODE on a selection of proto-typical New Zealand houses in a range of climates and different uses (including space temperatures and heating regimes).

ALF3 is a tool for designers, builders, building contractors and others involved in the planning of residential buildings. The tool can also be applied to evaluate energy efficiency retrofits for existing buildings. The ALF3 calculation method allows designers to:

- estimate the annual heating energy requirement for a given house design and construction, including the effect of thermal mass
- compare how different building orientations affect the heating energy requirement
- determine the Building Performance Index (BPI), which is one of the compliance options with the Energy Efficiency Clause H1 of the NZBC Approved Documents
- estimate what impact heating habits have on the heating energy
- estimate the cost benefits of increased insulation by taking account of the energy costs from your power supplier and insulation costs
- evaluate energy efficiency retrofit options for existing buildings.

7.4.3 Scenario programmes

Scenario modelling to quantify the effect of energy-use policies is possible with either *bottom-up* or *top-down* model programmes. These approaches represent the two extremes of simplifying assumptions, making it possible to model the complex relationships between energy use, energy supply and economic drivers. The following comparison of the two modelling approaches is based on a discussion by Johnston (2003), and shows the advantages of using a bottom-up approach for HEERA.

The basic difference between top-down and bottom-up models is in the type of variables that are used to model energy demand and supply.

A *top-down modelling approach* focuses on the interaction between the energy sector and the economy at large, and uses econometric equations and variables to model the relationships that exist between the energy sector and economic output. Consequently, top-down models avoid detailed technology descriptions, as their emphasis is not on the individual physical factors that can influence energy demand, but rather on the macroeconomic trends and relationships. The data input required for top-down models consist of econometrically-based data, such as Gross Domestic Product (GDP), fuel prices and income.

The use of econometrically based data within top-down models means that these techniques are capable of modelling the interactions that occur between various economic variables and energy demand. This ensures that macroeconomic factors are taken into consideration (including cost factors and cost incentives) and provides feedback from the economy. For

[xx] ALF software: www.branz.co.nz/main.php?page=ALF%20Software

instance, higher energy prices may result in a reduction in the demand for energy by a number of mechanisms.

Thus, top-down models are particularly appropriate for modelling the societal cost-benefit impacts of various energy and emissions policies and scenarios. However, the lack of detailed technology description makes it difficult to model the impact of energy-use policies aimed at this level.

A *bottom-up modelling approach* focuses on the energy sector alone, and tends to use highly disaggregated physically-based engineering-type variables to model in detail the energy demand and supply sectors. The data input required for these models largely consists of quantitative data on physically measurable variables, i.e. the thermal performance of a wall, the efficiency of a space heating system, or the specific energy consumption of a TV.

This data is used to describe in detail the past, present and future stocks of energy using technologies within particular sectors of the economy. The use of such data takes into consideration the fact that, over time, the current stocks of energy-using technologies will be replaced with new ones, as their useful lifetime is reached.

The physically measurable data, along with other relevant information, can be aggregated to determine the demand for energy within various sectors of the economy. Alternatively, the data can be used to obtain a picture of the individual end-uses of energy.

It is important to note that economic variables, such as income and fuel prices, are not explicitly modelled within bottom-up methods. Instead, they are incorporated within the model in terms of their effect on physically measurable variables, such as mean internal temperatures, the ownership and usage of appliances and the different fuels that are used. Consequently these models are poor at describing market interactions, and can neglect the wider relationships that exist between energy use and macroeconomic activity.

The use of physically measurable variables in bottom-up models has resulted in these models being widely used to suggest the likely outcome of policies based on such variables, or to identify a range of technological measures that are intended to improve end-use efficiencies.

Unlike the building thermal simulation programmes discussed under Section 7.4.2, which focus on energy use in a time period between one hour and one year, the longer term temporal dimension is included in bottom-up scenario models. These models may repeatedly estimate annual energy use for many building types over each building's projected lifetime, and must do this within a short period of real time in order to be practical.

If models such as BREDEM or ALF3 are used as the basis of the energy-use simulation procedure, the number of variables in the simulation procedure has to be reduced by making assumptions about the building envelope, heating patterns and the impact of climate. *This requires the national residential building stock to be categorised into a number of standard building types and heating patterns, and New Zealand's climate range into a number of climate zones.*

In order to model the impact of socio-economic drivers such as occupancy and income on the energy use in houses, building and equipment variables that affect energy use have to be expressed explicitly in terms of these drivers where possible. When this is impractical, as in the case of building envelope specifications and equipment efficiencies, the temporal effect on energy use is taken into account implicitly by projecting changes in efficiencies or specifications over time for a particular scenario.

Different scenario modelling programmes are likely to be limited to one type (top-down or bottom-up) and to one country. The underlying structure may be able to be used in other locations or countries, but this is subject to ensuring the many assumptions and base data are altered appropriately. In this way they differ from thermal simulation programmes, which require only the provision of appropriate weather data.

7.4.3.1 United Kingdom

In the UK, models based on empirical measurements are now seen as critical in the development of policy. Two model programmes are of interest – BREHOMES and DECADE.

BREHOMES (Building Research Establishment Housing Model for Energy Studies) (Shorrock et al, 1991) deals with national and regional issues, but is in turn based on the **BREDEM** (Building Research Establishment Domestic Energy Model) single-house model.

BREHOMES disaggregates the UK housing stock into seven age groups, 18 built forms, four tenures and the presence (or absence) of central heating. For each of these 1,008 variations, BREHOMES uses a version of BREDEM to evaluate the energy use of 10 typical heating patterns using three iteration loops. The calculated energy is reconciled to the known total energy used, using a variable related to the average demand indoor temperature. BREHOMES identifies key opportunities for energy efficiency, and can be used to evaluate the benefits of different measures.

The DYNAMIC module in BREHOMES provides the possibility of developing residential energy-use scenarios. This is done by changing the BREDEM parameters for future years based on best-guess estimates and on extrapolating historic trends. BREHOMES does not contain a feedback loop from a macroeconomic module to determine these parameters according to a general equilibrium or other optimisation mechanism.

DECADE (Domestic Equipment and Carbon Dioxide Emissions) (Boardman et al, 1995) examines the electricity consumed in lights and appliances in British homes. Data has been collected and analysed for the period 1970 to 1994 and projected forwards to 2020. The DECADE model combines information about the ownership and use of domestic electrical lights and appliances. The residential information covers changes in technology, behaviour and demographic factors, to give a detailed breakdown of electricity consumption and the resultant emissions of carbon dioxide. Statistical modelling has been used to analyse the data and the careful selection and application of the appropriate techniques is one of the main reasons for confidence in the findings.

As with end-use models of this kind, the effects of policy options, which change the price of fuels, cannot be estimated through macroeconomic interaction with the demand side. Top-down models usually carry out this type of analysis, where price elasticities are used as model parameters. In DECADE, as in most bottom-up models, the effect of economic policy options on the appliance stock is estimated exogenously.

7.4.3.2 United States of America

The Department of Energy's **Residential Sector Demand Module** is part of the **National Energy Model System** (NEMS) model (Office of Integrated Analysis and Forecasting, 2003). It is used for mid-term forecasting purposes and energy policy analysis over the forecast horizon of 1997 through 2025. The model generates forecasts of energy demand, i.e. energy consumption, for the residential sector by service, fuel and Census Division. The policy impacts that result from the introduction of new technologies, market incentives and regulatory changes can be estimated using the module and defining alternative input and parameter assumptions.

The Residential Sector Demand Module uses inputs from the NEMS system to generate outputs needed in the NEMS integration process. The inputs required by the Residential Sector Demand Module from the NEMS system include energy prices and macroeconomic indicators. These inputs are used by the module to generate energy consumption by fuel type and Census Division in the residential sector. The NEMS system is a general equilibrium model that uses these forecasts to compute equilibrium energy prices and quantities.

The residential sector encompasses residential housing units classified as single-family, multi-family, and mobile homes. Energy consumed in residential buildings is the sum of energy required to provide specific energy services that use selected technologies according to energy efficiency levels of building structures. The Residential Sector Demand Module projects energy demand following a sequence of steps:

- forecast housing stock
- select specific technologies to meet the demand for each energy service
- forecast appliance stocks
- forecast changes in building shell integrity
- project the amount of distributed generation equipment
- calculate the energy consumed by the equipment chosen to meet the demand for energy services.

The Residential Sector Demand Module is an analysis tool used to address current and proposed legislation, private sector initiatives, and technological developments that affect the residential sector. Examples of policy analyses include assessing the potential impacts of:

- new end-use technologies (such as natural gas heat pumps)
- changes in fuel prices due to tax policies
- changes in equipment energy efficiency standards
- financial incentives for energy efficiency investments
- financial incentives for renewable energy investments.

7.4.3.3 Canada

CREEEM (Canadian Residential End-use Energy and Emission Model) (Fung et al, 2000) is a bottom-up and engineering model used to estimate Canadian residential end-use energy consumption and GHG emissions. CREEEM has the following features and capabilities:

- represents the Canadian housing stock provincially, regionally and nationally
- estimates energy consumption and greenhouse gas emission for different residential end-uses such as space and DHW heating, cooling and appliances
- incorporates information from new data sources as they become available
- capable of conducting comparative techno-economic analysis for a wide range of building retrofit and fuel switching scenarios

- capable of assessing the energetic and emissions impact of changes to the NZBC.

CREEEM is used to estimate the average annual household end-use energy consumption (UEC) and associated GHG emissions categorised according to:

- province
- space heating fuel type
- usage (end-uses)
- vintage
- type of dwelling.

Data from the Survey of Household Energy Use (SHEU)[xxi] (NRCan and Statistics Canada, 1977), the Modified STAR-HOUSING database (STAtistically Representative HOUSING Stock), the "200-House Audit" project and HOT2000 default values are used as basis for CREEEM. Overall household energy consumption associated with GHG emission and provincial electricity generation GHG intensity factors are estimated with the HOT2000 energy simulation program (se Section 7.4.2.3).CREEEM contains no feedback loop to a general equilibrium procedure.

ISTUM (Intras-Sectoral Technology Use Model) was originally developed by DOE in the 1980s. It was further developed by J Nyboer of the Simon Fraser University of Canada (Nyboer, 1998) and as the ITEMS model in the USA[xxii].

ISTUM assesses the impact of various policy options on industrial emissions of carbon dioxide. Nyboer's model is bottom-up, which projects the future by analysing changes in industrial and residential technology. ISTUM includes optimisation procedures for the selection of technologies competing for energy-use services.

The model has been used to analyse energy use in the Canadian residential and commercial sectors, as well as in eight industrial sub-sectors in seven regions (the Atlantic provinces taken together plus the other six provinces). The industrial sub-sectors include chemicals, mining, iron and steel, metal smelting and a catch-all for other manufacturing. Sub-models have been developed for some speciality products and processes including wood products, lime and aluminium smelting. A transportation model is under development.

7.5 Recommendations

Five international residential, bottom-up scenario model programmes have been identified: BREHOMES, DECADE, NEMS, CREEEM and ISTUM. The EERA modelling and database structures have many features in common with BREDEM-12 and DECADE. It has been decided to use EERA as basis for HEERA, and to improve HEERA building on the approach and structures used in the BREDEM-12 and DECADE structures.

The aspects of HEERA affected by this decision and the way in which they are to be modified to comply with the HEEP requirements are:

[xxi] See: http://oee.nrcan.gc.ca/neud/dpa/data_e/neud_publications.cfm?text=N&printview=N
[xxii] See: www.cieedac.sfu.ca/CIEEDACweb/index.php

7.5.1 Appliance stock model

At present the EERA appliance stock is modelled only by the total annual stock per appliance type, i.e. the stock envelope, without the annual addition and retirement of stock being accounted for separately. In HEERA, the annual addition and retirement of stock will be used in a vintage stock model to build up the stock envelope. This vintage stock model is based on the structure of the DECADE appliance vintage stock model (Boardman et al, 1995).

Vintage stock models allow for the time-related effects of new products or dwellings entering and old ones leaving the stock, and enable the evaluation of the effect of policy options on energy consumption. This type of model is most useful for analysing the effect of changes in technology, usage or ownership through time.

7.5.2 Dwelling stock model

At present the EERA dwelling stock is modelled only by the stock envelope. In HEERA the annual addition and retirement of stock being will be used in a vintage stock model to build up the stock envelope. This vintage stock model is based on the structure of the DECADE appliance vintage stock model (Boardman et al, 1995).

7.5.3 Space-heating energy demand model

The present EERA model employs a space-heating energy demand sub-model based on ALF3 (Stoecklein and Bassett, 2000). This currently provides only for four geographic regions and does not include the effect of thermal mass. HEERA will employ the complete ALF3 space-heating model, providing for 16 Regional Council areas and including the effect of thermal mass.

7.5.4 Appliances energy demand models

At present the energy demand per unit appliance (energy intensity) for water heating, lighting, cooking, refrigeration, laundry and other electrical appliance loads, is specified in the EERA database for each appliance type, along with its stock.

The energy intensities of appliances have previously been determined from the appliance stocks and total energy demand per dwelling, based on the assumption that the total electrical energy demand per dwelling comprises space heating plus these other appliances. For HEERA the models will be developed from HEEP monitored data, building on correlations between the end-use energy demand and socio-demographic model parameters.

The energy intensities of appliances as estimated in this way could be limited due to assumptions about the model parameters. The sector residential energy demands of HEERA will be compared to that given in Energy Data File (MED, 2004a) and Energy Outlook projections (Smith et al, 2003).

7.6 Conclusions

This literature survey has:

1. Identified international databases and models that could assist in the development of HEERA, a residential energy-use model and database for storing and utilising the HEEP data to the advantage of the HEEP stakeholders.

2. Compared the capabilities of these models and databases and concluded that New Zealand's EERA and the UK's BREDEM-12 and DECADE models have features in common that are desirable for HEERA.

3. Determined how EERA can be used as basis for HEERA, and how it can be improved by incorporating the best features of the BREDEM-12 and DECADE models.

8. DEVELOPMENT OF HEERA

The development of a residential database and scenario model from EERA (Energy Efficiency Resource Assessment) to store data from HEEP and to enable the stakeholders to utilise it to their best advantage is the subject of this section. This residential scenario model is referred to as the Household Energy Efficiency Resource Assessment (HEERA) model and database.

8.1 Background

It is important to be clear on what is required from the HEERA model in terms of HEEP outputs, and how BRANZ and other stakeholders intend to use HEERA. The following HEERA features are designed to achieve the above aim:

- HEERA is a scenario model that allows the investigation of trends in energy consumption and the impact of energy efficiency options on energy consumption and greenhouse gas emissions.
- The energy-use scenarios are capable of being analysed and the impact of policy measures determined from a range of viewpoints. This requires database disaggregation at the regional, dwelling type, end-use and appliance levels and information on occupant socio-economic and demographic characteristics.
- No macroeconomic equilibrium mechanism is necessary at this stage to provide an energy-price feedback to the demand-side. However, when the effects of policy options which change the price of the fuels need to be taken into account, and if end-use fuel-price elasticities justify it, such a feedback loop development would be required.
- The database stores the HEEP data and additional residential information in a consistent framework that enables the historic and projected estimation of residential energy use, energy supply and greenhouse gas emissions through models driven by basic economic, demographic and socio-economic drivers. These models calculate the dwelling and appliance stock, and the space heating, water heating, cooking, lighting, refrigeration, laundry and electrical appliance energy use.
- Dwelling and appliance stock models 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 model simulates a dwelling's space heating requirements by taking into account its physical features (construction, heating systems, location) and uses external inputs about the household operations (temperatures and heating regimes). Water heating, lighting, cooking, refrigeration, laundry and electrical appliances contribute to the space-heating internal heat gains through their models.
- The rest of the models calculate the energy used by dwellings for water heating, cooking, lighting, refrigeration, laundry and electrical appliances with the use of household demographics and operation, e.g. family type, size, composition and income, water and energy use, temperatures and usage regimes.

To establish what modelling practices are employed in modern international residential energy-use models, a literature survey (Section 7) was undertaken to:

- compare the existing EERA residential model and database with international databases and models with regard to purpose, capabilities and construction

- recommend how the HEERA model can be developed from the EERA model with HEEP requirements in mind.

The recommendations of the literature survey are incorporated in the development of the following HEERA model.

8.2 HEERA Model

The EERA and HEERA models are based on information about the number of energy-using appliances in a dwelling, e.g. fridges and freezers, towel rails, dehumidifiers and washing machines to mention a few. How often are they used? An oven may, for instance, be used only occasionally. High-efficiency wood burners replace old wood burners. These changes and replacements have a considerable impact on energy consumption. The same applies to other energy-using appliances. The relationships, variables and drivers that determine the stocks and energy demand of the energy-using appliances are incorporated into the HEERA model, and have been discussed in an EERA report (Rossouw, 2003). A summary of these relationships, indices, variables and drivers that are applicable to the HEERA model is given in Section 8.2.1.

The energy consumption of appliances is the product of the appliance stock and the energy intensity, i.e. the energy consumption per unit appliance. Sections 8.2.3 and 8.2.7 show that the stocks of dwellings and the most important residential appliances can be determined from official historic and projected statistics. Such statistics are not available for the energy intensity, i.e. the energy consumption per unit appliance. At best the national and regional energy demand for the residential sector is provided by official Ministry for Economic Development (MED) surveys.

However, in the HEERA model the effects of occupant socio-economic and demographic characteristics and behaviour should be reflected in the appliance energy intensities. This means that the space heating, water heating, cooking, lighting, refrigeration, laundry and electrical appliance models have to provide the *end-use energy demand per dwelling* from which the appliance energy intensities can be calculated with the help of appliance stocks per dwelling. These energy demand models, and their derivation from literature sources and with the help of the HEEP measurements, are described in Section 8.2.10.

8.2.1 Basic quantities and relationships

A stock model formulation of energy demand is used in HEERA. In this formulation the total energy demand for the residential sector is described in terms of energy consuming units (appliances) and variables that allow the time-dependent calculation of the energy demand and of the impact of energy efficiency measures on the energy consumption. This is possible at different levels of aggregation, corresponding to different levels of available data and refinement of energy efficiency measures.

The total delivered end-use energy consumption (DEC) per year at time *t* by all appliances (technologies) is given by the energy demand function Equation 1:

$$E(t) = \sum_r \sum_z \sum_h \sum_i \sum_d \sum_a \sum_e \sum_b E_{rzhidaeb}(t) \qquad (1)$$

$E_{rzhidaeb}$(t) is the annual DEC at year *t* of appliance type *a*, belonging to a configuration described by a particular geographic region *r*, activity *z*, end-use *d*, energy type *e* and combination *b*, surrounded by a thermal envelope *h* with insulation level *i*.

The indices *r, z, h, i, d, a, e* and *b* specify the geographical, economic, environmental and physical configuration of the appliance. All the indices and variables are assumed discrete, with one year as the unit of time. How these indices are employed in the HEERA model is discussed in Sections 8.2.2 to 8.2.9.

The DEC is defined as the energy delivered to an appliance, as compared to the useful energy output (UEO) of the appliance. The efficiency factor η accounts for appliance energy conversion losses and the DEC is obtained from the UEO and η by: DEC = UEO/η.

The function $E_{rzhidaeb}$ (t) in equation (1) can be expressed in the stock model formulation as:

$$E_{rzhidaeb}(t) = N_{rzhidaeb}(t)Q_{rzhidaeb}(t) \quad (2)$$

where:

$N_{rzhidaeb}(t)$ = appliance population of type *a* at time *t*, belonging to the configuration specified by its indices

$Q_{rzhidaeb}(t)$ = energy intensity, i.e. annual DEC per unit of appliance type *a* at time *t*, belonging to the configuration specified by its indices.

The appliance population in equation (2) can be further expanded as:

$$N_{rzhidaeb}(t) = p_{rz}(t)n_{rzhi}(t)n_{rzhidaeb}(t) \quad (3)$$

where:

$p_{rz(t)}$ = sector activity, i.e. some economic quantity *z* that characterises the energy use of the appliance in region *r* (see Section 8.2.3)

$N_{rzhi}(t)$ = envelope intensity, i.e. thermal envelope stock in terms of thermal envelopes per unit activity for the indices *r, z, h* and *i* and variable *t* (see Section 8.2.4)

$n_{rzhidaeb}(t)$ = appliance intensity, i.e. appliance stock in terms of stock per unit envelope for the indices *r, z, h, i, d, a, e* and *b* and variable t (see Section 8.2.7).

The change in the population of an appliance at time *t* is the difference between annual addition and removal terms as described in Section 8.2.7 by the appliance vintage stock model.

In this formulation the effect of user operation is contained in the energy intensity factor $Q_{rzhidaeb}$(t). Since the energy intensity is determined from the appliance stocks and energy demand per dwelling, the effect of user operation is implicit through the energy demand models described in Section 8.2.10.

Space-heating simulation procedures and models such as ALF3 (Stoecklein and Bassett, 2000) and EnergyPlus calculate the heating load required to maintain the difference between the set temperature inside a thermal envelope and that of the environment, using the thermal properties and configuration of the thermal envelope. Such models could therefore be used to calculate the total annual heating energy of all the appliances inside a given environment and envelope configuration (e.g. a building in a given region), such that the inside temperature of the envelope is maintained at the set point temperature of the envelope by a specified heating schedule.

A specific appliance type *a* used inside the envelope would have an annual delivered energy consumption per unit appliance of $Q_{rzhidaeb}$ (t), belonging to the configuration specified by its indices, with $N_{rzhidaeb}$ (t) appliances converting delivered energy of type *e* into heating energy with efficiency η_{aeb}. In order to use the envelope heating energy (u_{rzhi}) as determined by a building simulation model to calculate the $Q_{rzhidaeb}(t)$ for an appliance, the fraction $\varphi_{rzhidaeb}(t)$ of u_{rzhi} contributed by appliance type *a* must be known. Then:

$$Q_{rzhidaeb} = \frac{\varphi_{rzhidaeb}(t)u_{rzhi}}{\eta_{aeb}N_{rzhidaeb}(t)} \tag{6}$$

8.2.2 Geographic region

The geographic region (r = 1, 2 … R) specifies where the appliance is employed and affects the environmental temperature, i.e. the degree-days required to heat a thermal envelope to a specified temperature. In the Approved Documents to Clause H1 of the NZBC, the regions are specified by the following three climate zones (Standards New Zealand NZS 4218: 1996 and NZS 4243: 1996):

- Zone 1: Thames-Coromandel District, Franklin District and all districts north of these
- Zone 2: the remainder of the North Island excluding Taupo and Ruapehu Districts and the northern part of Rangitikei District
- Zone 3: the remainder of the country, being the South Island and the central North Island excluded from Zone 2.

The insulation requirements for dwellings are the same for Zones 1 and 2, but higher insulation (R-values) are required for Zone 3. In rough terms, the thickness of insulating material for dwellings in Zone 3 is approximately 30 percent greater than for Zones 1 and 2.

In order to analyse energy consumption and the impact of energy efficiency measures in a meaningful way, however, HEERA stakeholders require a finer regional specification based on Regional Council and, in some cases, Territorial Authority boundaries. Such boundaries also make sense since electricity and gas supply statistics are available at the Regional Council level through Information Disclosure Statistics from suppliers.

Energy-use statistics for Territorial Authority analysis have to be estimated by splitting up the Regional Council data by means of an economic statistic that is related to energy use at the Territorial Authority level. The chosen statistic is the stock of occupied dwellings, since this is directly proportional to residential energy use and is also used as sector activity in HEERA.

An important consideration for developing the capability to estimate the energy use at the Territorial Authority level is the ability it provides to combine the Territorial Authorities into Regional Council groupings of choice, as required by the HEERA stakeholders.

The basic HEERA regional boundaries are therefore chosen as that of the following 16 Regional Councils, given in Table 25 in terms of their Territorial Authority combinations,[xxiii]

HEERA Regional ID (Regional Council)	Territorial Authority Combination
Northland	Far North DC, Whangarei DC, Kaipara DC
Auckland	Rodney DC, North Shore CC, Waitakere CC Auckland CC, Manukau CC, Papakura DC, Franklin DC (North)
Waikato	Franklin DC (South), Waikato DC, Hamilton CC, Waipa DC, Otorohanga DC, Waitomo DC, Thames-Coromandel DC, Hauraki DC, Matamata-Piako DC, South Waikato DC, Taupo-West DC, Rotorua DC (South West)
Bay of Plenty	Taupo-North East DC, Tauranga DC, Whakatane DC, Kawerau DC, Western Bay of Plenty DC, Opotiki DC, Rotorua DC (North East)
Gisborne	Gisborne DC
Hawkes Bay	Taupo DC (South East), Wairoa DC, Hastings DC, Napier CC, Central Hawkes Bay DC, Rangitikei DC (North East)
Taranaki	New Plymouth City DC, Stratford DC (West), South Taranaki DC
Manawatu-Wanganui	Stratford DC (East), Ruapehu DC, Wanganui DC, Rangitikei DC (South West), Manawatu DC, Tararua DC, Palmerston North CC, Horowhenua DC
Wellington	Kapiti Coast DC, Masterton DC, Carterton DC, South Wairarapa DC, Upper Hutt CC, Lower Hutt CC, Wellington CC, Porirua City CC
Marlborough	Marlborough DC
Nelson	Nelson CC
Tasman	Tasman DC (North East)
West Coast	Tasman DC (South West), Buller DC, Grey DC, Westland DC
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)
Otago	Waitaki DC (South East), Central Otago DC, Queenstown-Lakes DC, Dunedin CC, Clutha DC
Southland	Southland DC, Gore DC, Invercargill CC

Table 25: HEERA 16 regions – Regional Councils and Territorial Authorities

8.2.3 Sector activity

The sector activity with index (z = 1, 2 … Z) is expressed by the quantity p_{rz} (t) in Equation (3). It measures the energy-dependent economic activity of the residential sector by means of an inflation-independent physical quantity such as dwelling stock or floor area. The purpose of expressing the energy-using appliance stock as a fraction of the sector activity in Equation (3) is to base the projection and interpolation of the energy-dependent appliance stocks and energy intensities on an acknowledged economic-growth index.

For scenario stock models such as HEERA, the sector activity is the central quantity that drives the projection and interpolation of other energy-dependent data. Choosing as sector activity an economic quantity that affects all other energy-dependent data in a sector, and for

[xxiii] DC = District Council, CC = City Council
Local Government New Zealand: www.lgnz.co.nz/lg-sector/maps/index.html accessed 6 Dec 2004

which reliable economic projections are available, is necessary to the success of the HEERA model.

HEERA requires data about regional appliance stock levels. This is supplied in the form of household appliance ownership statistics and energy consumption statistics per household by Statistics NZ (Statistics NZ, 2001). Furthermore, historic stocks of existing (Statistics NZ, 2001) and new (Statistics NZ, 1998, 2003) regional dwellings and projected households (Statistics NZ, 2004) are available from Statistics NZ. This combination of dwelling-related statistics makes the regional occupied permanent private dwelling stock the logical choice as residential sector activity.

The NZ Census defines (Statistics NZ, 2002a, 2002b), a private dwelling as accommodating a person or a group of people, but as not available to the public. Permanent private dwellings include houses and flats, residences attached to a business or institution, and bachs, cribs and huts. Caravans, cabins, tents and other makeshift dwellings that are the principal or usual residence of households are classified as temporary private dwellings.

Census statistics over the historic period covered by HEERA are available for the occupied permanent private dwelling stock at national, Regional Council, Territorial Authority and even mesh block level. No projections of the *occupied permanent private dwelling stock* exist.

However, Statistics NZ provides projections of the *household stock* at the Territorial Authority, Regional Council and national levels up to 2021. A household is defined (Statistics NZ, 2002a, 2002b) as either one person who usually resides alone or two or more people who usually reside together and share facilities (such as eating facilities, cooking facilities, bathroom and toilet facilities, a living area).

From the definitions of occupied permanent private dwellings and households, it seems reasonable to equate occupied permanent private dwellings and households for projection purposes. The term *dwelling* has been adopted for both concepts.

In the same way as with appliance stock, the regional dwelling stock at time t also is the difference between annual addition and removal terms which can be described by a dwelling vintage stock model. The following dwelling vintage stock model is an adaptation of the appliance vintage stock model developed for the UK's DECADE stock model (Boardman et al, 1995).

8.2.3.1 Dwelling vintage stock model

In the dwelling vintage stock model the stock of dwellings in a region can be presented as in Figure 55 and expressed by Equation (7).

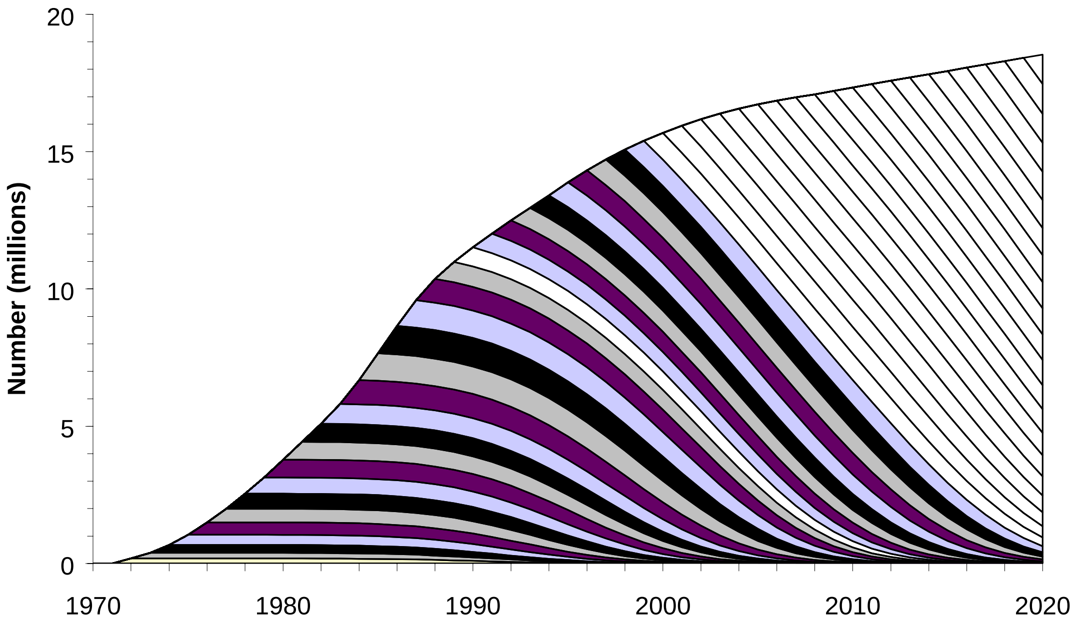

Figure 55: Contribution of new dwellings to the stock of dwellings

$$Stock(k) = \sum_{k-start}^{End} \sum_{j=start}^{End} New(j) \times Remain(j,k) - Removed(j) \qquad (7)$$

Stock(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 model operates
End	=	Last year of period over which the model operates

In Equation (7) it is assumed that dwellings are removed by retirement 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.

The *Remain(j,k)* factor can be described in terms of statistical terminology (Hastings, 1974), where it represents the survival function, i.e. the probability of stock surviving to a specified year. The distribution function *F(j,k) = 1-Remain(j,k)* is the probability of retirement *by* that year. The probability of stock retiring *in* that year is the probability density of *F(j,k)*, i.e. the derivative of *F(j,k)* with reference to time, designated by Δ*Remain(j,k)*.

The *Remain(j,k)* factor can be represented by a number of functions, e.g. step, linear, exponential, logistic, normal or extreme value function. *Remain(j,k)* depends on the mean lifetime L of a dwelling and in the case of the logistic, normal and smallest extreme value distributions, also on the standard deviation σ about the mean lifetime. In the case of the logistic and smallest extreme value functions, the lifetime and standard deviation are expressed in terms of parameters that are defined for these functions in the Appendix. The mean lifetime is obtained by weighting the lifetime with $\Delta Remain(j,k)$ and is given by:

$$L = \frac{\sum_{j=start}^{End} Lifetime(j) \times \Delta Remain(j, End)}{\sum_{j=start}^{End} \Delta Remain(j, End)} \qquad (8)$$

The different types of survival and related functions, expressed in terms of the mean lifetime L and the standard deviation σ, are described in the Appendix.

A typical dwelling survival function is used by the Dwelling Stock Model in the NEMS Residential Model (Office of Integrated Analysis and Forecasting, 2003). This Dwelling Stock Model calculates dwelling stock additions, survival, and retirements in order to produce the total dwelling stock by vintage, type and region. Dwelling units are removed from the dwelling stock at a constant rate over time. The annual survival rates, *a,* for dwelling stock types are assumed by the model to be 0.996 for single-family homes, 0.993 for multi-family homes and 0.965 for mobile homes. From the expression $\ln a = -1/L$ for the exponential function of the Appendix, the mean lifetimes are respectively 249, 142 and 28 years. In the United Kingdom, the lifetimes of the building components of dwellings have been reported by the English House Condition Survey. The mean lifetime of the major residential components is 48 years (Bates et al, 2002 and OPDM, 2003).

The mortality of New Zealand dwelling stock has been investigated by Johnstone (1994), who developed a dynamic dwelling mortality model based on a model by Gleeson (Gleeson, 1985) and New Zealand National Housing Commission dwelling records over a period from 1860 to 1980. The most important aspects and results of this deterministic model are:

1. The model is driven externally by a series of net gain variables and internally by endogenous probability of loss variables, which are amplified by predetermined expansion rates of dwelling stock.
2. The mortality model simulates dwelling losses from individual surviving dwelling cohorts over each time interval, where all these cohorts contribute to the total dwelling loss of a particular future time interval.
3. The mortality of a dwelling cohort upon entry determines the dwelling life expectancy:
    - Under a hypothesis of *static mortality*, dwelling cohorts are exposed to the same mortality regime, resulting in the cohorts having the same life expectancy.
    - Under *variable mortality*, dwelling cohorts are exposed to mortality regimes that change over time, resulting in dwelling cohorts having different life expectancies upon entry.

- Under *dynamic mortality*, the mortality regimes of all cohorts change simultaneously over a period due to economic circumstances, resulting in the life expectancy of dwelling cohorts changing during their lifetimes.

4. The main findings are that the New Zealand dwelling stock has been exposed to a dynamic mortality regime which is a function of age and the expansion rate of the dwelling stock. As a result of fluctuations in the expansion rate, *each dwelling cohort has been exposed to different regimes of mortality*.
5. About 50% of dwellings have been lost from each dwelling cohort by the age of 90 years and the distribution of losses follows a bell shape skewed to the left.

In principle the HEERA dwelling vintage stock model could be used to model the New Zealand dwelling stock in the same way as Johnstone's model (1994) under the following conditions:

- A smallest extreme value survival function is assumed for *Remain(j,k)*, i.e. one having a bell-shaped probability density distribution Δ*Remain(j,k)* skewed to the left.
- The lifetime and standard deviation of Δ*Remain(j,k)* determine the mortality of dwelling cohorts entering the dwelling stock, and both the lifetime and standard deviation depend on the expansion rate of the dwelling stock at time of entry.
- If economic conditions change the expansion rate at any time, the lifetimes and standard deviations of all dwelling cohorts are adjusted accordingly.

How the restrictions of information availability in New Zealand affect the extent to which the HEERA dwelling vintage stock model can be used for the HEERA BAU scenario, is discussed in sections 8.2.3.2 and 8.2.3.3, which describe the national and regional dwelling stock models.

8.2.3.2 National dwelling stock model

The New Zealand dwellings that are considered in HEERA for sector activity purposes are assumed to be permanent domestic dwellings occupied by private households. These are defined by Statistics NZ for the Census of Population and Dwellings purposes (Statistics NZ, 2002a, 2002b) as "occupied permanent private dwellings". It includes: separate houses, two or more houses or flats joined together, flats or houses joined to a business or shop, and bachs, cribs and other holiday homes. It excludes non-private dwellings (e.g. hotels and motels), temporary dwellings (e.g. tents and caravans) and unoccupied dwellings.

This definition of dwellings corresponds exactly with that used for the Census dwelling categories. However, only projections of *households* for a range of birth, mortality and immigration scenarios are available from Statistics NZ's "Subnational Household Projections" (Statistics NZ, 2004). To enable the use of the Statistics NZ projection data for HEERA sector activity purposes, households are therefore equated with occupied permanent private dwellings and categorised as dwellings.

The number of dwellings within Regional Council and Territorial Authority boundaries is available as five-yearly Census time-series statistics for the period 1878 to 2001 (Statistics NZ, 2001). Projections at the Regional Council level for the medium birth, mortality and immigration growth scenarios are available at five-yearly intervals for the period 2001 to 2021 (Statistics NZ, 2004). Annual additions to the dwelling stock in Regional Councils and Territorial Authorities are available from Statistics NZ's Building Consents (e.g. Statistics

NZ, 2003). Annual additions to the *national* dwelling stock are available from 1974 to 2003 (e.g. Statistics NZ, 1998, 2003).

The dwelling vintage stock model described in the previous section requires for its use the annual new dwelling stock, the new dwelling lifetime and the standard deviation of the probability of retiring at a specified year after its erection. This allows the calculation of the net annual dwelling stock as the sum of the annual additions remaining at the specified year. Alternatively, if the net annual dwelling stock, the annual lifetimes and standard deviations are known, the annual dwelling stock additions can be calculated. Since the historic and projected dwelling stock for the medium growth New Zealand scenario is available from Statistics NZ, the alternative method is employed as follows to determine the annual new dwelling stock for the business-as-usual (BAU) residential HEERA dwelling stock model:

1. A logistic growth function is fitted to the five-yearly Census statistics (1878 to 2001) and the subnational household projections (2001 to 2021) to estimate annual net dwelling stock over the period 1850 to 2070 (Figure 56):

$$2{,}500{,}000 \times (1 - 1/(1 + esp(0.286735617 \times yr - 57.2301901301)), \quad R^2 = 0.9982 \qquad (10)$$

   The logistic smoothing distribution function is used for estimating New Zealand dwelling stock instead of Census statistics, even when these are available. This is a consequence of the need for smoothly varying annual new dwelling stocks by the dwelling stock model, since the model is used for interpolation and extrapolation purposes. The effect on the calculation of new dwelling stock with the dwelling vintage stock model when using the logistic smoothing function is illustrated in Figure 57.

2. According to the findings of Johnstone, the New Zealand dwelling stock has been exposed to a dynamic mortality regime which is a function of age and the expansion rate of the dwelling stock. The expansion rate for a given year is defined by the ratio of that year's net dwelling stock to that of the previous year. The lifetime and standard deviation for a given year is calculated by multiplying the lifetime and standard deviation of the previous year with the expansion rate and a scale factor. These scale factors are optimised by minimising the sum of the squares of the deviation between the calculated and surveyed new dwelling stock over the period 1974 and 2003, a period for which new dwelling stock records are available from Building Consent records.

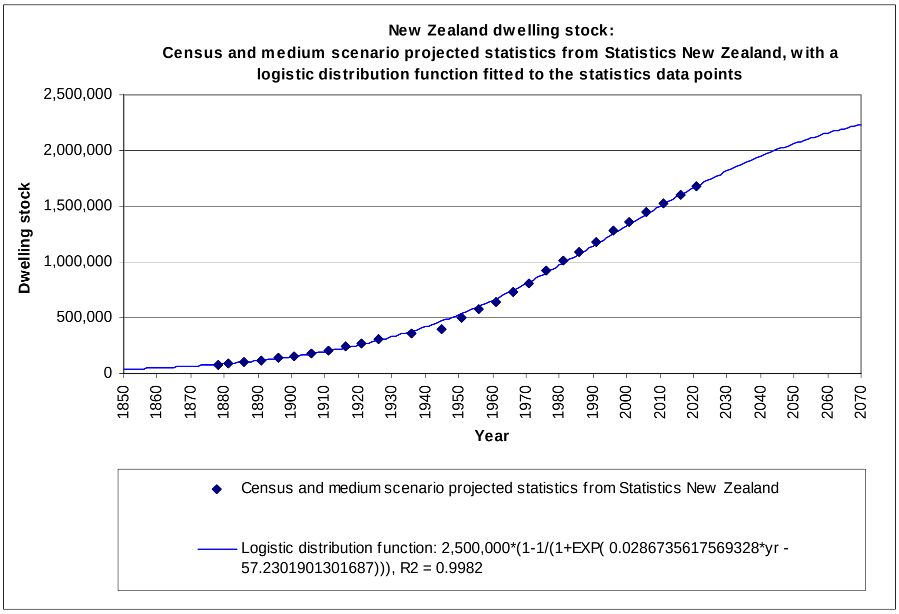

Figure 56: Net dwelling stock growth over the period 1850 to 2070

3. Subsequently the relationships Equation (7) above and Equation (A.1) in the Appendix are used to calculate the smoothed annual new dwelling stock numbers from the net dwelling stock (Figure 57). The calculation uses the net dwelling stock logistic distribution function and a survival function based on a smallest extreme value retirement probability function that is skewed to the left. This incorporates the findings of Johnstone for the dwelling stock over the period 1860 to 1980.

   Annual lifetimes and standard deviations are obtained by multiplying a previous year's lifetime and standard deviation with an optimised adjustment factor depending on the annual dwelling expansion rate.

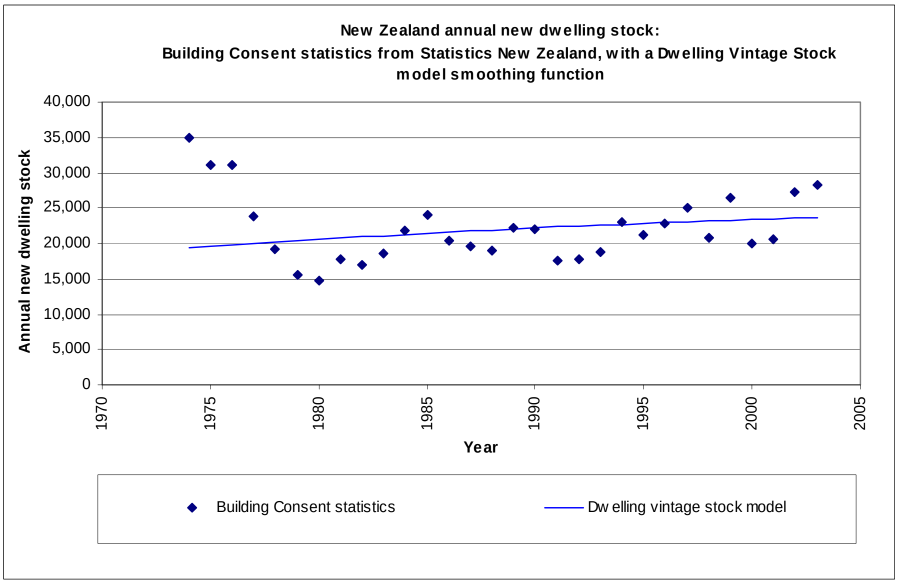

Figure 57: Building consents (1974 to 2003) compared to vintage stock model

The new dwelling survival function is based on smallest extreme value distribution and probability density functions with an average mean lifetime and standard deviation of 95 years and 25 year respectively. Figure 58 also illustrates the smallest extreme value survival and Figure 59 illustrates the probability density functions used in the dwelling vintage stock model.

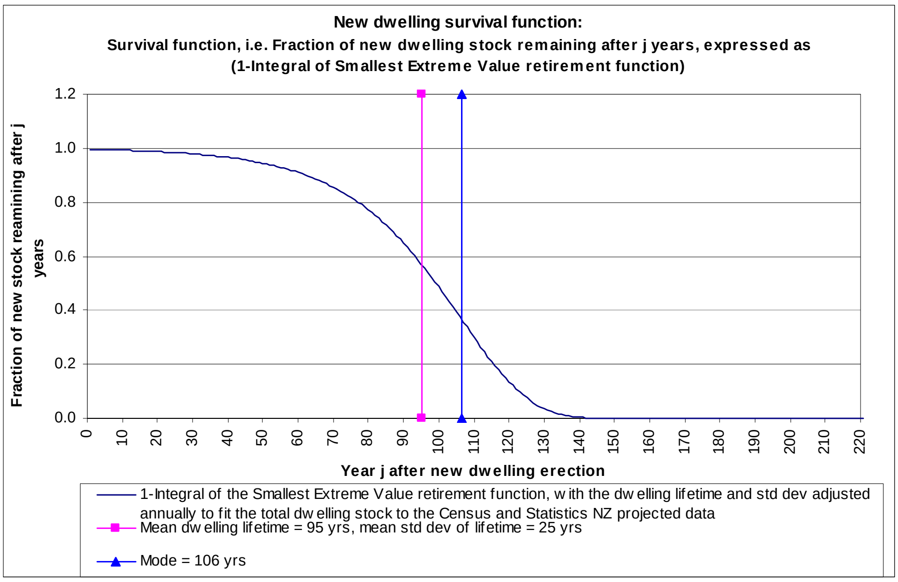

Figure 58: New dwelling survival function

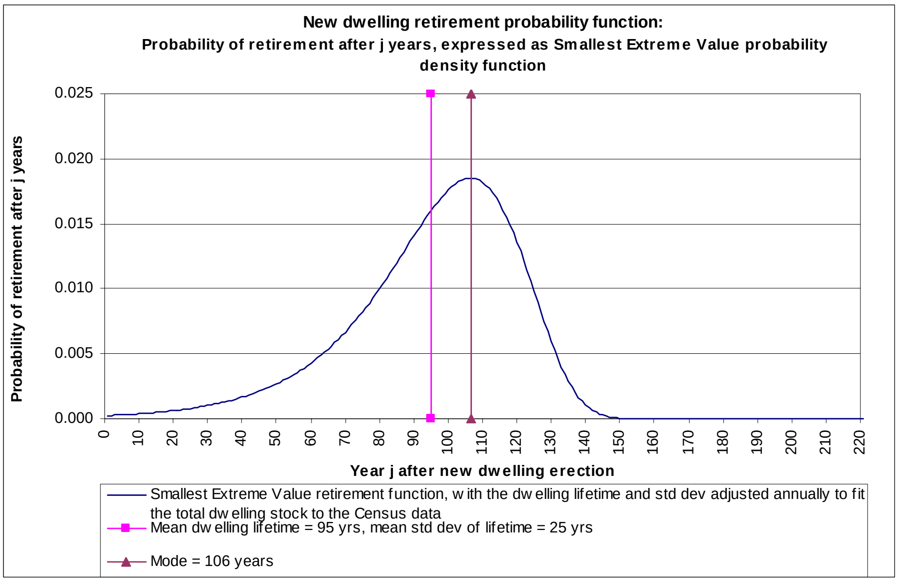

Figure 59: Probability of new dwelling stock retirement function

8.2.3.3 Regional dwelling stock model

The regional dwelling stock model describes how the national dwelling stock of Section 8.2.3.2 is distributed among the HEERA regions. This model is to be developed during the 2004/05 year

8.2.4 Thermal envelope and envelope intensity

The thermal envelope index (h = 1, 2 … H) specifies the thermal envelope that surrounds an appliance and depends on the economic sector in which it functions. For the residential sector it is chosen as dwelling type. Since it is possible to categorise dwellings in terms of their overall insulation level, energy efficiency measures that influence the thermal envelope index would influence the insulation level indirectly through changes to the dwelling stock. The choice and range of dwelling types therefore have important consequences for the application of energy efficiency measures.

The quantity n_{rzhi} (t) in Equation (3) is the envelope intensity, i.e. envelopes per unit activity for the indices r, z, h and i. By defining thermal envelopes as dwellings, the envelope intensity is expressed as the dwelling intensity, i.e. dwellings of a specified type per unit activity. Since the activity p_{rz} (t) is the sum of all dwelling types for a region, the dwelling intensity is expressed as the fraction of the total dwelling stock in a region.

The New Zealand dwelling stock is grouped into a number of basic types (Table 26) that represent different levels of thermal insulation for each region and therefore different levels of energy consumption by appliances in that region. The dwelling types of Table 26 represent the minimum thermal insulation levels required by the NZBC H1/AS1 for each zone and construction method. Revisions to the NZBC may add further dwelling types.

Dwelling type	Description
Uninsulated	Wood frame, wood floor: Pre-1978 NZBC: Clause H1. Uninsulated
Insulated roof	Wood frame, wood floor: Pre-1978 NZBC: Clause H1. Insulated roof
NZBC1978	Wood frame, wood or concrete floor: Rev 1978 of the NZBC: Clause H1
NZBC2000Z1	Wood frame, wood or concrete floor: Rev 2000 of the NZBC: Clause H1, Zone 1
NZBC2000Z2	Wood frame, wood or concrete floor: Rev 2000 of the NZBC: Clause H1, Zone 2
NZBC2000Z3	Wood frame, wood or concrete floor: Rev 2000 of the NZBC: Clause H1, Zone 3
Super-insulated	Wood frame, concrete floor: Solar and super-insulated, full double glazing
NZ average	Wood frame, wood or concrete floor. NZ weighted mean insulation specifications
Unspecified	Unspecified thermal envelope

Table 26: Basic dwelling types for categorising New Zealand dwelling stock

These basic dwelling types can be extended to describe the dwelling stock in more detail, as shown in Table 27.

Dwelling type	Thermal insulation specification
Uninsulated	Frame wall, Suspended floor: Pre-1977 NZBC: Clause H1. Uninsulated, i.e. Insulation: Roof: R0.5, Wall: R0.5, Floor: R0.5, Windows: Single glaze R0.18, Infiltration rate: 0.75 ACH
Roof insulated	Frame wall, Suspended floor: Pre-1977 NZBC: Clause H1. Roof insulated, i.e. Insulation: Roof: R1.9, Wall: R0.5, Floor: R0.5, Windows: Single glaze R0.18, Infiltration rate: 0.75 ACH
NZBC1977FrameSuspendSG	Frame wall, Suspended floor: Rev 1977 NZBC: Clause H1 Insulation: Roof: R1.9, Wall: R1.5, Floor: R1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC1977FrameSlabSG	Frame wall, Slab floor: Rev 1977 NZBC: Clause H1 Insulation: Roof: R1.9, Wall: R1.5, Floor: R2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z1FrameSuspendSG	Frame wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 1 Insulation: Roof: R1.9, Wall: R1.5, Floor: R1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z1SolidSuspendSG	Solid wall , Suspended floor: Rev 2000 NZBC: Clause H1, Zone 1 Insulation: Roof: R3.0, Wall: R0.6, Floor: R1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z1FrameSlabSG	Frame wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 1 Insulation: Roof: R1.9, Wall: R1.5, Floor: R2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z1SolidSlabSG	Solid wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 1 Insulation: Roof: R3.0, Wall: R0.6, Floor: R2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z2FrameSuspendSG	Frame wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 2 Insulation: Roof: R1.9, Wall: R1.5, Floor: R1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z2SolidSuspendSG	Solid wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 2 Insulation: Roof: R3.0, Wall: R0.6, Floor: R1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z2FrameSlabSG	Frame wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 2 Insulation: Roof: R1.9, Wall: R1.5, Floor: R2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z2SolidSlabSG	Solid wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 2 Insulation: Roof: R3.0, Wall: R0.6, Floor: R2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z3FrameSuspendSG	Frame wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: 2.5, Wall: 1.9, Floor: 1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z3SolidSuspendSG	Solid wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: R3.0, Wall: R1.0, Floor: 1.3, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z3FrameSuspendDG	Frame wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: 2.5, Wall: 1.9, Floor: 1.3, Windows: Double glaze R0.33, Infiltration rate: 0.50 ACH
NZBC2000Z3SolidSuspendDG	Solid wall, Suspended floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: R3.0, Wall: R1.0, Floor: 1.3, Windows: Double glaze R0.33, Infiltration rate: 0.50 ACH
NZBC2000Z3FrameSlabSG	Frame wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: 2.5, Wall: 1.9, Floor: 2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z3SolidSlabSG	Solid wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: R3.0, Wall: R1.0, Floor: 2.0, Windows: Single glaze R0.18, Infiltration rate: 0.50 ACH
NZBC2000Z3FrameSlabDG	Frame wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: 2.5, Wall: 1.9, Floor: 2.0, Windows: Double glaze R0.33, Infiltration rate: 0.50 ACH
NZBC2000Z3SolidSlabDG	Solid wall, Slab floor: Rev 2000 NZBC: Clause H1, Zone 3 Insulation R-values: Roof: R3.0, Wall: R1.0, Floor: 2.0, Windows: Double glaze R0.33, Infiltration rate: 0.50 ACH
Superinsulated	Frame wall, Slab floor: Solar & Superinsulated Insulation R-values: Roof: 3.5, Wall: 2.5, Floor: 2.0, Windows: Double glaze R0.33, Infiltration rate: 0.50 ACH
NZ average	Frame wall, Suspended or slab floor. Insulation R-values for roof, wall, floor and window: Weighted mean values for New Zealand
Unspecified	Unspecified thermal envelope

Table 27: Extended dwelling types used for categorising the NZ dwelling stock

Since the thermal envelopes are defined as dwellings, the envelope intensity is expressed as the dwelling intensity, i.e. dwellings of a specified type per unit activity. The activity $p_{rz}(t)$ is the sum of all dwelling types for a region, and the dwelling intensity is therefore expressed as the fraction of the total dwelling stock in a region.

All new dwellings in a region have to conform to the NZBC energy efficiency performance requirement for that region – generally represented by the Acceptable Solution in the form of NZS 4218:1977P or NZS 4218:1996. Using the NZBC to specify dwelling types therefore makes it possible to use the dwelling vintage stock model to estimate the annual new dwelling stock of the dwelling type specified for that region. Figure 60 shows the New Zealand national dwelling stock, as estimated by the EERA dwelling stock model, for the dwelling types of Table 26. The dwelling types NZBC 2000Z1, NZBC 2000Z2 and NZBC 2000Z2 have been consolidated to the NZBC Rev 1996 Timber Floor and Concrete Floor types in Figure 60.

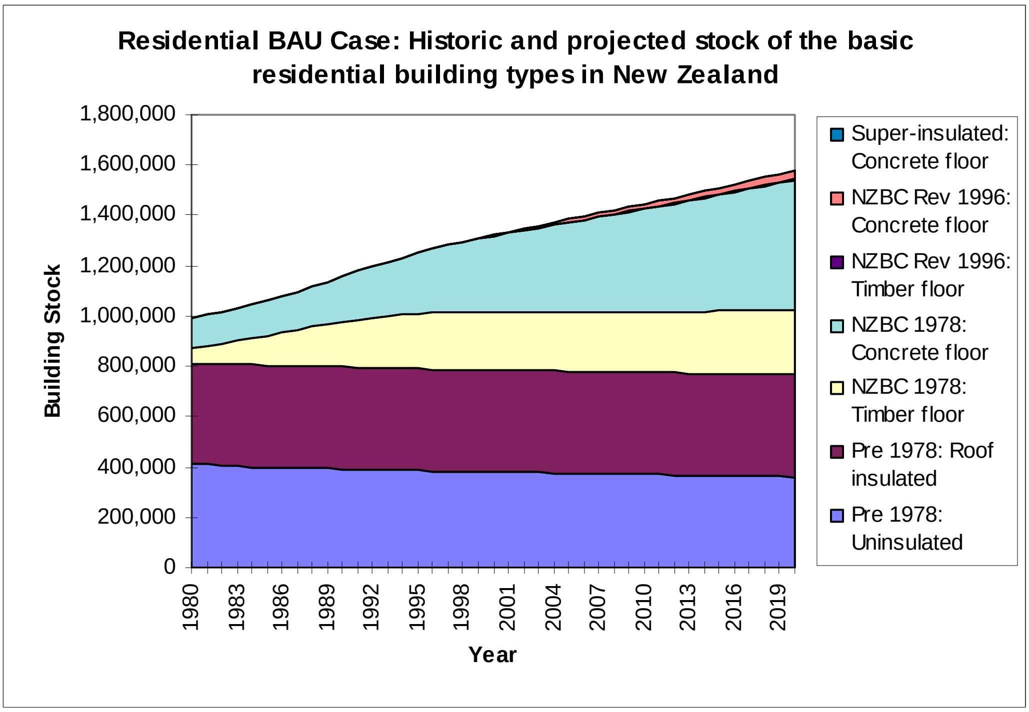

Figure 60: National dwelling stock by insulation level

8.2.5 Thermal insulation level

The thermal insulation level index (i = 1, 2 … I) specifies the level of thermal insulation of the dwelling that surrounds the appliance. This could range from the NZBC specification (usually the minimum allowed) to the highest level of additional insulation that could practically be added. The effect of infiltration (draughtiness) on the insulation level is assumed to be included in the specification.

The thermal insulation specifications of the HEERA dwelling types are given in Table 27. The R-values for the ceiling, wall, floor and windows are the minimum requirements of the NZBC Clause H1. In the case of concrete slab floors, however, the R-value (including floor covering) has been calculated by a method reported by BRANZ. The infiltration rate is given in terms of air changes per hour (ACH).

8.2.6 End-use

The end-use (d = 1, 2 … D) can be any residential end-use. For HEERA these are space heating, water heating, lighting, cooking, refrigeration, laundry and electrical appliances, including moisture control. This index defines the context in which the appliance is utilised.

8.2.7 Appliance type

The appliance type (a = 1, 2 … A) can be any residential appliance, e.g. space heater, heat pump, water heater, refrigerator, light, stove plate, oven, TV, computer, air-conditioner, etc. Although appliance types are prone to variation, explicit time dependence is not assumed. The choice and range of appliance types are important from an energy efficiency point of view. The regional ownership of residential appliances is available from Statistics NZ surveys (Statistics NZ, 2001).

The change in the population of an appliance is described by appliance vintage stock model, which will be developed in the 2004/05 year.

8.2.8 Energy type

This is the energy type (e = 1, 2 … E) consumed by the appliance, e.g. electricity, gas, petrol, diesel, liquid gas, coal, wood. The choice and range of energy types for a specific appliance are important from an energy efficiency point of view and allow the use of fuel switching as an energy efficiency measure.

8.2.9 Demand energy combination

Demand energy combination (b = 1, 2 … B) is the fraction of useful energy provided by an appliance, using a particular energy type for some end-use. This could, for instance, be the fraction of the useful energy that is provided by element heaters using electricity for space heating, where the total space heating is provided by electricity and solid fuels. The demand energy combination is important from the energy use and energy efficiency points of view, especially for space and water heating where a number of demand energies may contribute to the useful energy.

8.2.10 Energy demand sub-models

The lack of energy consumption statistics for appliances necessitates the determination of the energy demand of dwellings by the space-heating, water-heating, cooking, lighting, refrigeration, laundry and electrical appliance models. The energy intensities of appliances are determined from the appliance stocks and energy demand per dwelling.

The fractions of the total residential electricity and gas demand due to the end-uses represented by these energy demand models are according to the HEEP Year 7 report (Isaacs et al, 2003), water heating (29%), space heating and conditioning (22%), lighting (11%), refrigeration (10%), cooking (8%), laundry and other electrical appliances (20%). These percentages indicate the relative importance of the different energy demand models.

Currently the models are developed as Excel spreadsheets which allows their easy development, modification and testing. The models are described in Section 8.2.10, and will be incorporated into the HEERA Access database framework during the 2005/06 year.

The average residential energy intensities of appliances as estimated by the energy demand sub-models can be incorrect due to assumptions about the sub-model parameters. Since the sector residential energy demands of the Energy Data File (MED, 2004a) and the sector energy demand projections of the Energy Outlook (Smith et al, 2003) are the best national estimates available, these have to be used to normalise the residential energy intensities determined by the energy demand sub-models. A scheme for this normalisation procedure is given in Table 28 and Table 29.

In Table 28 the delivered sector energy demands as estimated by MED are used to determine the useful energy intensities of appliance stock. In Table 29 the dwelling variables of the energy demand sub-models are adjusted to produce useful energy intensities of appliance stock that correspond to those of Table 28.

Breakdown of delivered sectoral energy demand into useful energy demand / dwelling / end-use

Delivered sectoral energy demand / energy type, historic and projected (Source: MED)

Wood	Coal	Geothermal	LPG	NatGas	Electricity

Delivered energy demand / dwelling / energy type, calculated using national dwelling stock (Source: Stats NZ)

Wood	Coal	Geothermal	LPG	NatGas	Electricity

Delivered energy demand / dwelling / end-use / energy type, calculated using energy demand and end-use ratios (Source: HEEP and EERA databases)

Space Heating						Water heating						Cooking						Lighting	Refrigeration	Laundry	Appliances
Wood	Coal	Geothermal	LPG	NatGas	Electricity	Wood	Coal	Geothermal	LPG	NatGas	Electricity	Wood	Coal	Geothermal	LPG	NatGas	Electricity	Electricity	Electricity	Electricity	Electricity

Useful energy demand / dwelling / end-use / energy type, calculated from the delivered demand, thermal efficiencies and appliance stock (Source: Stats NZ)

Space Heating						Water heating						Cooking						Lighting	Refrigeration	Laundry	Appliances
Wood	Coal	Geothermal	LPG	NatGas	Electricity	Wood	Coal	Geothermal	LPG	NatGas	Electricity	Wood	Coal	Geothermal	LPG	NatGas	Electricity	Electricity	Electricity	Electricity	Electricity

Table 28: Components of delivered sectoral energy as useful energy

	Space heating	Water heating	Cooking	Lighting	Refrigeration	Laundry	Appliances
Useful energy demand / dwelling / end-use, calculated by the HEERA submodels and normalised to the useful energy demand derived from the delivered sectoral energy demand							
Variables contributing to the useful energy demand / dwelling / end-use calculated by the HEERA submodels	Configuration Thermal properties Location Temp & Schedule Internal Gains	Configuration Water demand Temp & Schedule	Configuration Energy demand Temp & Schedule	Configuration Electricity demand Temp & Schedule	Configuration Electricity demand Temp & Schedule	Configuration Electricity demand Temp & Schedule	Configuration Electricity demand
Household variables influencing to the useful energy demand / dwelling / end-use calculated by the HEERA submodels	Occupancy Composition Income	Occupancy Composition Income	Occupancy Composition Income	Occupancy Composition Income	Occupancy Composition Income	Occupancy Composition Income	Occupancy Composition
Dwelling variables used to normalise the demand-side and HEERA submodel UEO values	Floor area & others	Floor area & others	Floor area & others	Floor area & others	Floor area & others	Floor area & others	Floor area & others

Table 29: Factors affecting the useful energy demand/dwelling/end-use

8.2.10.1 Space heating energy demand

The latest version of the single-zone ALF procedure (ALF3) (Stoecklein and Bassett, 2000) will be used to estimate the space-heating requirement of dwellings in the New Zealand Regional Council 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, laundry and electrical appliances are obtained from their energy demand models.

The construction of the Excel version of ALF3 involved setting up the ALF, AGF, R-value and other supporting spreadsheet tables to form the basis of the ALF3 procedure. 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. This procedure has been tested with two worked examples from the ALF3 manual.

8.2.10.2 Water heating energy demand

As a first approximation, a spreadsheet (Table 30) of the water heating model was developed based on BREDEM (Shorrock and Anderson, 1995, Anderson et al, 1985, 2002a, 2002b).

Variable or Calculation	Value
Total floor area (TFA) (m2)	150
Family size (Occupancy) N (Calculated for TFA<450m2),	4.54
N=0.0365*TFA-0.00004145*TFA**2 for TFA<=450m2,	
N=9/(1+54.3/TFA) for TFA>450m2	
Hot water demand (litre/day)=38+25*N	151.55
Efficiency from cylinder to tap (Assumed 0.85 in BREDEM report)	0.85
Energy use at taps Q_u (W)=78.2+51.85*N	313.72
Hot water cylinder volume V_{hw} (litre) =	180
Cylinder insulation thickness I_{hw} (mm) =	10.00
Primary heat loss factor Q'_t (W)	
(From Primary heat loss factor table, Water heating Tables worksheet) =	150.00
Secondary heat loss factor Q''_t (W)	
(From Secondary heat loss factor table, Water heating Tables worksheet) =	1.50
Tertiary heat loss factor Q'''_t	
(From Tertiary heat loss factor table, Water heating Tables worksheet) =	1.00
HWC storage heat loss Q_t (W) = Q'_t * Q''_t * Q'''_t =	196.56
Primary pipe losses Q_{pp} (W) =Table (3.1, BREDEM12 report, assumed =0 for electric HWC)	0
Distribution losses Q_d (W) =0.176*Qu (17.6% of energy leaving tap)	55.21
Solar collector panel efficiency f_{sp} (default = 0.5)	0.50
Radiation on north-facing 30deg inclined, for given deg-day region S_{30} (W/m2),	
assumed = 140 W/m2	140
Area of solar panel A_{sp} (m2), assumed 1mx1.5m=1.5m2	1.50
(1/LR)=(0.5*f_{sp}*S_{30}*A_{sp})/(Q_u+Q_t) with LR=load ratio=demand/supply ratio	0.10
UT=-0.61*(1/LR)**2+0.63*(1/LR)+0.35, for (1/LR)<0.65;	
UT=0.65/(0.67+(1/LR)), for (1/LR)>=0.65	0.41
Q_s=f_{sp}*S_{30}*A_{sp}*UT	42.88
Efficiency of water heater EPS_w (From Water heaters table)	0.85
Total fuel used Q_w (W) =(Q_u+Q_t+Q_d+Q_{pp}-Q_s)/31.7/EPS_w	614.84
Total fuel used Q_w (GJ/year) =(Q_u+Q_t+Q_d+Q_{pp}-Q_s)/EPS_w/31.7	19.39

Table 30: HEERA water heating model adapted from the BREDEM model

The model is driven by the hot water demand (litre/day) derived from the occupancy (household size), which in turn is derived from the dwelling floor area. As Table 30 shows, the energy demand is further influenced by a number of other parameters, mostly unique to each dwelling. This model is to be replaced in 2004/05.

8.2.10.3 Lighting energy demand

Two provisional lighting models were developed with the assistance of the analysis of a number of HEEP houses. The models are based on empirically derived relationships between the lighting energy demand and the number of occupants, number of children, floor area and number of bedrooms of a dwelling.

Lighting energy use on dedicated lighting circuits was measured in approximately 25% of the 200 HEEP dwellings, with currently a total of 61 houses with lighting circuits monitored and modelled. The lighting energy data was annualised using a linear model that fitted a cosine function of period 1 year, centred on June 20, the shortest day of the year. There is a large variation of energy use between dwellings, ranging from 0.2 to 10.2 kWh/day, with an average consumption of (2.7 ±0.3) kWh/day. Portable or plug-in lights are not included since they are not monitored as part of lighting.

To attempt to explain the variation in lighting energy consumption between households, a variety of models were created and tested. A number of variables were expected to influence the average lighting load, most obviously the floor area of the dwelling and the number of occupants. This was borne out by early investigations, which found that these variables strongly influenced the lighting load.

From a graphical examination, evidence was found that the relationship between floor area and lighting consumption changes with the presence of children in the household, with the slope increasing as the number of children increases. Further occupant characteristics were examined, including the type of household (family, single person, etc), the tenure type (rented, owned etc), income type (superannuation etc), plus others. None of these variables had any relation to the lighting energy use. Further examination is warranted, however, especially in categorisation of the type of household.

Other physical characteristics of the dwelling were also tested, including the house shape, house form (single, two-storey, etc), insulation levels, total number of rooms, number of bedrooms and others. Most of these had no correlation with lighting energy consumption, except house form which showed a modest correlation. This has not been included in the final model due to complexity, and awaiting a better understanding of how this variable may affect lighting energy consumption.

The provisional lighting model selected was based on the floor area and the number of children at home at night. The preferred provisional model with R^2-value = 0.5141 is:

Lighting (kWh/day) =

$$-0.008941 + FloorArea \times 0.01531 + FloorArea \times ChildrenHomeNight \times 0.009526 \quad (11)$$

Another possible model uses the number of bedrooms and number of people but has a lower R^2-value = 0.3088:

$$Lighting\ (\text{kWh/day}) = 2.5732 - 0.8883 \times Nbedrooms + Nbedrooms \times Npeople \times 0.3151 \quad (12)$$

An important consideration when choosing a model for scenario projection purposes is whether the independent variables are available from Census statistics. Since the floor area is not a Census statistic, Equation (12) may be preferable to Equation (11), even if Equation (11) has a higher R^2-value with relation to its independent variables.

This model is to be further developed during 2004/05.

8.2.10.4 Cooking energy demand

As a first approximation, a spreadsheet version (Table 31) of the HEERA cooking model was developed from the formulas used in the BREDEM model.

The model is driven by the electricity, solids and gas demands for cooking (GJ/yr) which are derived from the occupancy (household size), which in turn is derived from the dwelling floor area. As Table 31 shows, the energy demand is further influenced by a number of secondary parameters, mostly unique to each dwelling. This model will be replaced in 2004/05.

Variable or Calculation	Value
Total floor area (TFA) (m2)	150
Family size (Occupancy) N (Calculated for TFA<450m2),	
N=0.0365*TFA-0.00004145*TFA**2 for TFA<=450m2,	
N=9/(1+54.3/TFA) for TFA>450m2	4.54
Electricity demand E_{KE} (GJ/yr) = 1.70+0.34 * N =	3.24
Electricity adjustment factor F_{EADJ} =	
(Above average use = 1.2, Average = 1.0, Below average = 0.8, Well below average = 0.60)	1
Adjusted electricity demand E_{KEADJ} (GJ/yr) = F_{EADJ} * E_{KE} =	3.24
Gas demand E_{KG} (GJ/yr) =2.98+0.60 * N =	5.70
Gas adjustment factor F_{GADJ} =	
(Use: Above average = 1.2, Average = 1.0, Below average = 0.8, Well below average = 0.60)	1
Adjusted gas demand E_{KGADJ} (GJ/yr) = FG_{ADJ} * E_{KG} =	5.70
Solids range demand E_{KS} (GJ/yr) =3.91+0.85 * N =	7.77
Solids range adjustment factor F_{SADJ} =	
(Use: Above average = 1.2, Average = 1.0, Below average = 0.8, Well below average = 0.60)	1
Adjusted solids range demand E_{KSADJ} (GJ/yr) = F_{SADJ} * E_{KS} =	7.77
Gas hob demand E_{KGH} (GJ/yr) =1.49+0.30 * N =	2.85
Gas hob adjustment factor F_{GHADJ} =	
(Use: Above average = 1.2, Average = 1.0, Below average = 0.8, Well below average = 0.60)	1
Adjusted gas hob demand E_{KGHADJ} (GJ/yr) = F_{GHADJ} * E_{KGH} =	2.85
Electric oven demand E_{KEO} (GJ/yr) = F_{EOADJ} * E_{KEO} =	1.62
Electricity adjustment factor F_{ADJ} =	
(Use: Above average = 1.2, Average = 1.0, Below average = 0.8, Well below average = 0.60)	1
Adjusted electric oven demand E_{KEOADJ} (GJ/yr) = F_{EOADJ} * E_{KEO} =	1.62
Microwave oven demand E_{KMADJ} (GJ/yr) (Not given)	0
Total fuel used E_K (GJ/yr) =(E_{KEADJ}+E_{KGADJ}+E_{KSADJ}+E_{KGHADJ}+E_{KEOADJ}+$E_{KEKMADJ}$)/EPS_w	331.67

Table 31: HEERA cooking model adapted from the BREDEM model

8.2.10.5 Refrigeration energy demand

This model will be developed during 2004/05.

8.2.10.6 Laundry energy demand

This model will be developed during 2004/05.

8.2.10.7 Electrical appliances energy demand

As a first approximation, a spreadsheet version (Table 32) of the HEERA appliances model was developed from the formulas used in BREDEM. The model is driven by the average electricity demand for lighting and electrical appliances (GJ/yr) which are derived from the occupancy (household size), which in turn is derived from the dwelling floor area. As Table 32 shows, the energy demand is further influenced by a number of secondary parameters, mostly unique to each dwelling. This model is to be replaced during 2004/05.

Variable or Calculation	Value
Total floor area (TFA) (m2)	150
Family size (Occupancy) N (Calculated for TFA<450m2), N=0.0365*TFA-0.00004145*TFA**2 for TFA<=450m2, N=9/(1+54.3/TFA) for TFA>450m2	4.54
Average electricity demand for lighting and appliances E_{LA} (GJ/yr), E_{LA} = 4.47+0.232*TFA*N for TFA*N<710, E_{LA} = 11.98+0.0146*TFA*N-2.78E-6(TFA*N)^2 for 710<=TFA*N<2400, E_{LA} = 4.47+0.232*TFA*N for 2400<=TFA*N E_{LA} adjustment factor = (Use: Above average =1.2, Average = 1, Below average = 0.8, Well below average = 0.6 Adjusted for consumption E_{LADJ}=	20.27 1.0 20.27
Low Energy Lights fraction (LEL) (From Appliance Tables worksheet) Low lights electricity demand reduction E_{red} (GJ/yr) =0.8*0.16*E_{LA} * LEL Electricity demand for pumps and fans)(GJ/yr) (From Electricity Consumption for Pumps and Fans, worksheet Appliance Tables), assume none)	0.29 0.75 0
Overall electricity demand for lights and appliances E_L (GL/year) = E_{LADJ} – Reduction due to low energy lighting + Electricity demand for pumps and fans	19.52

Table 32: HEERA lighting and appliances model adapted from BREDEM model

8.3 Conclusions

An essential part of HEEP is the development of the HEERA model and database, and the 2003/04 results will provide a solid foundation for the successful development and completion of HEERA in 2004/05 and 2005/06. This conclusion is based on the following 2003/04 achievements:

1. A comprehensive literature survey was undertaken to establish the requirements and state-of-the-art of modern residential energy-use models. The BREDEM-12 model used by the UK's Building Research Establishment and the DECADE model used by the Energy and Environment Programme of Oxford's Environmental Change Unit were selected as models for future HEERA development.
2. A theoretical basis for the HEERA energy-use stock model was developed from the EERA theoretical background and the data requirements of the model were established.
3. 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 NZ. National residential sector energy demands were obtained from MED. Together with the HEEP energy-use measurements, this information forms the core of the HEERA database.
4. A national dwelling vintage stock model was developed for the residential sector, based on the appliance vintage stock model used by DECADE and on a research study of the New

Zealand housing stock. A regional dwelling stock model will be developed with the national model as basis.

5. National and regional appliance vintage stock models will be modelled on the dwelling vintage stock models.
6. Household energy demand sub-models for space heating, water heating, lighting, cooking, refrigeration, laundry and electrical appliances were developed, based on the dwelling configuration and occupancy and on the household composition. The space-heating and lighting sub-models are based on HEEP measurements, while the water-heating, cooking and electrical appliance sub-models were derived from the BREDEM-12 model. All the BREDEM-based sub-models will be replaced with HEEP derived sub-models.
7. A scheme was developed to determine normalised appliance energy intensities from national residential sector energy demands, appliance ownership data and household energy demand models. These normalised appliance energy intensities will be used in conjunction with the appliance stock to estimate appliance energy demand in HEERA.

9. CONCLUSION

This, the eighth annual HEEP report, has provided:

- a review of the importance of energy end-use data to New Zealand energy planning
- preliminary analysis of the emerging social data
- information on the use of LPG heaters
- an analysis of temperatures found in New Zealand homes
- a comparison of the space heating energy use with the ALF3 programme
- a literature review of international demand-side energy models
- background details to the development of the HEERA model.

HEEP is currently in its final year of data collection. Early in 2005, the last monitoring equipment will be removed from a house somewhere in New Zealand. It will represent a major milestone for HEEP as our focus will then be on analysis of a unique database of household energy use data. No other country in the world has the level of data, and the opportunities that will be identified, as a result of this research.

HEEP results have already made their impact on New Zealand energy, building and health policies. They have in the past, and will do even more so in the future, identify opportunities for business and policy initiatives.

One of the most important roles for the HEEP data will be to provide a baseline for many other activities. These have included investigations into housing and health, the consequences of improved thermal efficiency for the NZBC, the development of standards and the development of performance requirements for household appliances. We expect there to be many other opportunities which will be revealed as the analysis creates opportunities.

The last two years of HEEP (2005–2007) will be focused on analysis, reporting and technology transfer. The physical and social data collected by the research will be examined for lessons relating not only to individual appliances and households, but also for their regional and national implications.

The Household Energy Efficiency Resource Assessment (HEERA) model will be developed to provide the only national energy end-use model supported by actual end-use data. This will have policy implications for energy supply as well as national energy policy. It will be of importance to the development of the next edition of the National Energy Efficiency and Conservation Strategy (NEECS), as well the NZ Building Code as it is revised under the new requirements of the Building Act 2004.

HEEP will continue to provide new knowledge to support our developing information society.

10. REFERENCES

10.1 HEEP reports

Electronic (PDF) copies of the most recent HEEP executive summaries are available from the BRANZ website at no charge. Printed copies of the last three reports are available from BRANZ at the addresses given in Section 1.2 at the current advertised price. The full reference for each report is given below:

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

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

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

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

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

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

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

10.2 HEEP *BUILD* articles

The BRANZ magazine *BUILD* has published results from HEEP on a regular basis. Articles since the HEEP Year 7 report listed here:

Isaacs, N.P. 2004. **From Kaitaia to Bluff – HEEP at work**. *BUILD* 83 Aug/Sep 2004, p82.

Isaacs, N.P. 2003. **Year 7 Results of the Household Energy End-use Project (HEEP).** *BUILD* 79 Dec 2003/Jan 2004, pp72–73.

Pollard, A. 2003. **Heating from the Top Down**. *BUILD* 75, April/May 2003, pp40–41.

10.3 HEEP conference papers

A number of the papers presented over the years by the HEEP team are available at no charge in PDF format from the BRANZ website. Hard copies can also be purchased online from the BRANZ Bookshop. The list provided here is current to October 2004.

Isaacs, N.P. and 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. and 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. and Pollard, A.R. 2004. **Housing, Health and Energy** in Howden-Chapman, P. and 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., Isaacs, N., Bishop, S., James, B., Ryan, G., and Sanders, I. 1998. *Energy End-use and Socio/Demographic Occupant Characteristics of New Zealand Households*. In ***Proc IPENZ Conference,*** Vol. 2, pp51–56 (BRANZ Conference Paper 52).

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11. APPENDIX – TYPES OF SURVIVAL FUNCTIONS

The following are types of survival functions that can be used with dwelling and appliance vintage stock models. The following survival and related functions are expressed in terms of the mean lifetime L and the standard deviation σ, and shown in Figures A.1 and A.2:

Step function:

Survival function	=	*Remain(j,k)*
	=	1 for $(k\text{-}j) < L$
	=	0 for $(k\text{-}j) \geq L$
Distribution function	=	*F(j,k)*
	=	0 for $(k\text{-}j) < L$
	=	1 for $(k\text{-}j) \geq L$
Probability density function	=	Δ*Remain(j,k)*
	=	0 for $L < (k\text{-}j) < L$
	=	1 for $(k\text{-}j) = L$, assuming a one year unit of time
Mode	=	L
Median	=	L
Mean	=	L

Linear function:

Survival function	=	*Remain(j,k)*
	=	$1 - (k\text{-}j)/2L$ for $(k\text{-}j) \leq 2L$
	=	0 for $(k\text{-}j) > 2L$
Distribution function	=	*F(j,k)*
	=	$(k\text{-}j)/2L$ for $(k\text{-}j) \leq 2L$
	=	1 for $(k\text{-}j) > 2L$
Probability density function	=	Δ*Remain(j,k)*
	=	$1/2L$ for $(k\text{-}j) \leq 2L$
	=	0 for $(k\text{-}j) > 2L$
Median	=	L
Mean	=	L

Exponential function:

Survival function	=	*Remain(j,k)*
	=	$\exp[-(k\text{-}j) / L]$ for $(k\text{-}j) > 0$
Distribution function	=	*F(j,k)*
	=	$1 - \exp[-(k\text{-}j) / L]$ for $(k\text{-}j) > 0$
Probability density function	=	Δ*Remain(j,k)*
	=	$(1/L)*\exp[-(k\text{-}j) / L]$ for $(k\text{-}j) > 0$
Mode	=	*0*
Median	=	L * Ln(2)
Mean	=	L
σ	=	L

Note: For a constant removal rate a other than the natural number e =2.7183, the identity a =exp(ln a) is used to convert a to base e. Ln a =-1/L is used to calculate a in terms of L.

Logistic function:

Survival function = *Remain(j,k)*

= $\{1+\exp[((k-j)-a)/b]\}^{-1}$ for $(k-j) > 0$

Distribution function = *F(j,k)*

= $1 - \{1+\exp[((k-j)-a)/b]\}^{-1}$ for $(k-j) > 0$

= $\{1+\exp[-((k-j)-a)/b]\}^{-1}$ for $(k-j) > 0$

Probability density function = Δ*Remain(j,k)*

= $\exp[((k-j)-a)/b]/b/\{1+\exp[((k-j)-a)/b]\}^{2}$ (for $(k-j) > 0$)

a = L

b = σ * sqrt(3) / π

= 0.5513 σ

Mode = L

Median = L

Mean = L

Normal:

Survival function = *Remain(j,k)*

= 1 – Integral of Δ*Remain(j,k)* from 0 to *(k-j)*

Distribution function = *F(j,k)*

= Integral of Δ*Remain(j,k)* from 0 to *(k-j)*

Probability density function = Δ*Remain(j,k)*

= [1/sqrt(2π)/σ]*exp[-0.5*([(k-j)-L]/σ)** 2] (*for (k-j) > 0*)

Mode = L

Median = L

Mean = L

Smallest extreme value function:

Survival function = *Remain(j,k)*

= $\exp\{-\exp[((k-j)-a)/b]\}$ for $(k-j) > 0$ ….(A.1)

Distribution function = *F(j,k)*

= $1 - \exp\{-\exp[((k-j)-a)/b]\}$ for $(k-j) > 0$

Probability density function = Δ*Remain(j,k)*

= $(1/b)\exp[((k-j)-a)/b]*\exp\{-\exp[((k-j)-a)/b]\}$ (for $(k-j) > 0$)

a = L – Γ′(1) σ * sqrt(6) / π = L + 0.45 σ

b = σ * sqrt(6) / π = 0.7797 σ

Γ′(1) = -0.57721

Mode	$= a$	$= L + 0.45\,\sigma$		
Median	$= a + b \ln(\ln 2)$	$= L + 0.1642\,\sigma$		
Mean	$= L$	$= a + \Gamma'(1) * b$	$=$	$a - 0.57721 * b$

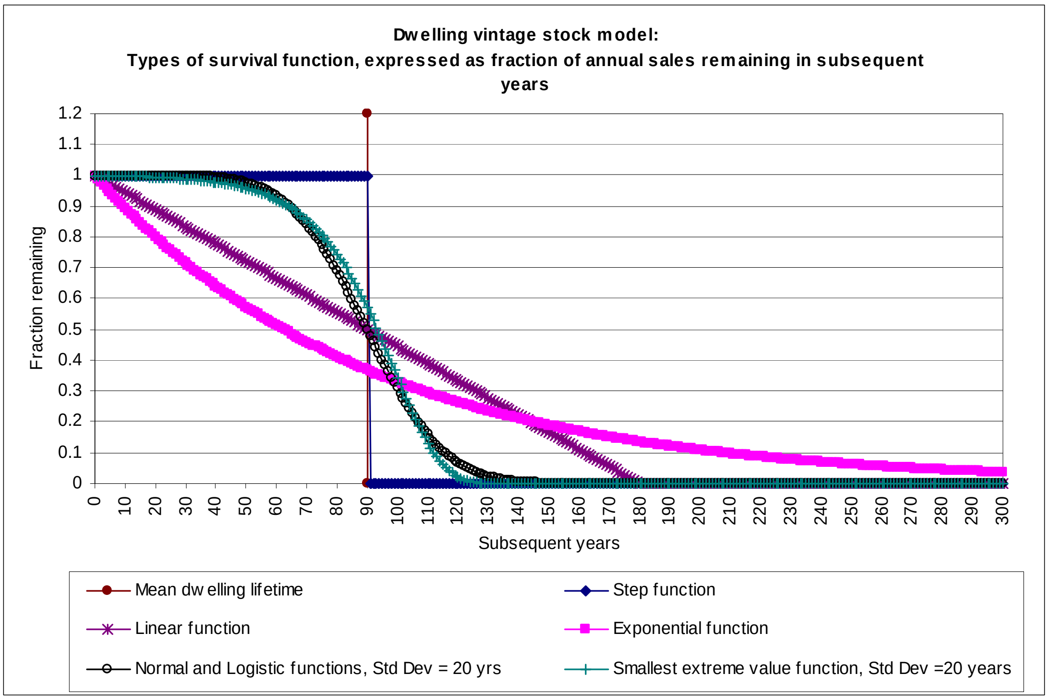

Figure A.1: Comparison of different forms of the survival function that can be used with the dwelling vintage stock model

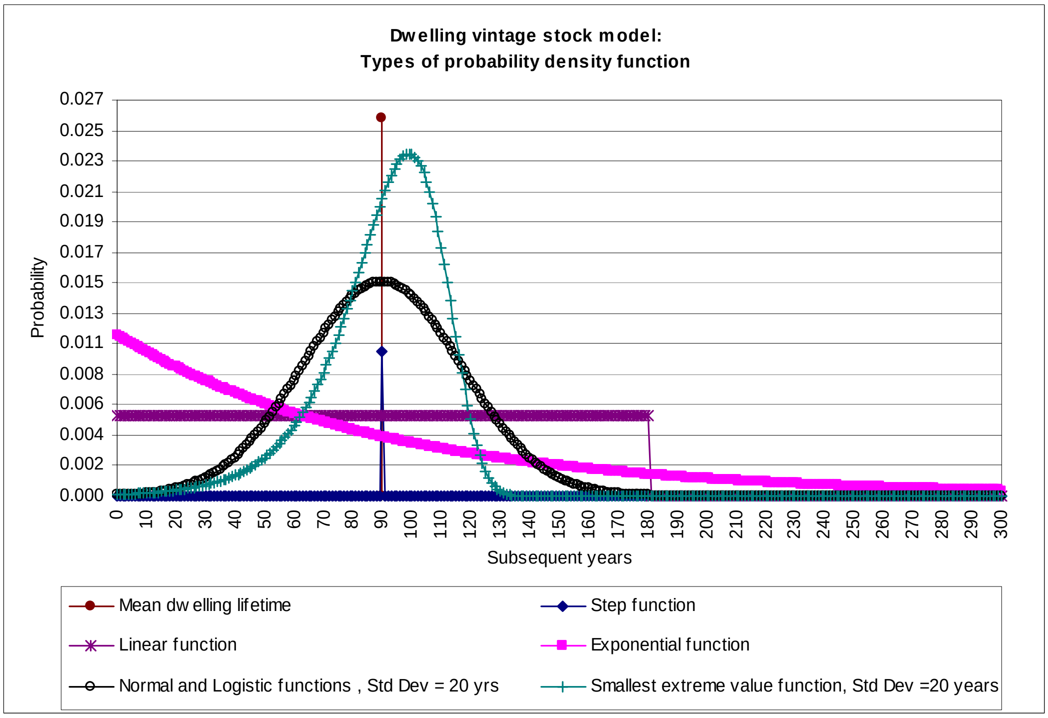

Figure A.2: Comparison of different forms of the probability density function that can be used with the dwelling vintage stock model