Why Bother Collecting Data?
Experiences of the Household Energy End-Use Project

Nigel Isaacs, Michael Camilleri, and Lisa French, BRANZ Ltd.

ABSTRACT

Collecting real energy use data is expensive, time-consuming and subject to error. Why not just use the regular utility bills coupled with sophisticated statistical analysis, or even just stick with the mathematics of thermal modeling?

The Household Energy End-use Project (HEEP) involved detailed energy and temperature monitoring, occupant surveys and energy audits of 398 houses. This paper explores some of the lessons of importance to policy development as well as to other researchers. It concludes that market surveys and thermal models based on 'conventional knowledge' are no substitute for monitored data.

Previous official statistics suggested wood and coal accounted for 5% of residential energy use, but this has now been increased to 14% based on HEEP analysis. Monitoring has also found that houses heated with solid fuel burners are warmer than those heated by open fires or portable electric heaters. The implications of this new knowledge on the air quality based policies to encourage a shift away from solid fuel burners have yet to be explored.

An additional set of monitoring rules are proposed for understanding energy use in houses: (1) no matter how bizarre the behaviour, somewhere, someone is doing it; (2) there is no practical maximum to the number of appliances of a particular type in a house; (3) any imaginable (or unimaginable) electrical appliance can be found in houses; and (4) there is no practical maximum or minimum energy consumption.

Introduction

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

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

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

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

It is easy when dealing with houses to assume that one knows how people use them – we all live in a house and know what we do, so surely all other people do similar things? Are energy use facts really necessary to build energy policy, or are market-based surveys and models enough?

The HEEP Experience

HEEP is a multi-year, multi-discipline research project that involved detailed energy and temperature monitoring, occupant surveys and energy audits of 398 houses (for background details see Isaacs et al. 2004). HEEP is unique in that no constraints were placed on fuel uses in the monitored houses. Whatever fuel was used in the house, it was monitored – electricity, natural gas, LPG, coal, wood, oil and solar water heating. Monitoring used electronic dataloggers recording at intervals of 10 minutes or less (Camilleri, Isaacs and French 2006). Annual reports have provided preliminary results (Isaacs et al. 2005).[1]

The completion of the data collection in 2005 allows us to begin to examine the facts, information and knowledge that have been gained and compare it to the previous state of knowledge. The results have at times been expected, sometimes surprising, sometimes shocking, sometimes obvious in hind-sight, and sometimes have just left us shaking our heads in disbelief.

Some of the observations we have made defy common sense (which is another good reason to collect data – many modern scientific theories defy common sense e.g. the theory of relativity and quantum mechanics). Our experience in HEEP is that there is a bewildering array of behaviours, and no matter how crazy or inconceivable the behaviour, someone is doing it.

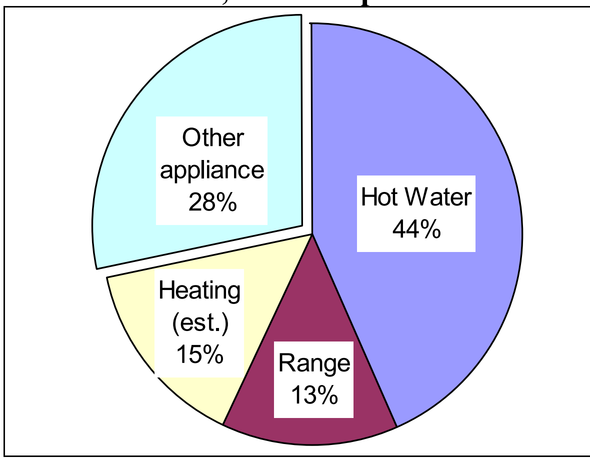
Has Energy Use Changed over Time?

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

In the past 35 years there have been major changes in household energy use, but the old results have continued to support both Government and industry policy. As the 1971/72 study monitored only electricity, the use of other fuels was left unquantified.

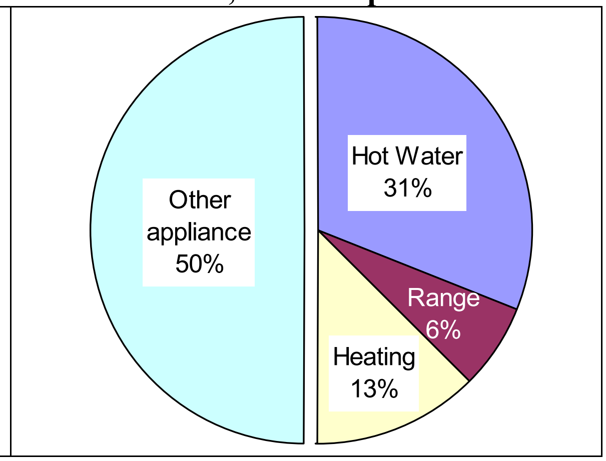
[1] Additional information on the HEEP research is available from www.branz.co.nz

Figure 1. Electricity Breakdown 1971/72 8,400 kWh pa



Source: NZ Department of Statistics 1973

Figure 2. Electricity Breakdown HEEP 7,750 kWh pa



Source: HEEP analysis

Figure 1 shows the breakdown in electricity end-uses from the 1971/72 study, while Figure 2 gives the breakdown from HEEP for 2003. The 1971/72 heating was estimated by comparing summer to winter electricity usage, as the plug-load heaters were not separately monitored. Although space heating remains close to the same proportion, there have been sizable changes in the importance of the other electricity uses.

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

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

It is appliances where the greatest shift is seen. A wider range of ‘modern’ appliances, increased lighting, new combination fridge-freezers and the increased use of electronic controls (with increased standby power demand) have all played a role – one that was undetectable by simple observation or even counting of appliances.

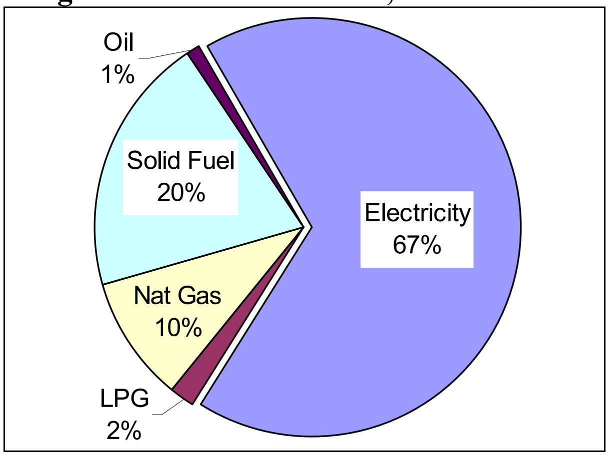
Analysis of the HEEP data has found there is no simple relationship between the number of electric appliances and either the total energy or peak power demand. The use of the electrical appliances is more important than the number e.g. the second (third, fourth etc) television is used far less than the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

Other changes have also occurred in the residential sector. The average number of occupants has fallen 22%, from 3.55 per house in the 1971 Census to 2.78 in the 2001 Census (NZ Department of Statistics 1975; Statistics NZ 2002). Manufactured gas is no longer made, but about 14% of houses are now on reticulated natural gas and many others use bottled LPG. Many open fires, and old solid fuel stoves, have been replaced by more modern, efficient solid fuel burners.

Checking Official Energy Statistics

Figure 3 breaks down residential sector fuel use based on the HEEP research.

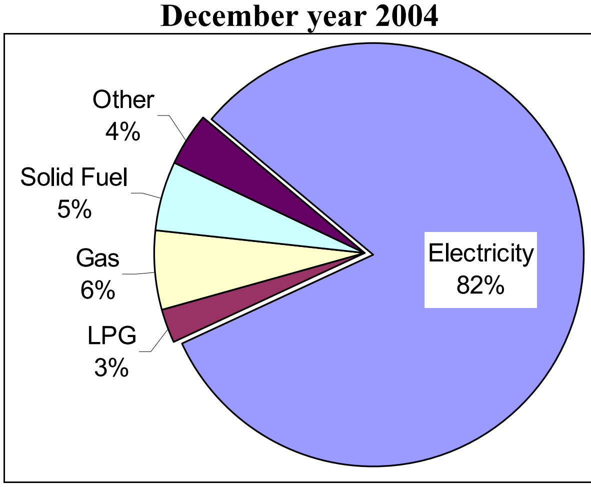
Figure 3. Fuel Breakdown, All End-Uses



Source: HEEP analysis

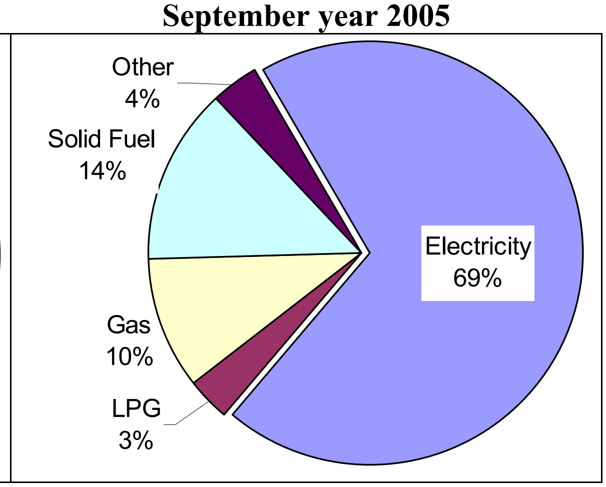
The Ministry for Economic Development (MED) publish national energy statistics, which include a breakdown of fuels used in New Zealand houses (MED 2006). Figures 4 (for 2004) and 5 (for 2005) are calculated from the published MED data (MED 2005; MED 2006). 'Other' in Figures 4 and 5 includes geothermal and solar.

Figure 4. Fuel Breakdown, All End-Uses December year 2004



Source: MED 2005

Figure 5. Fuel Breakdown, All End-Uses September year 2005



Source: MED 2006

Figure 4 shows the official estimate for wood and coal ('Solid Fuel') used in the December 2004 year was 5% of total domestic energy use. However in Figure 5 it has increased to 14% – yet there has been no increase in the actual residential use of wood or coal. The difference is explained in the supporting text (MED 2006 189-90):

In previous editions of the Energy Data File the figures for residential wood use included in the Energy Balances were based on an average use of 4.3 GJ per household using firewood. This figure had been estimated by an industry analyst in 1996. The 'Household Energy End-use Project' (HEEP) carried out by BRANZ monitored actual firewood use and reported average annual use of 13.7 GJ.

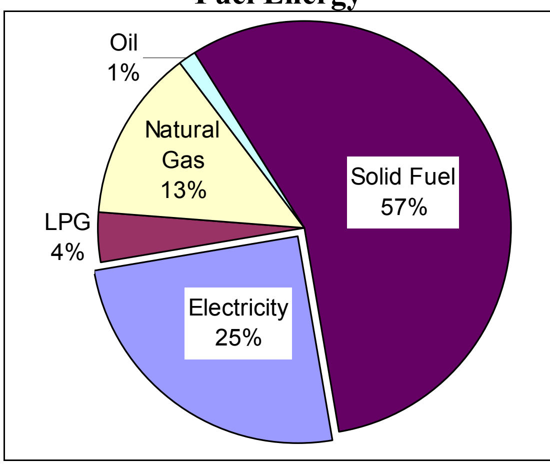
Due to the BRANZ figure having more validity than the earlier figure, values published in this edition have been re-calculated using this new figure.

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

Space Heating Fuels and Temperatures

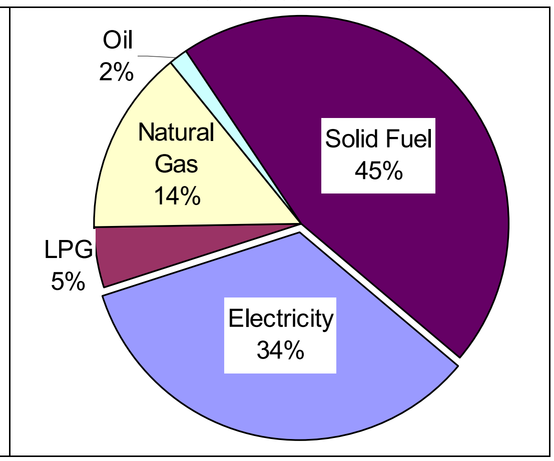
Figure 5 provides the HEEP estimate for the proportions of the main space heating fuels as delivered to the house i.e. before taking into account appliance efficiencies. Figure 6 takes account of conversion efficiencies and represents the heating energy delivered into the space. Solid fuel, far from being a minor player, is actually the most important heating fuel in New Zealand houses, almost to the exclusion of all other fuels in some parts of the country.

Figure 5. Space Heating Fuels – Fuel Energy



Source: HEEP analysis

Figure 6. Space Heating Fuels – Delivered Heat



Source: HEEP analysis

The type of heating is an important factor in the achieved temperatures. Table 1 shows average winter evening living room temperature by heater type. Winter is defined as the months of June, July and August while the evening is from 5 pm to 11 pm. Living rooms heated by open solid fuel fires are coolest, averaging 16°C (61°F), followed closely by portable electric heaters. Rooms heated by enclosed solid fuel burners are the warmest, averaging 18.8°C (66°F).

Table 1. Winter Living Room Evening Temperatures by Heater Type

Heater type	Temperature		Standard deviation		Sample count
	°C	°F	°C	°F	
Open solid fuel	16.0	61	0.6	1.1	11
Electric	16.9	62	0.3	0.5	83
LPG	17.0	63	0.2	0.4	54
Fixed electric	17.8	64	0.3	0.5	18
Heat pump	18.0	64	0.4	0.7	4
Gas	18.1	65	0.5	0.9	28
Gas central	18.3	65	0.6	1.1	8
Solid or liquid fuel central	18.5	65	0.7	1.3	2
Enclosed solid fuel	18.8	66	0.2	0.4	142

The monitored use data on solid fuel burners found that they are over-sized, but not under-utilised. With a typical maximum output of 12-18 kW, and a minimum rated output of 4-5 kW, most solid fuel burners spend most of their time putting out 3-5 kW. This low output is below the levels at which air quality testing is undertaken – and therefore the relationship between the air quality testing results and their performance in real use is unknown.

Some New Zealand cities suffer from poor air quality – and there is no question that in part this is due to the inefficient use of solid fuels for home space heating. Government policy is currently to promote alternatives to solid fuel heating as well as reduced emissions from wood burners in urban areas (MfE 2006). The replacement of solid fuel burners by heat pumps is a popular approach. Unfortunately, this has serious (and previously unforeseen) implications for the electricity generation, transmission and distribution system, which is already stretched in some areas.

Table 1 raises the question of how people will behave if their main source of heating is changed – will they maintain the same warmer temperatures they experience using solid fuel if they switch to electricity, or will they reduce their comfort temperature expectations? Linking these questions to Figures 5 and 6 suggests that there is significant room for increased use of electricity in New Zealand homes, with unclear implications for both energy and peak power demand on the electricity system. Implications of shifting to other fuels also needs to be considered – the best policy goal might be for multiple heating fuels, coupled with improved house thermal performance.

Lessons from the Past

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

- **1st ELCAP Law**: It is easier to recover from bad analysis than from bad data e.g. the HEEP house occupant survey has now been through 19 versions.
- **2nd ELCAP Law**: 1,000 is much bigger than 10 e.g. the first four years of HEEP were taken up with a pilot study monitoring 10 houses at a time, which increased to 41 houses in the 4th year, and 100 houses for the final years. Each increase required more staff and better systems and management techniques.
- **3rd ELCAP Law**: People are not noise. HEEP has not used automatic data screening procedures. We visually checked every data channel when it arrived, during and after

initial processing, and before and during analysis. More than 10,000 channel years of data have been inspected. Some really weird usage patterns were followed up and in most cases found to be genuine.

Knowledge for the Future – Laws of HEEP

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

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

Bizarre Behaviour

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

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

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

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

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

Inveterate Collectors

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

Unimaginable Appliances

From the understandable hospital oxygen machine (used for the medical needs of one occupant), to the amusing emu egg incubator (the Australian large flightless bird), to the trout farm (a mere adjunct to the house), to the solid fuel powered spa pool, to the house that still used a copper[2] to heat water – any appliance that ever existed can be found in some house today.

Houses are not always just homes – sometimes they are business premises. One had a commercial freezer as they ran a catering business from home (unfortunately our monitoring equipment pulled the plug out from the socket and it thawed out a week before Christmas!). Another house had a walk-in 10 m^3 (35 ft^3) commercial fish freezer (apparently not in current commercial use), which really blew out our estimates of average refrigeration volumes. We avoided metering the energy used by the full-scale car repair workshop only by re-wiring part of the house circuit board.

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

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

Unimaginable Appliance Energy Consumption

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

Despite being present in nearly 40% of households, portable LPG heaters consume only 4% of residential heating energy. The reason relates to their use – 30% of the portable LPG heaters were not used during the winter, while just under half (48%) were only ever used in the low setting – equivalent to a 1½ bar electric heater.

---

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

Conclusions

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

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

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

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

The examples discussed in this paper are just a few of the possibilities that result from examining real monitored energy data. We have not had the space to discuss the many other opportunities that come from understanding the distribution of energy use. For example, although many energy efficiency programs focus on low-income households, a quick review of the distribution of energy use reveals that there may be even more opportunities by looking at high energy using households – and it is not only income that drives high energy use.

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

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

Acknowledgements

We would like to acknowledge the support and assistance of the many HEEP researchers, field staff, contractors and house occupants for making it such a successful project. HEEP has financial support from a number of organisations – Foundation for Research, Science and Technology; Building Research and the Building Research Levy; EECA; Transpower; and a range of other government and industry supporters.

References

Camilleri, M., N. Isaacs and L. French. 2006. "Standby and Baseload in New Zealand Houses – A Nationwide, Statistically Representative Study". In *ACEEE 2006 Summer Study on Energy Efficiency in Buildings* (in press).

Isaacs, N., M. Camilleri and A. Pollard. 2004. "Household Energy Use in a Temperate Climate". In *Proceedings ACEEE 2004 Summer Study on Energy Efficiency in Buildings* 1:141-53. Washington D.C.: American Council for an Energy-Efficient Economy.

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

[MED] Ministry of Economic Development. 2005. *Energy Data File July 2005*. Wellington, New Zealand: Ministry of Economic Development.

[MED] Ministry of Economic Development. 2006. *Energy Data File January 2006*. Wellington, New Zealand: Ministry of Economic Development.

[MfE] Ministry for the Environment. 2006. *National Environmental Standards for Air Quality.* Available online: www.mfe.govt.nz/laws/standards/air-quality-standards.html. Wellington, New Zealand: Ministry for the Environment.

NZ Department of Statistics. 1973. *Report on the Survey of Household Electricity Consumption 1971-72.* Wellington, New Zealand: NZ Department of Statistics.

NZ Department of Statistics. 1975. *New Zealand Census of Population and Dwellings 1971. Vol. 9 Dwellings.* Wellington, New Zealand.: Government Printer.

NZ Department of Statistics. 1976. *Survey of Household Electricity Consumption 1971-72 – Report on the Temperature/Insulation Study.* Wellington, New Zealand: Government Printer.

Peterson, F., J. Patton and M. Miller. 1993. "End-use Load and Consumer Assessment Program: Motivation and Overviews." *Energy and Buildings* 19:159-66.

Socolow, R. 1978. "The Twin Rivers Program on Energy Conservation in Housing: Highlights and Conclusions." *Energy and Buildings* 1:207-42.

Statistics NZ. 2002. *New Zealand Census of Population and Dwellings 2001: Housing.* Wellington, New Zealand: Statistics New Zealand.

Stoops, J. 1998. "Managing the Practical Challenges in a Large End-Use Metering Project: Methodology of Monitoring Energy Consumption in Dispersed Buildings. Operational Experiences, Protocols, Etcetera." In *Proceedings Improving Electricity Efficiency in Commercial Buildings Conference (21-3 September 1998)*. Amsterdam, Netherlands: SAVE and NOVEM.