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Findings from the Household Energy End-use Project (HEEP)

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Abstract – the Household energy end-Use Project (HEEP) is a long-term study with the objective to measure and model the way energy is used in New Zealand households. The envisaged model will use physical building and appliance characteristics as well as socio-demographic factors to describe the energy consumption patterns and some of the energy services, in particular the achieved indoor temperatures. The model will be used to understand current and future national household energy requirements, and as a tool to evaluate the implications of building and appliance performance changes.
The project commenced in 1995 with a pilot study. At present approximately 130 households have been monitored for 5-11 months each recording energy consumption profiles, temperature patterns, physical properties of buildings and appliances and socio-demographic factors.
This paper describes several of the intermediate findings of the project, in particular the energy usage for water heating, baseload and standby consumption as well as comfort perceptions in the investigated households. Even at this preliminary stage of data monitoring and analysis, HEEP provides some interesting findings, highlighting areas of current information gaps and required performance improvements in New Zealand houses.
***Index terms*—energy monitoring, energy model**

I. INTRODUCTION

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

HEEP was established in late 1995 as a long-term research activity to create a scientifically and technically rigorous, up-to-date public knowledge data base of energy use and end-uses, energy services provision and key occupant, building and appliance determinants of energy use in residential buildings[1].

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

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

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

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

Systems investigated or underway

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

This work involved a series of selected households as pilot studies, as well as specific case studies that concentrated on particular areas or household types such as this year's pensioner study. These selected households now total 66. Random selection of households started in 1999 with a target sample of 400. Taken together with the non-random households completed to date, the total HEEP database now includes 126 households, with another 48 currently being monitored in Auckland (Figure 1). The randomly selected households are now statistically representative of approximately 13% of New Zealand's households.

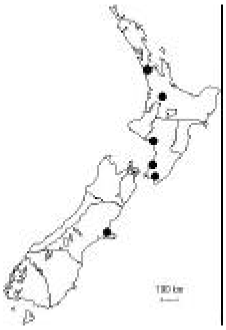

Figure 1: New Zealand. Dots indicate past and current monitoring locations.

The following highlights some of the most interesting parts of the year 5 work.

II. Broad Level Statistics:

Some broad level statistics are now available from this project. These results are based on the random houses monitored to date. The findings can be considered as indicative of future results, despite still being preliminary at this stage.

Total energy: Average overall total (excluding LPG)	9000 kWh/a/house
Gas only	2400 kWh/a/house
Electricity only	6700 kWh/a/house
Hot water 44% of total energy	4000 kWh/a/house
Average hot water standing loss 11-12% of total 25-30% of hot water	1050kWh/system /a
Lighting 8% of total	740 kWh/a/house
Standby & baseload power 10% of total	920 kWh/a/house

Table 1: Basic energy values

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

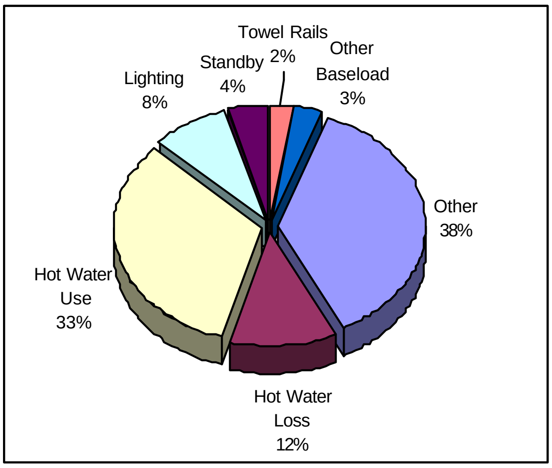

Figure 2: End-use contributions to total energy use.

III. Influences on Hot Water Demand

Storage hot water systems in New Zealand are generally not very efficient, with merely an estimated 5% of hot water cylinders meeting "A" Grade specifications[2]. A 140l A-grade cylinder has a standardised 'Water Mark' heat loss of 2.1kWh/day including 0.7 kWh/day for pipe losses from the cylinder. Consequently the potential for national energy savings, and Greenhouse Gas emission reductions, from improvements in hot water systems is likely to be large. The random sample of HEEP households have an average standing loss of about 25-30% of hot water energy use. These measured standing losses appear to be significantly higher (up to 1.4kWh/day) than the standardised "Water Mark" standing losses. Standing losses for all of New Zealand's electric hot water cylinders could amount to as much as 5.5 PJ.

New performance requirements under NZBC Clause H1[3], which became mandatory on 29th December 2000, will improve the overall performance of electric hot water cylinders in new homes, as will retrofitting of insulation wraps to existing cylinders. The application of Minimum Energy Performance Standards (MEPS) and energy labelling will result in improvements in existing homes as old cylinders are replaced.

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

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

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

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

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

The first step in the analysis must be the separation of lost energy and used energy components of the total energy consumption. To separate lost energy and used energy, total hot water energy use was averaged over the logging periods of each house as shown in Figure 3.

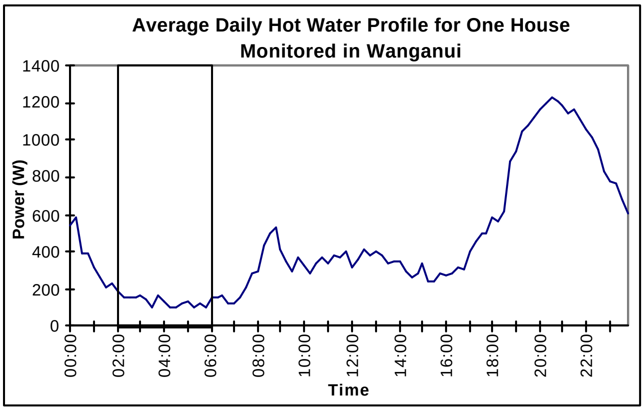

Figure 3: Average daily hot water energy use

Periods of standing loss were assumed to be the flatter areas of the graph, found typically in the early morning when no water is drawn from the cylinder, the shaded zone of Figure 3. The average standing loss was calculated for this period, extrapolated to cover the full 24-hour day, and then subtracted from the total energy use to give the average used energy. In some cases, such as for water cylinders on electricity night rate, more sophisticated methods were necessary. These are loosely based on the End-use Load and Conservation Assessment Program (ELCAP) method[4]. The results of the separation of the hot water energy into lost energy (Standing Losses) and used energy (Consumed Energy) for a number of randomly selected HEEP houses are shown in Table 2.

From Table 2 it is seen that the electric hot water cylinders are losing about 30% of their energy in standing losses. About 18.3 PJ of New Zealand's electricity is consumed by water heaters[5]. Assuming that 30% of this energy is lost in standing losses then the total energy lost in New Zealand for standing losses from electric hot water cylinders is approximately 5.5 PJ/annum.

Type	Used Energy (kWh/day)	Lost Energy (kWh/day)	Percent Lost (%)	Count (n)
Electricity Hot Water	5.7–6.5	2.5–2.7	28-32%	32
Natural Gas Hot Water	14.4–14.9	3.2–3.8	18-21%	8
Natural Gas Instant Hot Water	13.3	NIL	n/a	4

Table 2: Average standing losses and consumed energy

It is also interesting to note that the used hot water energy in houses with water gas heating is more than twice the consumption in houses with electric water heating. We have conducted some preliminary investigation into links with demographic factors and have not yet been able to establish any correlations, i.e. in particular the number of occupants in gas water heated households is not significantly different from the number in electrically water heated households.

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

IV. STANDBY POWER AND LOSSES

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

If the average New Zealand national baseload is similar to that found for the randomly selected Wellington and Hamilton households, then the total baseload is around 130 MW continuous and CO_2 emissions of around 730,000 tonnes, if supplied by thermal generation. This is approximately 3% of New Zealand's total electricity generation, and up to 1% of New Zealand's total GHG emissions. Clearly, the potential reductions of baseload and standby consumption in NZ households are large, and has potential for demand side management and greenhouse gas reductions.

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

Appliance	Standby power consumption per appliance (W)	Standby Energy per house (kWh/a/house)
Fridge Freezer	7.1	49.6
Television	3.7	34.6
Video	4.5	32.0
Washing Machine	3.3	28.1
Microwave	3.6	24.2

Figure 4: Most important standby appliances.

The standby power consumption includes standardization in respect to the duty cycles of the appliances, i.e. once the appliance is "in use" the standby energy is assumed to be 0, although the "little red LED" might still be on and not prove any useful function. The standby energy also takes account of the ownership proportions of the appliances.

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

- Standby from common appliances 36 W
- Remaining unquantified baseload 42 W
- Consumption of heated towel rails 25 W
- Average total baseload 103 W

Common appliances include appliances such as fridge/freezer, TVs, VCRs, washing machines, microwaves, dishwashers, dryers and computers. Not included in these are smaller or rare appliances such as alarm clocks, answer-phones, fax machine, cordless phones, DVD players, burglar alarms, battery chargers, games consoles and satellite TV decoders.

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

V. INDOOR TEMPERATURES

An earlier New Zealand study[6] measured average winter (August-September 1971) temperatures in the kitchen, lounge and main bedroom. This study confirmed that New Zealand houses were then only heated to low levels. Although there was no measured evidence to support it, it has been assumed that nowadays occupants are demanding more comfortable temperatures, and that average temperatures have risen in response. Monitoring of randomly selected households in Wellington and Hamilton suggests this is not so. The average measured temperatures were about 1°C less than those measured almost 30 years ago.

The temperatures found in many New Zealand houses were below the level recommended by the World Health Organisation[7].

Survey results indicate that only about 50% of New Zealand households consistently achieve comfortable temperatures during the winter. Correlations of these responses with measured average evening living room temperatures over the winter show a clear relationship between temperatures and comfort perception (Figure 5). The average temperature in houses, which were reportedly always comfortable, was approximately 19°C.

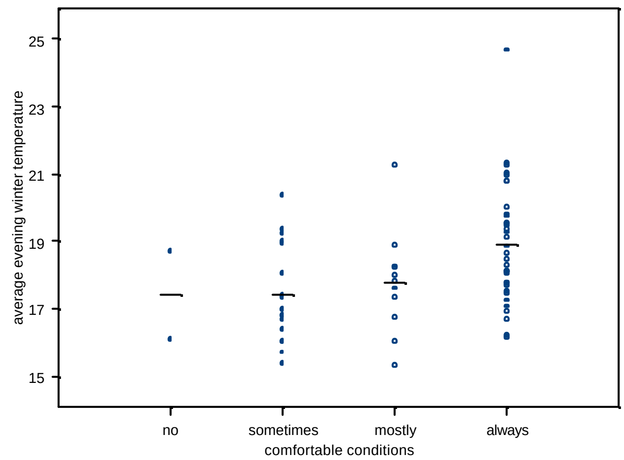

Figure 5: Average evening winter temperatures plotted against occupants' comfort perceptions (horizontal lines are mean values)

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

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

Figure 6 shows the average winter evening temperatures in the living rooms for all monitored houses plotted against the decade in which the house was built.

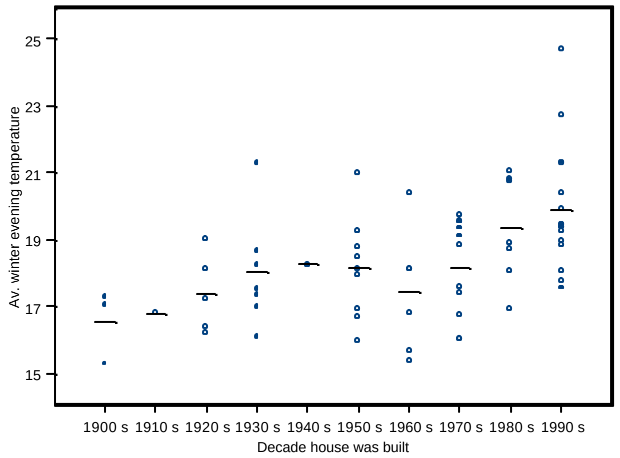

Figure 6: Average winter living room temperatures against age of the building

Figure 6 shows a clear increase in temperatures recorded in houses with later construction dates. The graph shows a steady increase in average temperatures in houses built in the 1980s and 1990s.

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

VI. Occupants' Perceptions

As each household is surveyed prior to monitoring actual energy use, results are now becoming available that provide insights into attitudes towards energy services.

One of the survey questions seeks to establish the priority of various energy services to the household occupants. The question reads:
'Suppose that you had to cut down the amount of energy you used in the home. In what order would you reduce your use in the areas listed on card 13? (rank responses, with 1 being the first area you would cut down in, 2 for the second etc)'.

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

Table 3: Reported energy service priority (based on random and non-random households)

Table 3 suggests that people are least willing to sacrifice heating and hot water services, while the easiest sacrifice appears to be electric blankets and lighting. It is interesting to note that lighting contributes significant amounts to the total energy consumption (8%), and is one of the energy end-uses where savings could technically be easiest achieved. Changes can be achieved through appeals to modified user behaviour and through technology changes. These findings suggest that energy efficient lighting usage behaviour could be easier achieved than changes in hot water heating and space heating behaviour. Also, the efficient lighting technology is already available and quite cost effective. No specialist knowledge is required for upgrading.

VII. Conclusion

The HEEP investigation is a long-term research activity with the objective to understand and model how New Zealanders use their energy at home. The project covers all fuel types and investigates also socio/demographic factors and energy services, such as indoor temperatures.

The results at this stage show that hot water heating is one of the major energy end-uses in New Zealand houses (44%). Standby and other base loads make up 10% of the total energy. Another important finding is that New Zealand houses are frequently colder than the WHO recommends and that New Zealanders prefer to have warmer houses. Home heating was also the area, which New Zealanders least preferred to sacrifice in order to save energy.

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