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Energy End-use and Socio/Demographic Occupant Characteristics of New Zealand Households

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Abstract

This paper presents results from the first two years of the Household Energy End-use Project (HEEP), a multi-party, multi-disciplinary investigation into energy end-use in New Zealand houses. The energy consumption in 28 houses in Wanganui was measured for half a year each and was linked to the surveyed socio/demographic household characteristic.

1. Introduction

The Household Energy End-use Project (HEEP) was established in late 1995 by a group of funding and research organisations as a long-term research activity to create and make available a scientifically and technically rigorous, up-to-date public knowledge base of energy use and end-uses, energy services provision and key occupant, building and appliance determinants in New Zealand residential buildings.

This paper provides an update on the 1997 IPENZ paper[1] which discusses the HEEP model and research approach and the inclusion of socio/demographic characteristics of the households in the model. Also discussed is the project design from monitoring at end-use level to total house to distribution point monitoring and the sample size required for statistical significance. Preliminary findings on total energy consumption, heating demand and some indications of the human impact on energy consumption are also discussed. The reports[2,3] published on HEEP provide background discussion on the scope of the project and preliminary findings.

With HEEP moving into its third year, attention is being focused on preliminary studies of the data gathered by the Building Research Association of New Zealand (BRANZ) at end-use level from the 28 houses monitored to date in Wanganui and comparison to similar data gathered in Christchurch by Industrial Research Ltd. The extension of the end-use monitoring combined with the commencement this year of logging at a total house level will provide the first statistically significant information and support the development of the nationwide, multi-fuel energy model. For the first time links between the energy usage, physical characteristics and the socio/demographic characteristics of households are being bought together to develop the energy model. Increased interest in participation in the HEEP project continues to be shown with the current participants including the Energy Efficiency and Conservation Authority (EECA), Fitzgerald Applied Sociology, Trans Power New

Zealand Ltd and PowerCo, and at research level the Building Research Association of New Zealand (BRANZ) and Industrial Research Ltd (IRL).

2. Monitoring

Data collection and analysis methods have been the focus of the first two years of HEEP. This has involved the development of measurement protocols for energy, temperatures, house construction and occupant behaviour and attitudes. The Building Research Association of New Zealand (BRANZ) continues to monitor energy consumption at end-use level and temperatures at up to ten points in each of the Wanganui houses. The first block of monitoring covering the period of April 1996 to July 1996 for Houses 1 - 5, the second July 1996 to November 1996 for Houses 6 - 10 and the third February 1997 to July 1997 for Houses 11 - 18. Houses 19 to 29 are currently being logged at end-use level and logging will continue in these houses until the end of January 1998. The end-use monitoring to date and the planned logging of end use and total house energy data is shown in Figure 1.

The end-uses being monitored in all cases include the hot water electricity use and a combination of the following: refrigeration; lighting; electric space heaters permanently-wired or plug-based at either individual appliance or circuit level; electric range; electric drier; electric washing machine, or even the electric jug. To date seven houses have been monitored for solid fuel usage. The primary objective was to develop monitoring and analysis protocols for this fuel type. Preliminary techniques are discussed in section 5.1. Trial gas logging has started in two Wellington houses and are discussed further in section 5.2.

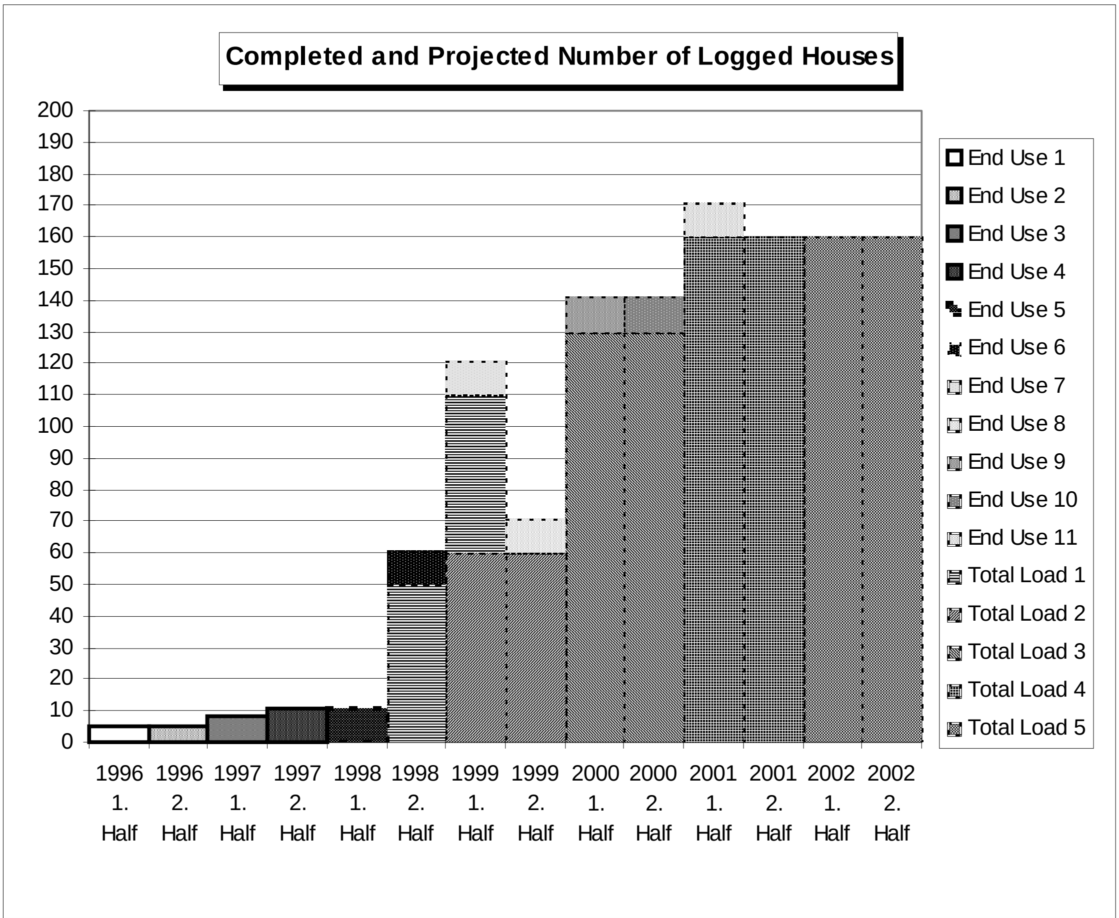

Figure 1: End-use monitoring to date and projected

Industrial Research Limited (IRL) is undertaking data collection and analysis in Christchurch and focused on the continuous monitoring of energy consumption at both end-use and whole house level, with information collected on a new set of 15 houses since May 1997.

The following graph in Figure 2 shows the average appliance energy uses for the Christchurch houses compared with the Wanganui houses. The three largest heating energy consumers in Wanganui are in houses with night store heaters. A number of end uses have not been monitored separately in the Christchurch houses and are included in the "other" category. It is interesting to note that in spite of that, the "other" category is generally higher in Wanganui than in Christchurch. The cooking energy consumption in Christchurch seems to be higher on average than in Wanganui. Both findings may be caused by different lifestyle habits in the two centres. However, the sample size is not large enough yet to draw statistically significant conclusions.

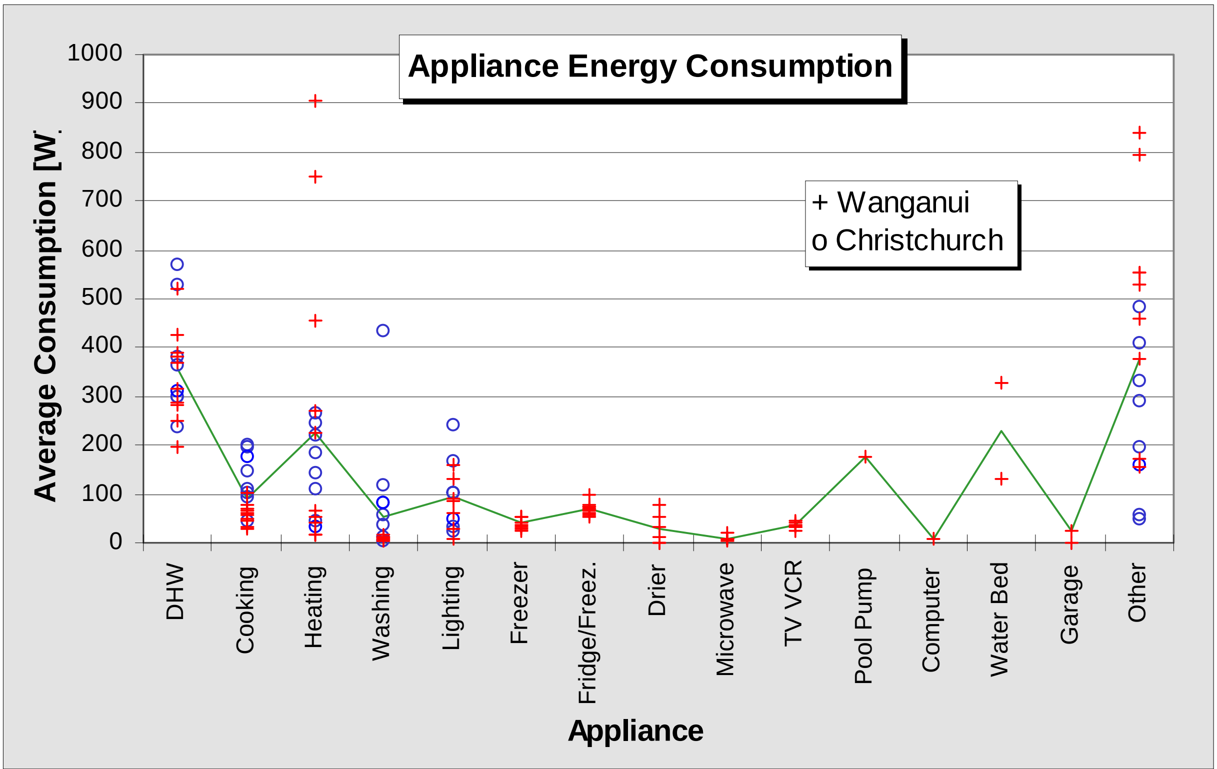

Figure 2: Appliance energy consumption in Wanganui and in Christchurch

3. Daily Electrical Energy Consumption

The average daily electrical energy of the Wanganui houses has been calculated over the logging period for each house in order to analyse the distribution of the daily energy demand. The result is shown in the box and whisker plot in Figure 3. The large variations shown could not be explained by the splitting of the data into weekdays and non-weekday groups, or by the number of occupants in each house. This emphasises the fact that energy is dependant on many factors, only looking at one or two factors will not describe variation seen in the total energy. It is important though to identify what factors are most influential on the energy consumption of a household. Previous investigations[4] have indicated the factors include house size and physical characteristics, income and other social factors. Preliminary statistical analysis has shown that the total electric energy consumption can to 71% be described through a multiple regression by the following five factors: Number of occupants in the household, whether or not the cylinder is wrapped, the number of fluorescent and incandescent lights and the level of household income. The effects of different occupant characteristics in the total electricity consumption is highlighted by the findings through peak power use analysis. For example in one house the electric jug contributed 7% to the peak consumption.

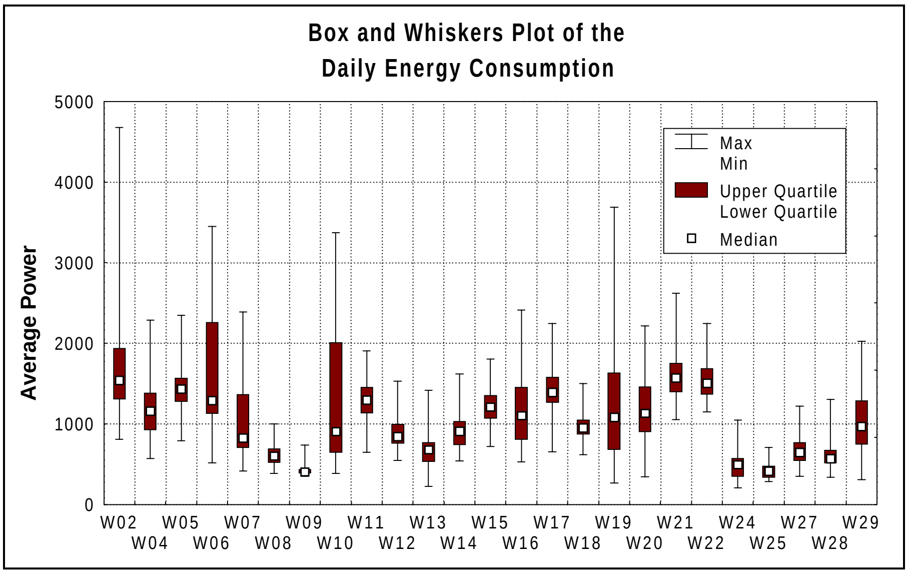

Figure 3: Plot of the daily variation of the total electricity use in the Wanganui houses

4. Detailed Appliance Level Analysis

4.1 Domestic Hot Water (DHW) Analysis

Domestic hot water electricity consumption is the second largest end-use consumption overall, after space-heating, and is in some households the largest end-use contributor. Energy for hot water heating is used to maintain the storage temperature and to replace hot water which was drawn-off for usage.

Standing losses and consumed hot water: The ratio of energy required to maintain the stored water temperature as a result of standing losses to the total energy consumed by the hot water cylinder has been calculated from the data gathered in Wanganui. The energy required to maintain the stored water temperature as a result of standing losses has been calculated using the following process: The average hot water energy use was calculated for those hours each day when no hot water was drawn by the users. These hours were found by an exploratory analysis of the hot water profile for each house, for house 17 shown in Figure 4 the hours between 3:30am and 7:00am were used. The hot water usage over this period for all the days was averaged for each of the houses. It was then assumed that the standing losses are the same for the rest of the day and thus the averages were extrapolated over the 24 hour period. This assumption ignores the fact that the external temperature is higher during the daytime than during the night, and therefore the standing losses may be lower. It also does not consider the effect of hot water drawn off during the day, which leads to on average slightly lower cylinder temperatures also reducing the standing losses. A typical pattern of the average hot water energy is shown in Figure 4 which has an average of 130W standing losses, equivalent to 3.1 kWh/day.

The standing losses were then subtracted from the total domestic hot water energy use to find the consumed energy. Figure 5 shows the comparison between the energy required to recover standing losses and the consumed energy - as a result of water being drawn from the cylinder. No correction for cylinder temperature or room temperature has been conducted at this stage.

In several cases the water heater was on a night rate tariff. In these cases above method could not be applied since all the water heating was conducted during the night periods. Therefore the standing losses were determined by selecting those nights with the lowest consumptions for hot water heating. The assumption was that in these cases no one has been in the house the during the previous day and all the hot water energy was used to recover standing losses. As a control the energy consumption of the other end uses - particularly lighting and TV - were investigated. In most cases this confirmed that no person was present in the house during the previous day. Since this method generally had to rely on only a few days when no person was at home it is much more prone to error than the other method applied for non night-rate heaters.

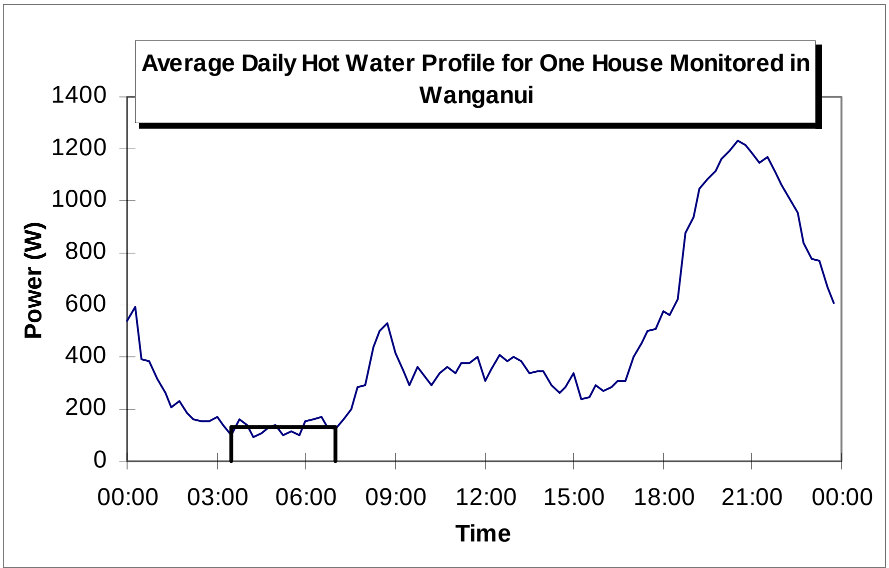

Figure 4: Example average domestic hot water profile.

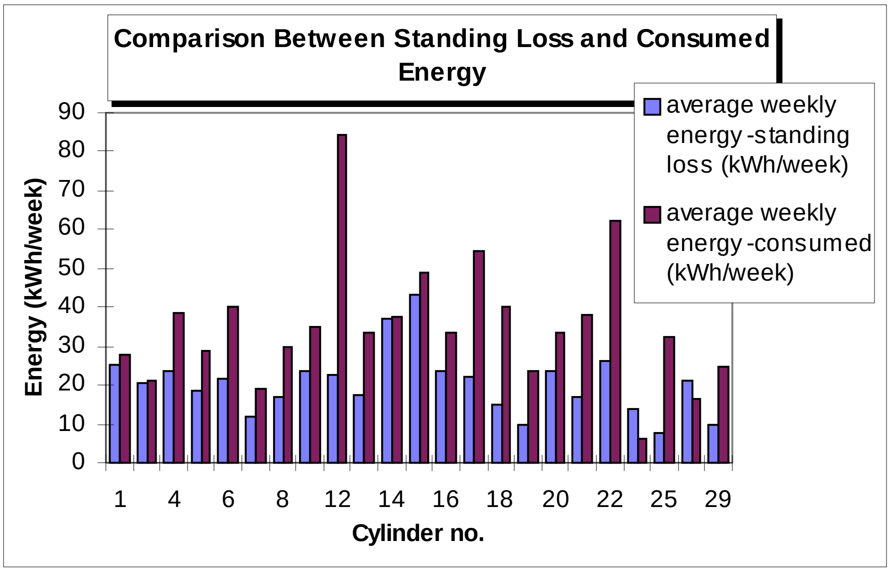

Figure 5: Comparison between the energy consumed to recover standing loss and the consumed energy as a result of cylinder draw off.

It was found that the energy used to maintain the cylinders water temperature as a result of standing losses made up on average 40% of the total energy consumption of the hot water cylinder. The proportion of energy used for standing losses varies between 20 % - 70%.

This high proportion of energy used to maintain the cylinders' water temperature as a result of standing losses opens the opportunity of marked reduction in energy consumption through more effective means of cylinder insulation and the installation of higher grade cylinders. An initial analysis has, however, not shown any clear correlations.

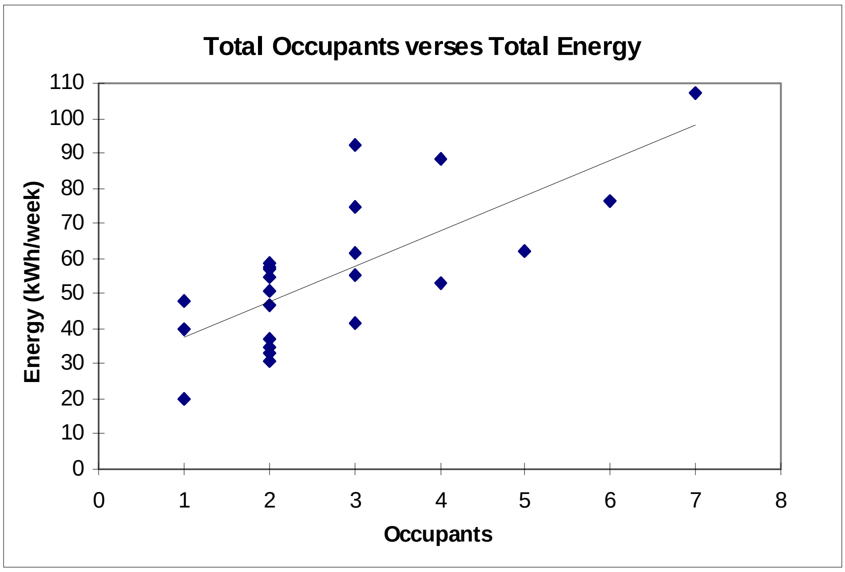

Figure 6: Exploration of the relationship between the number of household occupants and the total energy consumed by the hot water cylinder.

Demographic factors and hot water usage: It was expected that the number of occupants in the household would relate to the energy consumed by the hot water cylinder. The relationship between the number of occupants and the total energy consumed by the hot water cylinder is shown in Figure 6. While there is a general upward trend the predicted relationship is not statistically significant. Further breakdown of the occupant data into age brackets (under 18, 18 and above) did not improve the relationship. This suggests that other occupant characteristics including the use of hot water washing and physical characteristics including cylinder age/grade, insulation level have a large influence on the energy consumed.

Survey versus measured data: This analysis of the hot water energy consumption requires rather extensive data measurements. It was therefore investigated how the additional information collected in the occupant surveys could be evaluated. A good correlation between hot water energy consumption based on the survey information with the measured data would reduce the requirements to extensive data logging, and hence reduce the cost of further data collection.

As part of the survey the household occupants were asked for information on the frequency, duration and temperature of showers and baths each week. Temperatures were given in terms of in terms of “cool”, “warm” and “hot” and this information was converted to litres of water from the cylinder to produce the shower temperature as stated by the occupants. The energy required to raise the temperature of this amount of water from the supply temperature to the cylinder temperature was then calculated. $E = c_{Water} (T_{cyl} - T_{supply}) * V$ where c_{Water} is the heat capacity of water and V is the volume of required hot water. Assumptions were made as to the actual temperature of a “cold”, “warm” and “hot” shower, the temperature of the water drawn from the cylinder and the temperature of the water supplied to the cylinder. A shower flow rate of 8 L/min was assumed. The temperature level associated with each response was adjusted to find the best relationship with the measured energy use.

This analysis showed that measured and surveyed data could not be reconciled. A higher amount of energy to heat the shower and bath water than the overall energy consumed for hot water heating was found and indicates the surveyed information with a generally over-estimated of one or a combination of the frequency, duration and temperature. Measurement of the flow rates, supply temperature and cylinder temperature as well as accurate measurement of frequency, duration and temperature would provide a better understanding of the relationship between the energy required for showers and baths and the energy consumed for all hot water uses.

4.2 Surveyed Response verses Monitored Data

Following the investigation into the comparison between the surveyed shower and bath water use and the actual amount of hot water used comparison between the surveyed response and the monitored use of other end-uses was undertaken. Figure 7 and Figure 8 present the results found for the comparison between the surveyed response and monitored use of televisions. The data was broken down into weekdays and weekends and further into the hours of the day before 5pm and those after 5pm. It can be seen in the graphs the reasonable accuracy of the weekday after 5pm surveyed responses compared to the average actual usage in this time period. The weekday hours before 5pm show some houses where the surveyed response was that the television was not used at all, the monitored data shows that this was not the case. The level of accuracy of the surveyed responses of television usage indicates the potential of using the survey data for some end-uses without the need for logging the appliance, thus minimising the cost of the monitoring. Further comparisons between the surveyed response and the monitored use need to be done before reliance on the survey responses can be made.

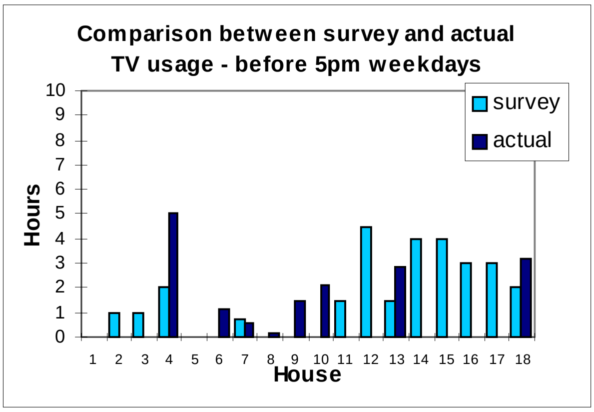

Figure 7: TV usage before 5pm weekdays - Comparison between surveyed response and monitored data.

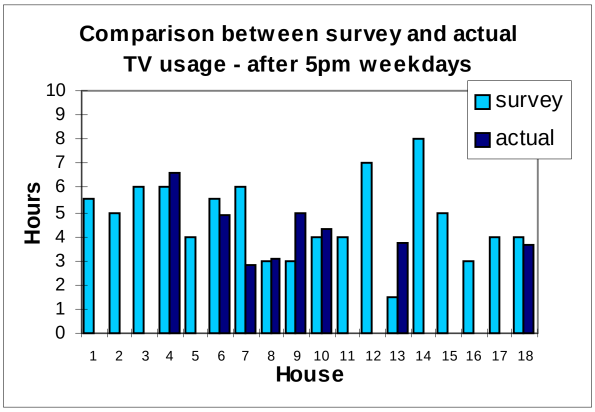

Figure 8: TV usage after 5pm weekdays - Comparison between surveyed response and monitored data.

4.3 Fridge, Freezer and Fridge-freezers

A number of refrigeration appliances have been monitored in Wanganui allowing an analysis to be undertaken to gain a better understanding of the relationship between the label value (the average annual energy consumption assigned to an appliance by the manufacturer after standard testing proceedures) and the actual consumed energy of the appliance. Where label values could not be found on the appliance, the model number was used to reference to a value from manufacturer provided charts. This comparison between label value and consumed energy is shown in Figure 9, with the difference between the label value and the consumed energy being calculated at an average 30% overstatement of the yearly energy consumption.

It was expected that freezers would use more energy due to the requirement that they maintain a considerably lower temperature. What is clear from the comparison is the lower overall energy use of freezers. This could be a result of a combination of factors including the higher level of insulation in freezers, the freezers ability to maintain a cold core (due to geometry) and less frequent opening of the freezer, the 'no-frost' feature of fridge-freezers requiring the constant running of a ventilation fan and the inefficient side opening of fridge-freezers.

The lack of an overall relationship between the label value and the consumed energy could be as a result of socio/demographic factors, where a higher number of occupants may result in an increased frequency of opening of the fridge and therefore a higher energy use.

There are opportunities to further extend this analysis by increasing the size of the data sample and determining the impact of factors including the number of occupants, deterioration due to age, surrounding environment temperature including whether the appliance is stand-alone or built in and determining the exact label value for each appliance. Correction for seasonal room temperature fluctuation may also have an impact on the relationship between label value and consumed energy.

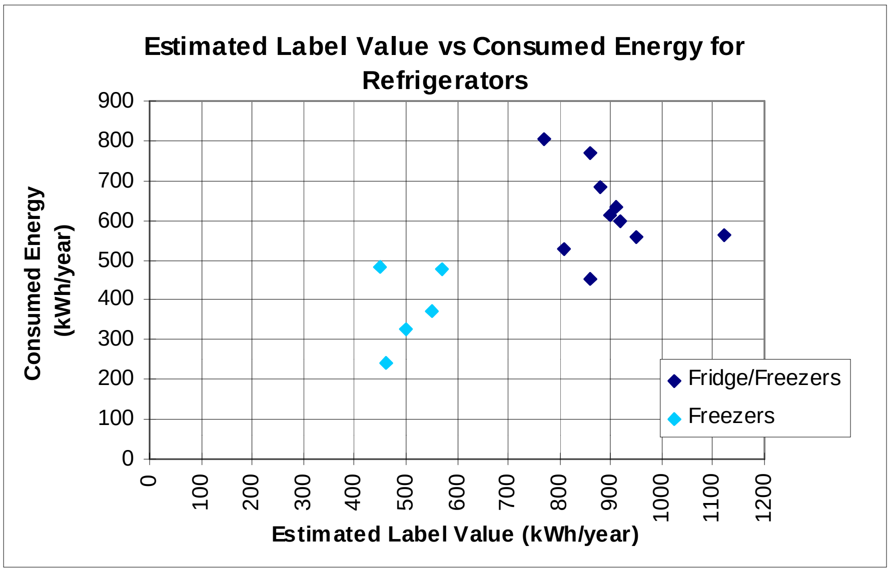

Figure 9: Comparison between the estimated label value and consumed energy for refrigeration appliances showing separate groupings of freezers and fridge-freezers.

4.4 Peak Demand Analysis

Daily total power consumption profiles from data collected by Industrial Research Ltd (IRL) show variations of the total power consumption profiles of different houses and occupants. The graphs shown in Figure 10 and Figure 11 of total energy consumption data collected show both variations across houses of when the peak power consumption occurs and variations within each house of total power consumption over weekdays and weekends. IRL has developed a method by which profile types can be assigned to different households depending on the way energy is consumed.

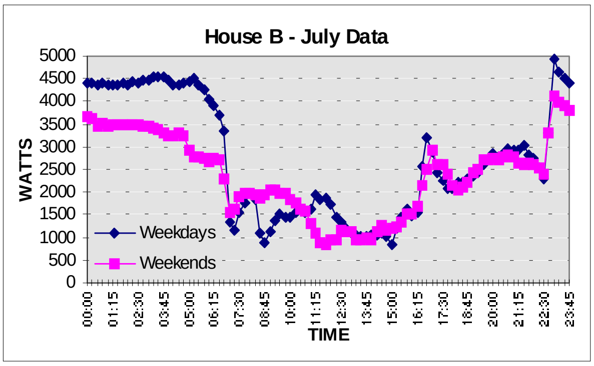

Figure 10: A sample weekday/weekend total power consumption profile for house B in July.

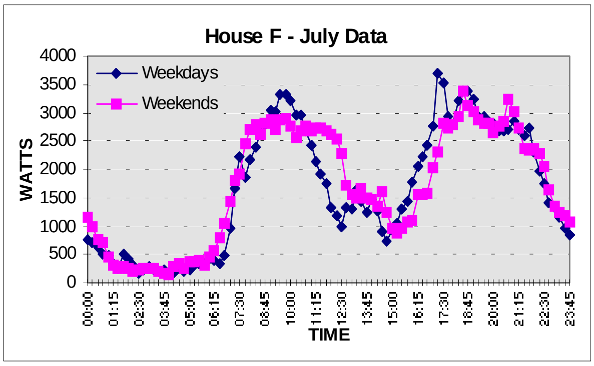

Figure 11: A contrasting weekday/weekend total power consumption profile for house F in July.

Analysis of the contribution to the peak power usage period is valuable in its ability to provide energy suppliers essential information enabling the development of demand profile charging if time based metering is not to be used and to aid in the reduction of line capacities through evaluation of the potential for demand load shifting. The extent to which each end-use contributes to the total consumption has been studied and is shown in Figure 12 for a sample house from Wanganui. The high contribution made by the domestic hot water cylinder and the consistent contribution made by appliances like the fridge-freezer can be seen in the profile.

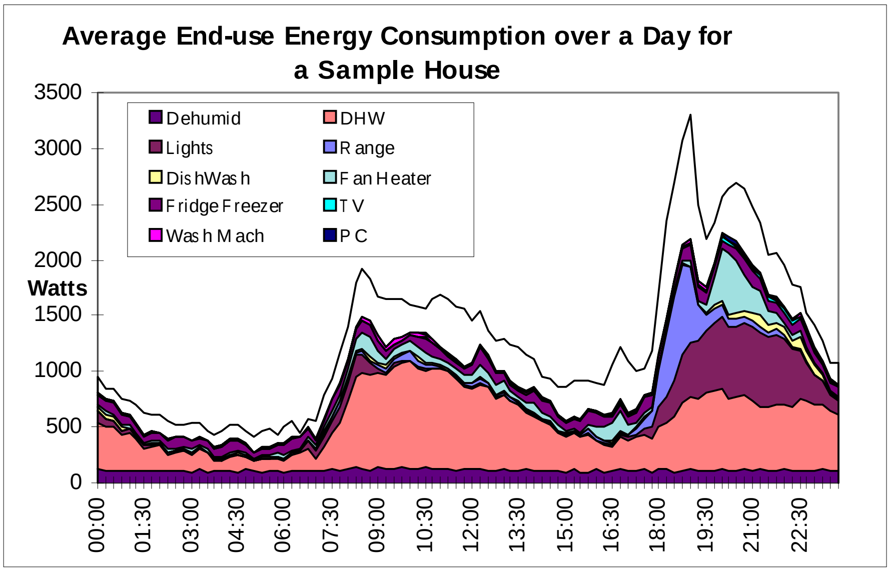

Figure 12: Profile of end-use contribution to total electricity consumption.

Further analysis has been done to determine the make-up of the peak power use period, which in the case of Figure 12 starts in the early evening. The identification of the end-uses which make significant contributions to the peak demand enables attention to be focused on particular end-uses to establish effective methods of reducing the peak demands.

Domestic hot water and heating were found to be the highest contributors while also having the biggest variation between houses indicating the impact on energy use of occupant demographics and behaviours. End-uses including refrigeration, TV and lighting were found to have a moderate level of, but more consistent, peak contribution. Range and driers also had a moderate contribution to the peak power consumption although there was a large variation between households. A significant peak contribution in some houses made by end-uses such as waterbeds, pool pumps and electric jugs was also found.

A shift in demand is possible for some of the end-uses that contribute to the peak power use period, in particular domestic hot water and driers. Ripple control of DHW is being used in some of the houses but it may be possible to control the individual house peaks. The contribution of driers to the peak load could be reduced with the use of delay switches or connection to night-rate power supply.

Due to the commercially valuable nature of this information on the contribution of end-uses to peak loading a more detailed report on the findings of this analysis is at this stage only available to HEEP participants.

5. Alternative Fuels

As the HEEP project continues to develop its nationwide, multi-fuel energy model techniques for monitoring the usage of common alternative fuel types such as solid fuel and gas are being developed.

5.1 Solid Fuel

A method is being developed where the heat energy delivered by the burning of solid fuel can be directly compared to the energy delivered by electric heaters. A technique using surface temperature recordings by modified temperature data loggers is being developed to permit the reported fuel use to be used to evaluate the delivered heating energy.

Data is collected from two sources. Firstly the occupants completed a logbook of the time the solid fuel burner was used recording the date, time of day, the amount and type of wood and kindling burned and the duration of the burn. The energy output of the fuel burned is determined by the weight of the fuel used, the calorific value of the fuel taking into account the moisture content, and the heating efficiency of the solid fuel burner. Secondly, modified temperature dataloggers were attached to the surface of the solid fuel burners, and recordings taken at 15 minute intervals. The area under the graph of the temperature over time, shown in Figure 13, appears to be a good representation of the energy consumed by the solid fuel burner. By comparison between these two data sets a conversion factor is calculated by which the amount of fuel burned could be established from the datalogger output. It has been seen during this preliminary analysis that the logbook alone does not provide an accurate record of the use of the solid fuel burner, with in some cases many burns not being recorded and discrepancies in the amount of fuel burned.

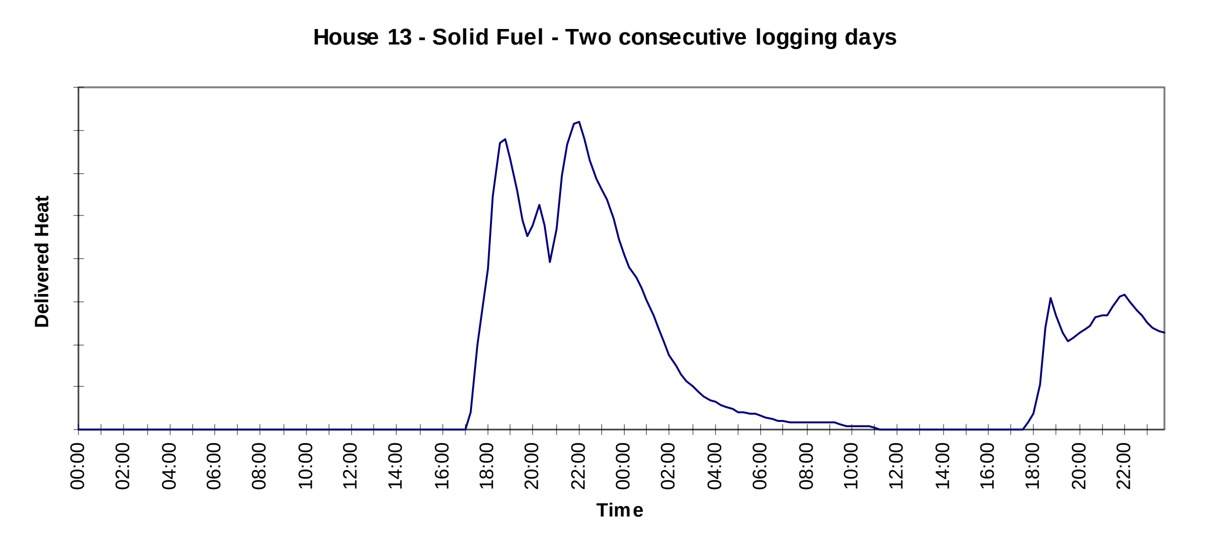

Figure 13:Profile of two consecutive days of solid fuel usage. The area below the line representing the energy consumed by the solid fuel burner.

Once the method discussed has been fully developed a number of cross fuel comparisons can be conducted. Solid fuel heated houses could be heated to a higher level than electrically heated houses, and the relationship of the level of heat output by the different heating methods when compared to the energy consumed will be able to be investigated.

5.2 Gas Monitoring

Logging has started in two Wellington houses to determine the best way of monitoring gas usage. Three end-uses - space heating, domestic hot water and cooking are currently being monitored. The aim is to develop a method by which comparisons can be made between gas consumption and the consumption of other energy types for an equivalent end-use.

The initial data logged is compared in Figure 14 to an electric DHW cylinder from one Wanganui house. The distinct patterns for the two systems are apparent, with the gas cylinder consuming a higher amount of power over a relatively short period of time, while the electric cylinder consumes power at a lower level for extended periods of time. The area under the graph, being the energy used by each of the appliances over the two days is equal to 75 kWh for the gas hot water system, and 30 kWh for the electric hot water system. A direct comparison between these two houses has to be qualified by the fact that due to the trial nature of this logging no adjustment has been made for the efficiency of the water heaters and the two cases differing in socio/demographic factors. However, the number of occupants in the Wanganui house (electric) is higher than in the Wellington house which would imply smaller gas usage than electricity usage.

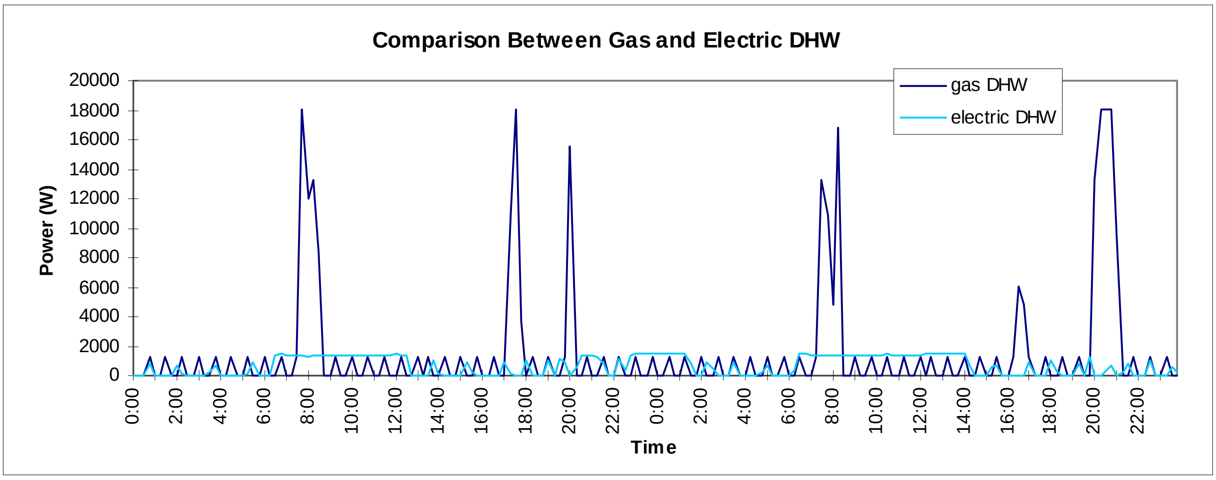

Figure 14: Comparison between Gas and Electric DHW heating for a period of two days in September.

6. Conclusion

On the completion of the logging of the current Wanganui houses end-use logging will shift from Wanganui to one of the main population centres. Monitoring at total house level is scheduled to start by the middle of 1998 with statistically significant information then becoming available for that region. Macro level logging at street transformer or distribution point servicing up to 50 houses which will effectively average the energy use profiles is due to commence within the next 18 months. Analysis at this macro level will be done using information supplied by Statistics New Zealand.

The HEEP project has just entered its third year of operation and already the benefits to both the commercial and private sector can be seen. As the sample increases this picture will become more representative of all of New Zealand. The results of the analysis reinforces the need for the study of the socio/demographic features of the different households and the effects these have on the energy consumption, by end-use patterns.

The initial findings at end-use level have highlighted the opportunity to reduce the energy consumption of domestic hot water which is the second largest overall end-use energy user in the New Zealand household. The preliminary studies done at peak power consumption level have indicated the opportunity for demand shifting of some household appliances to reduce peak power consumption and the potential for power suppliers to minimise line capacities. A project of this size and scope can only be done once and can only benefit from increased participation.

7. Acknowledgments

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