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Multi-disciplinary investigation of energy use in New Zealand households

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The Household Energy End Use Project was established in late 1995 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. This paper describes the research approach, the data and information collection and analysis undertaken to date, application of data to other research activities and the expected contribution of this investigation to the development of an efficient energy market in the household sector.

Keywords: energy - energy end use – household survey – socio/demographic survey

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1. Introduction

The Household Energy End Use Project (HEEP) commenced late in 1995. It is a long-term research project with the aim of determining and modelling energy use in residential buildings in New Zealand. The objective of the HEEP investigation is to establish and model how much energy is used and by which domestic appliances, including space heating equipment and domestic hot water heating equipment. The energy consumption is analysed in terms of time-of-use periods and seasons. A new approach is applied by determining not only the engineering aspects of energy use (efficiency of appliances, building, heating device etc.) but also the socio/demographic characteristics of the household occupants.

For some of the energy end uses the level of delivered 'energy service' will also be analysed. By the term 'energy service' we mean the tangible benefit which the consumer receives from using energy. This might, for example, be defined as the average indoor temperature of the living room when a certain amount of energy is used in a certain heating device.

International experience shows that in order to conduct an investigation of this type in a cost effective and technically rigorous manner, a large number of participants with different areas of expertise have to contribute to the project. At present the participants in the HEEP investigation include research organisations (Building Research Association of New Zealand "BRANZ" and Industrial Research Ltd. "IRL"), sociologists (Fitzgerald Applied Sociology), government agencies (Energy Efficiency and Conservation Authority "EECA"), power distributors (Trans Power New Zealand Ltd.) and power companies (Powerco). Energy supply companies and other commercial organisations such as manufacturers and retailers are also becoming increasingly interested and involved in the HEEP investigation.

Though focused on electrical energy end uses at present, the project will in the future include solid fuel, gas and solar energy, as well.

It is expected that the investigation will extend over a four to five year period, with a series of annual interim analysis results and reports.

2. The HEEP model and the research approach

Historically, energy use in houses was mostly described and modelled as purely a function of the thermal building performance and the energy efficiency of the space heating system, the hot water heating system and other appliances. In recent years it became increasingly clear that this modelling approach leaves one very important factor aside: the human dimension of energy use in houses. Various national and international research results indicate that a large proportion of the energy use can be explained by the behaviour of the energy consumer (1, 2).

This investigation is an attempt to close this knowledge gap. The envisaged model which will be produced will relate both physical and technological determinants as well as socio/demographic determinants to energy use in houses.

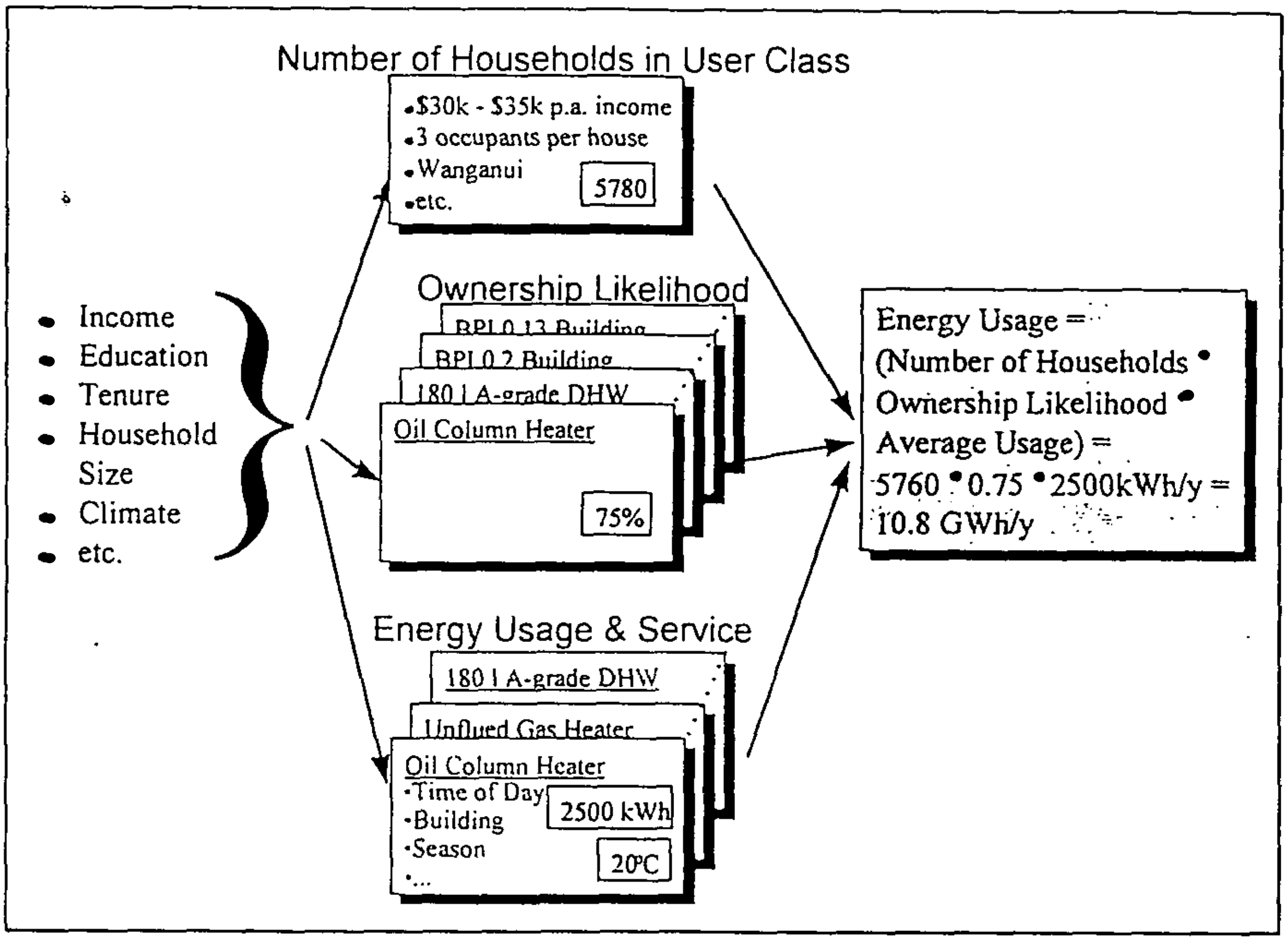

FIGURE 1: HEEP model structure

Figure 1 indicates one option for the structure of the proposed model. The energy use is determined by three components.

The first component is the number of households in a particular user class, i.e. all households matching certain physical and socio/demographic criteria. These criteria will have to be established during the research process. The household energy uses will be statistically analysed, together with the socio/demographic profiles of the occupants and the physical characteristics of the building and the equipment. Correlations would then indicate the significant determinants of energy use. These will then be used as the input determinants in the HEEP model, listed in the bullet list on the left side in Figure 1. The hope is that most of the determinants are factors which are generally available in existing statistical databases and which are being updated regularly so that no or very little further ongoing data collection has to be conducted to keep the model input up to date.

The second component of the model is the likelihood of the households in a particular user class to own certain appliances and room- and water-heating devices.

The third component is the average energy usage of a particular appliance when used by this user class. At the same time the energy service delivered by this appliance will be specified.

The example in Figure 1 would answer the question: "How much electric heating energy is used per year by all three-person households in Wanganui whose occupants have an annual income between $30,000 and $35,000 and who heat their houses with oil column heaters?" Consequently the result could be used to estimate potential energy savings through demand side management (DSM) measures or technological changes when they are targeted at this particular user group.

3. Applications of the household energy end use project

One major long-term application of the model is its use as an energy use forecasting tool. Because the model links socio/demographic and physical determinants with household energy use, the forecast scenarios can be defined in terms of both socio/demographic determinants and technology and policy-driven physical determinants. The model will be able to answer specific questions such as: "What impact will an increase of energy efficiency requirements in the New Zealand Building Code have on energy consumption in domestic constructions?" or "What impact do night-store heaters have on electricity demand during early evening hours?" or "What impact do time of day energy prices have on energy demand?".

This knowledge can then be used to design demand-side management and energy efficiency programmes. Potential users are both energy suppliers and government agencies. Energy distributors and suppliers will be able to use the information for their supply infrastructure planning and for evaluating load shiftability options. Even at the current stage of the investigation some interesting energy use patterns were found which show potential for DSM programmes through pricing policy, night electricity control and technological changes.

The collected end use data is being used to update current energy end use databases. The statistical robustness of the information will continuously increase. It is estimated that statistically reliable information on total annual energy use of a particular appliance group will be available by about the end of 1998 if data logging is continued at the current level. For some appliance groups with smaller variations in energy consumption the required sample size is smaller and the necessary amount of data will be available sooner.

The HEEP investigation takes account of socio/demographic aspects of energy use. Therefore the model can also provide information to help the marketing of equipment, appliances and other energy efficiency services through power companies or other energy consultants.

The data and information gathering, analysis and modelling activities have been linked in with other research projects and provide base-level information for studies like the Energy Efficiency Resource Assessment project (3) which quantifies, formulates and evaluates the energy saving potential resulting from the implementation of technical and behavioural energy efficiency measures in New Zealand.

Besides the long-term application there is potential to use data collected during the course of the project for immediate applications. Some of these are discussed in Section 7 below.

4. Project design

Four sets of input data are necessary to establish the envisaged model: socio/demographic information on house occupants; information on ownership of appliances and heating systems; records of the energy end use of households and appliances; and records of the indoor environment conditions. Linking these factors together will lead to a model to describe and forecast energy use in houses with higher accuracy than current models, which are solely based on physical properties. It therefore would be desirable to collect all the required information from a statistically representative number of houses and build the model based on this information. However, energy end use logging is a very expensive task. It is therefore not feasible to collect a statistically valid data set solely consisting of houses logged on end use level, i.e. appliance and circuit levels. Therefore the HEEP research plan consists of data sampling and analysis on three levels of detail. The collected data will then be integrated to gain maximum information from the raw data. Information is currently being gathered at the three levels of detail:

(1) Close-level studies of a small number of houses are being conducted to resolve detailed electrical energy use by time (15 minute intervals) and end use (on circuit and/or appliance level) and indoor temperature patterns. This provides new information about the actual proportions and timing of energy flows into space heating, hot water and other end uses. The socio/demographic composition of the houses will be determined through surveys. This data will also be used to develop methods to segregate total load curves into their end use components.

(2) At the medium level a large number of houses will be logged only for total household energy usage and indoor temperature. The houses will also be surveyed for occupancy and physical characteristics. This data firms up on the macro relationship between energy demand and physical

building and appliance determinants, socio/demographical determinants and climatic determinants. The data will also provide the main basis for the statistical analysis.

(3) At the highest level the electric load of groups of houses on common feeders and transformers will be logged. This information will be used to determine the effects of averaging of load patterns and it will be used to assign particular patterns to particular socio/demographic user classes. The data sets will be used to test the possibility of linking energy use data at feeder/transformer levels with socio/demographic information collected by Statistics New Zealand, which is detailed down to meshblock level, i.e. approximately 50 houses in a city block.

5. Current status of data collection and analysis

Industrial Research Ltd. began a long-term residential energy logging and research programme in Christchurch approximately three years ago. This programme, with the title "Electrical Energy Management", is funded by the Public Good Science Fund from the Foundation for Research, Science and Technology, and is scheduled to run until the year 2000. At present it covers eight houses at circuit level, and 28 houses logged at total household load level. Seven new loggers are currently being added for energy end use logging. Detailed information on this IRL research is contained in unpublished IRL working papers.

BRANZ commenced its logging programme in April 1996 and completed logging the first two sets of five houses in Wanganui in January 1997. Each of the houses was logged for a period of approximately five months, covering half a winter and half a summer season. Currently BRANZ is logging energy use and in- and outdoor temperature in another eight houses in Wanganui. Approximately eight electrical energy end uses and circuits uses are logged with 15 minute resolution in each house. The appliances being monitored are selected on the basis of two criteria: that the energy use of the appliance or appliance group is a significant proportion of the total household energy use, and that the energy use patterns have a strong dependency on user behaviour and climate conditions.

Temperature is recorded in three locations inside each of the Wanganui houses and one location outside. This quantifies the level of comfort and allows the energy use and the chosen comfort levels of the occupants to be correlated to their socio/demographic characteristics. Because of large room-to-room temperature differences and horizontal stratification effects the logging protocol for indoor temperature needs to be carefully designed. The three readings of the indoor temperature will be analysed in these terms. A Foundation for Research, Science and Technology-funded parallel project is examining these indoor temperature distribution effects. The number of temperature loggers in some of the houses will be increased to 10 loggers per house early next year.

The socio/demographic household characteristics are determined through surveys. The survey, which was developed by Fitzgerald Applied Sociology and recently updated by BRANZ covers socio/demographic, as well as physical parameters of the building, the space heating system, hot water heating and appliances. The surveys were conducted by IRL in the Christchurch houses during current data logging, and are planned to be conducted in the Wanganui houses early next year.

The 10 houses which have been investigated so far by BRANZ range from sizes smaller than 100 m² to more than 200 m². The occupant composition covers a wide range from a retired two person household to a four person family household. Also the family income includes a large range of income groups.

IRL and BRANZ are continuously exchanging data and research results, guaranteeing maximum benefits from the work. The two central logging regions in Christchurch and in Wanganui are representative of a cool and a mild climatic region. The intent is to extend the regional coverage in the future.

6. Statistical requirements for the sampling design

IRL has statistically analysed the data from the eight houses logged in Christchurch (4). The data were used to determine the necessary sample size and sampling period to collect necessary amounts of data to provide significant annual energy use information. The same analysis was then applied to the houses monitored by BRANZ in Wanganui as well.

Figure 2 shows the sample size required to determine the total annual electric consumption of households with an acceptable error of 10% with 90% confidence applying t-statistics for the 18 house sample currently logged by BRANZ and IRL. The large sample size in the 'washing' category is caused by the combination of washing and drying in some of the current houses. It is expected that separating the two categories will result in a significantly smaller sample requirement. The sample size which is required to determine the heating energy use was separated for houses with and without night-store heaters. This reduced the required sample size for heating from over 350 to less than 200.

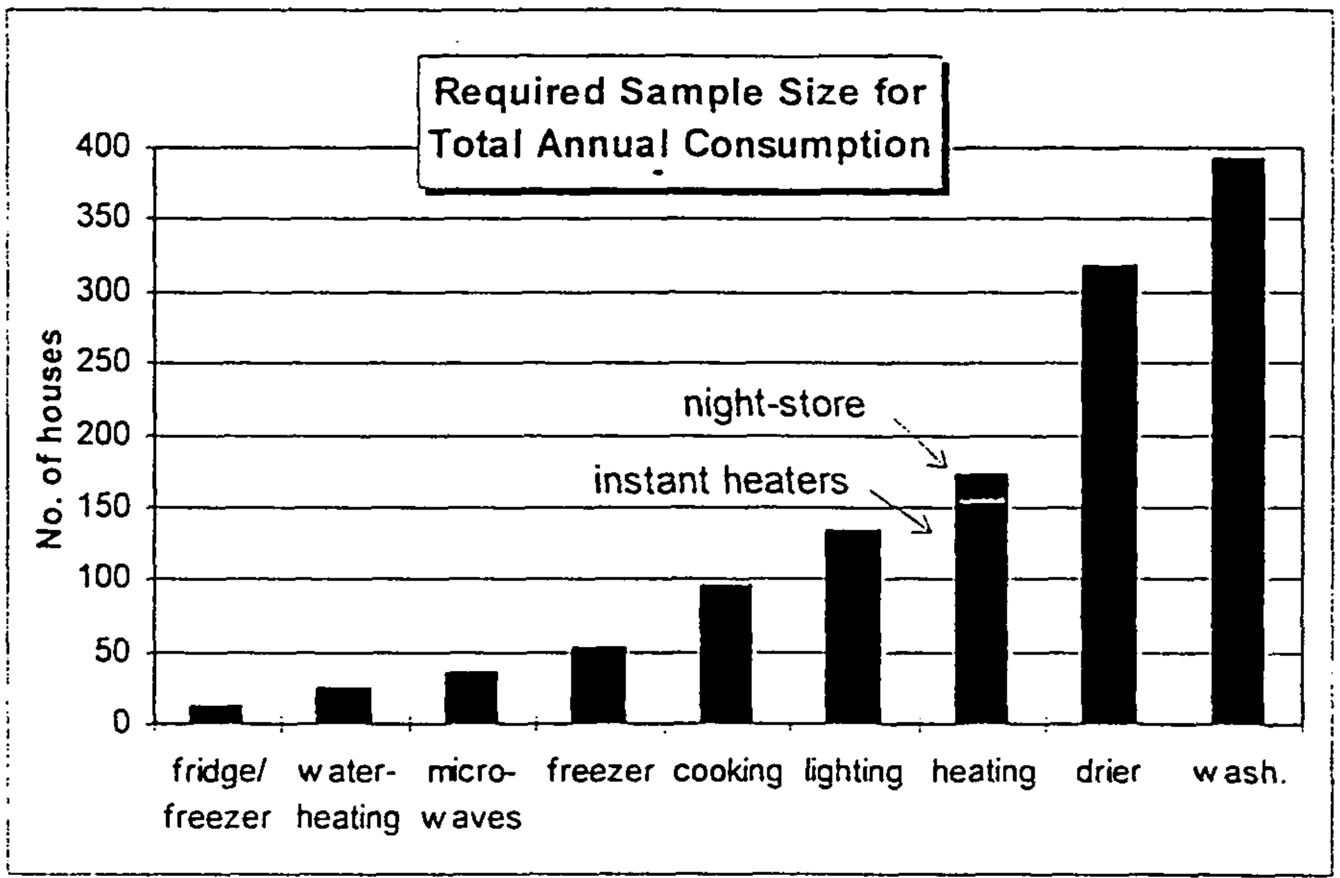

Figure 2: Required sample size for the total annual electricity consumption with an acceptable error of 10% and a confidence interval of 90%. The large sample size in the 'washing' category is caused by the combination of washing and drying in some of the current houses

It is important to realise that this sample size is required only to predict the average annual energy consumption of the total stock of the appliance group. This sample size requirement is smaller than the one which is required to develop the Household Energy End-Use model for two reasons. Firstly, the HEEP model establishes functional relationships between energy use and socio/demographic determinants, climatic determinants and other determinants. This increased capability will generally increase the required sample size depending on the correlations found because the number of variables increases. The second reason is that the above requirements apply only to average annual consumption. In order to describe daily and monthly usage patterns a significantly larger sample will be required.

The above statistical result is an important milestone in the HEEP study. It highlights the need for and provides the basis for applying a "smart" research strategy. The required sample sizes for statistically significant data are in some categories considerable (i.e. 175 houses for space heating energy use). For various reasons it seems unlikely that this number of houses can be monitored at the detailed end use level. This difficulty will be overcome by two design features of the project.

The sampling process will be optimised in terms of sample numbers and selection and it will be updated simultaneously with the availability of new information. The preliminary data will be analysed in order to determine the most efficient sampling strategy.

The main database on which the statistical evaluation (correlations etc.) is based will be the houses logged at the total household level only and not at end-use level, as briefly discussed in Section 3 above.

The HEEP investigation also includes the task of developing tools to segregate the total load information into the end use components. Applying this method will provide sufficient end use data for the investigation of correlations and the development of the model.

This initial statistical analysis has the additional benefit that it will determine the necessary sample size for average annual consumption of certain appliance groups. Having collected data from the necessary number of houses the generated information will be available to use confidently in updating energy use databases of New Zealand's household electrical energy consumption.

7. Results from ten houses logged in Wanganui

The analysis and the figures in the following charts are based on data from two logging periods, one covering April 1996 to July 1996 for houses 1 to 5 and the second July 1996 to November 1996 for houses 6 to 10.

7.1 Annual energy consumption of different electricity end use groups

Figure 3 shows the total weekly energy consumption for ten houses in Wanganui.

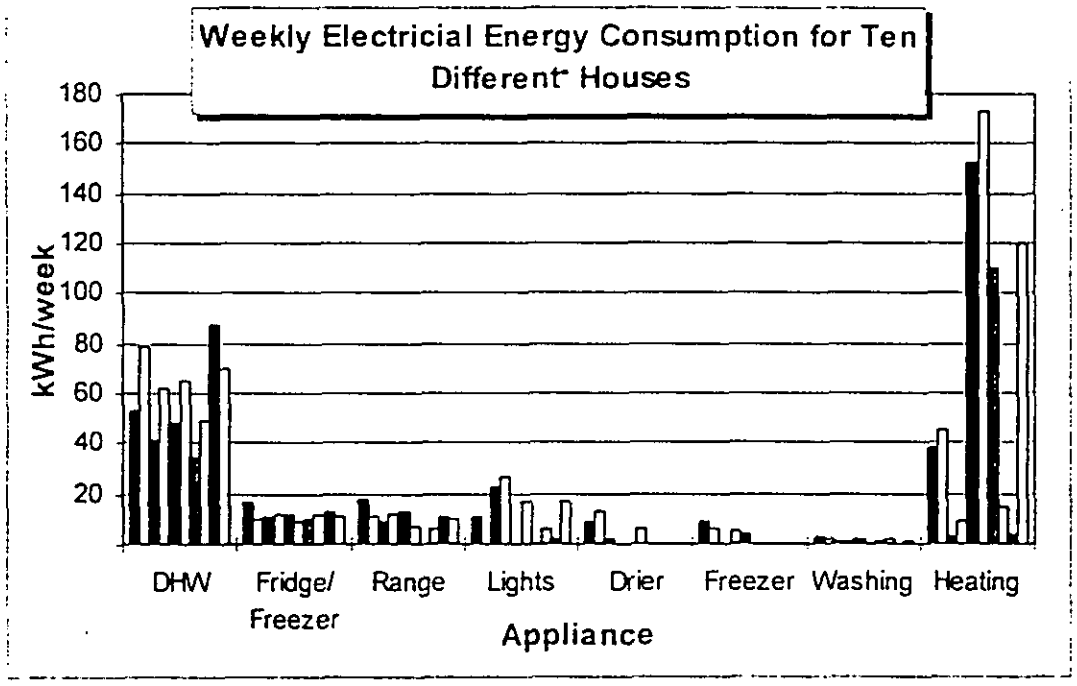

FIGURE 3: Comparison of weekly electrical energy consumption of the ten houses monitored in Wanganui. The largest variation in weekly electrical energy consumption appears for heating energy use. The four largest energy uses are in houses with night-store heaters.

Energy use for domestic water heating (DHW) is significant for all houses, but room heating energy use was, in four of the houses, the largest contribution to the total household energy consumption. The standard deviation of heating energy use in the ten houses is almost 100%. The highest four total consumptions are in houses with night-store heaters. (For further analysis they will be climate normalised. Houses 1 and 2 have auxiliary gas heating, which has not yet been considered in the analysis.)

Figure 4 shows the total electricity demand patterns for the ten Wanganui houses. The variations between the houses during day and evening periods are significant. Most houses show characteristic morning and evening peaks. Appliances on night rate tariffs turn on at 11:00 PM. This coincides generally with the end of the evening peaks.

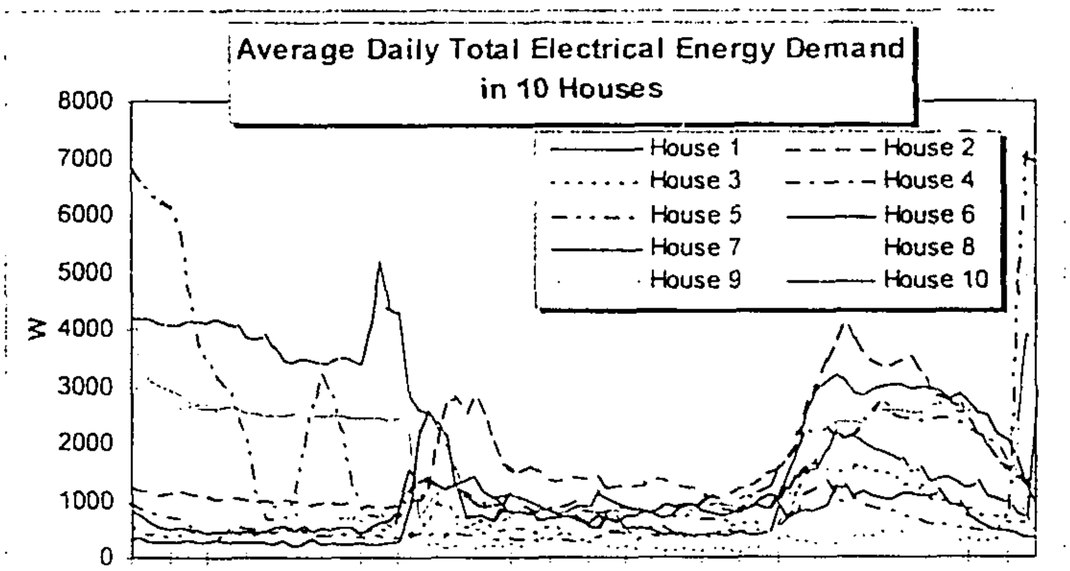

FIGURE 4: Comparison of average total demand for 10 houses in Wanganui. The relative variations between the houses are significant. The typical night-store demand pattern is visible for houses 5,6,7 and 10. House 9 uses night rate electricity for hot water heating.

There is a 24-hour continuous baseline load of at least 300W in all the houses which were monitored. This load is generally caused by fridge/freezers, freezers, clocks and "standby" loads of various appliances (TV, stove, stereo). The latter generally consume approximately 5W each. In some cases special additional appliances like aquarium pumps and heaters or external security lights also run continuously.

7.2 Average daily electrical heating demand

Figure 5 shows the average daily heating energy demand in ten houses for each period. The four houses with night-store heaters show their maximum load during the night rate period. In two of the four cases the night-stores have to recharge a second or third time during the night (approximately 3 kWh each night). The benefit of the heat released into the house during the late night and early morning hours might be questioned. Therefore this second and third recharge could be avoided through measures like using a delay timer switch set to make the heater come on at 3:00 am instead of at 11:00 pm.

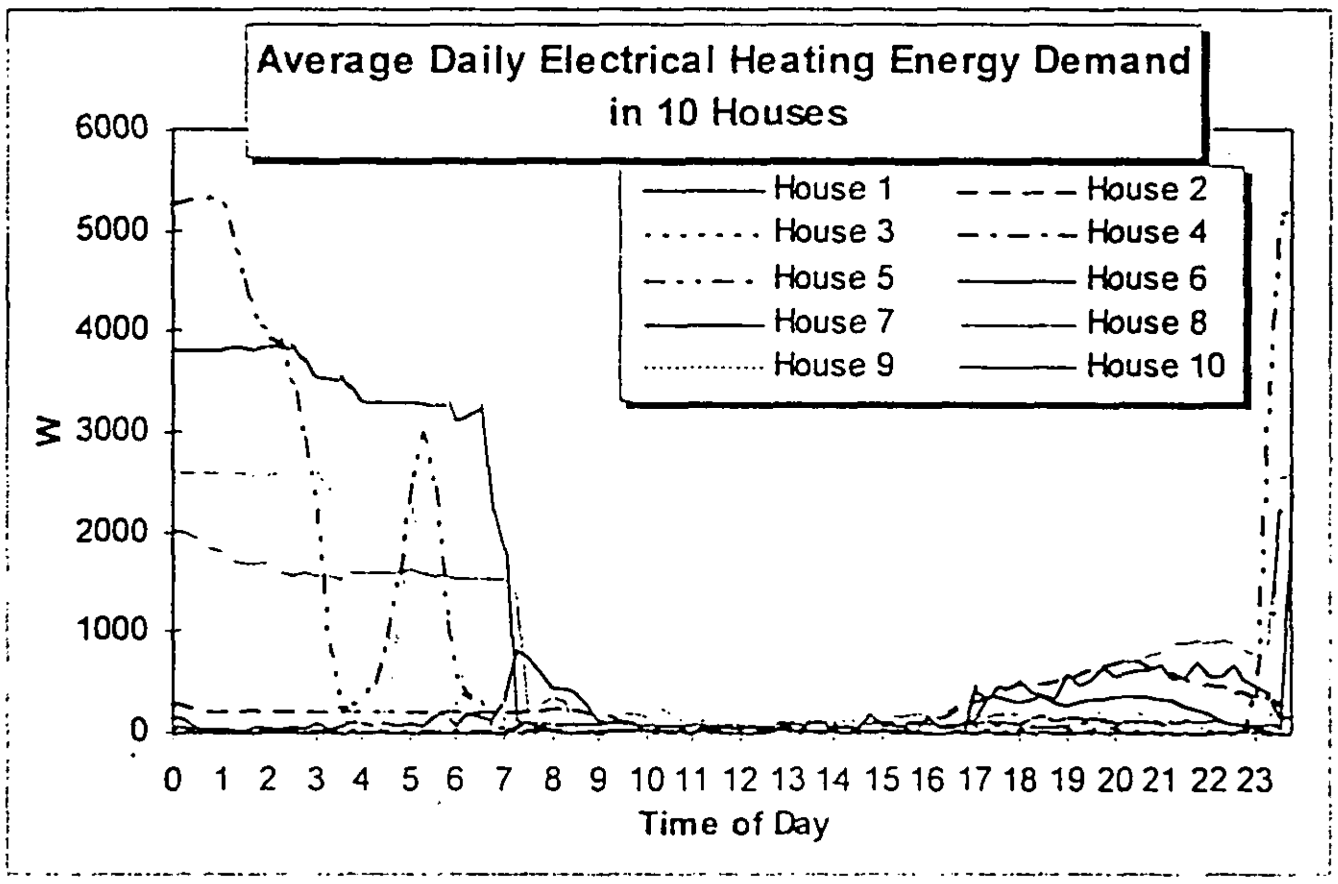

FIGURE 5: Average daily electrical heating energy demand in ten houses. There is a clear distinction in the demand pattern between houses with night-store heaters and those without. The heating energy use in the houses with night-store heaters is significantly higher than in those without. In two of the houses the night-store heater has to be recharged a second or even a third time during the night period.

The heating load patterns were analysed with the objective to define 'typical' heating pattern classes in the evening hours. Table 1 shows the large differences between the evening space heating electrical energy use in the ten houses.

TABLE 1: Average daily electric heating energy use between 5:00 pm and 11:00 pm in ten houses. Houses 5, 6, 7 and 10 have night-store heaters.

House	*Night-store ownership*	*Average daily electric heating energy use between 5:00 pm and 11:00 pm*
House 1		3.2 kWh
House 2		3.2 kWh
House 3		0.2 kWh
House 4		0.6 kWh
House 5	x	0.1 kWh
House 6	x	0.8 kWh
House 7	x	0.7 kWh
House 8		1.7 kWh
House 9		0.3 kWh
House 10	x	3.7 kWh

The standard deviation is over 95%. Houses 5, 6, 7 and 10 have night-store heaters and auxiliary heating systems. There does not seem to be any correlation between the existence of night-store heaters and the amount of electrical heating energy used during the evening hours between 5:00PM and 11:00PM. Classification of evening electrical heating demand does clearly not seem possible on the basis of night-store heater ownership.

These initial results seem to question the benefit of programmes which aim at shifting evening loads through propagation of night-store heaters. Evening heating energy use seems to be more determined by other factors than the ownership of night-store heaters. It has to be kept in mind, however, that these conclusions are based on a sample base which is not yet statistically significant and that no pre/post night-store energy comparisons could be conducted.

Night-store heaters release a large proportion of their heat during the night and early morning hours. At a later stage in the project the impact of night-store heaters on indoor climate and their costs and benefits will be investigated.

7.3 Findings on fridge/freezer electricity consumption

Figure 6 shows the electrical energy use of an old and a new fridge/freezer of similar sizes. Analysis of the data shows that the new model uses approximately 15% less electrical energy than the old model. Other factors could be different amounts of food stored in the fridge/freezers. The occupancy of the house had changed at the same time when the fridge/freezers were changed. The annual consumption of the new model was extrapolated and is approximately 660 kWh/year which is approximately 75% of the label rating. This deviation was also confirmed as a general rule by whiteware manufacturers (Lindsey Roke, Fisher & Paykel, pers. comm., 1996). This finding may indicate that labels might well be appropriate for inter-model comparisons, but they should not be used as an estimation of absolute energy consumption which would be used, for example, in national electricity demand forecast models. The true consumption can only be derived through actual data monitoring as conducted in the HEEP investigation or under scenarios more realistic than used for standard testing.

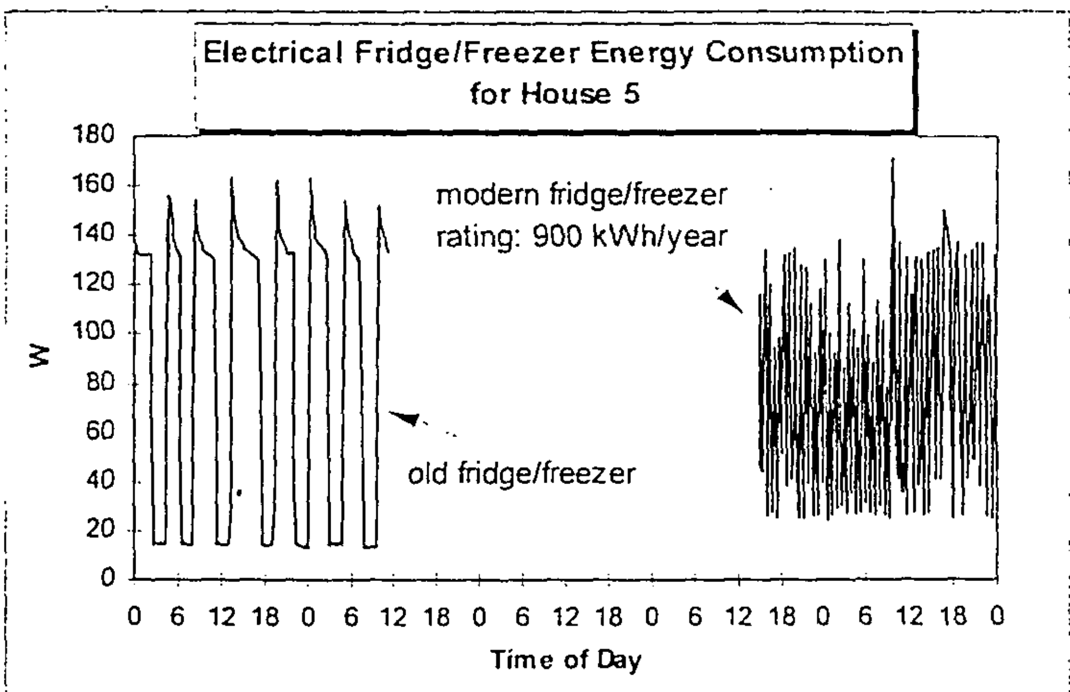

FIGURE 6: Energy consumptions of an old and a new fridge/freezer of similar sizes (260l fridge, 110l freezer volume). The old model uses approximately 30% more energy than the newer model.

The demand patterns of the two fridge/freezer models look significantly different, with the compressor cycles of the old model much longer than for the new model (3 hours versus 45 minutes).

7.4 Findings on freezer electricity consumption

Figure 7 shows the cycling of electricity consumption for the freezer in one of the houses in the pilot study. The chest freezer is an old model and from the recorded data it can be concluded that the cycling process is faulty. It has not yet been established whether the thermostat is defective or other parts are faulty. Since these defects are not easily detected by the users and, even if they are detected, they may not prompt an immediate fix or replacement of the appliance it can be expected that there are still a large number of faulty appliances in use in New Zealand households. The HEEP investigation provides an opportunity to estimate the proportion of these defective appliances, allowing better national energy use estimations. Additionally, the collected data provides information for manufacturers for fault analysis.

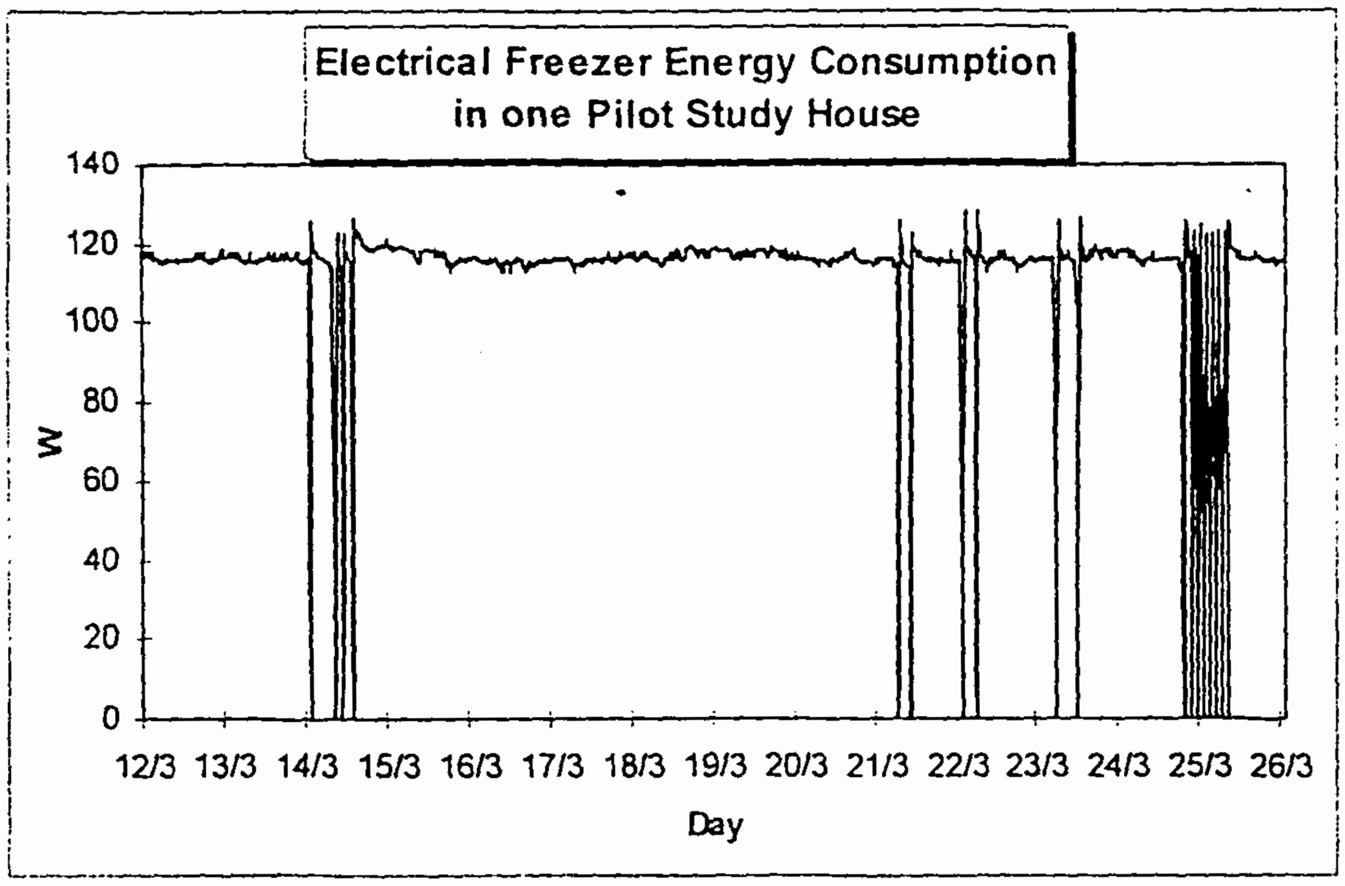

FIGURE 7: Energy consumption of an old chest freezer. The cycling process was obviously faulty. It has not yet been established whether the fault was caused by a defect in the thermostat or other faults.

7.5 Findings on electricity consumption of washing machines

Figure 8 shows the energy use of two modern washing machines with identical performances. Both operators stated that they use cold water washing cycles. After in-depth investigation it was found that one operator only assumed to be washing with cold water. The person had turned off the hot water tap and did not change the programme setting on the machine, assuming that this would automatically initiate the cold water cycle. In this case the washing machine used its built-in heating element to provide hot water according to the programme setting. This case highlights the influence of human behaviour on energy consumption and indicates the need for clear consumer guidance on technical energy saving potentials of modern household appliances.

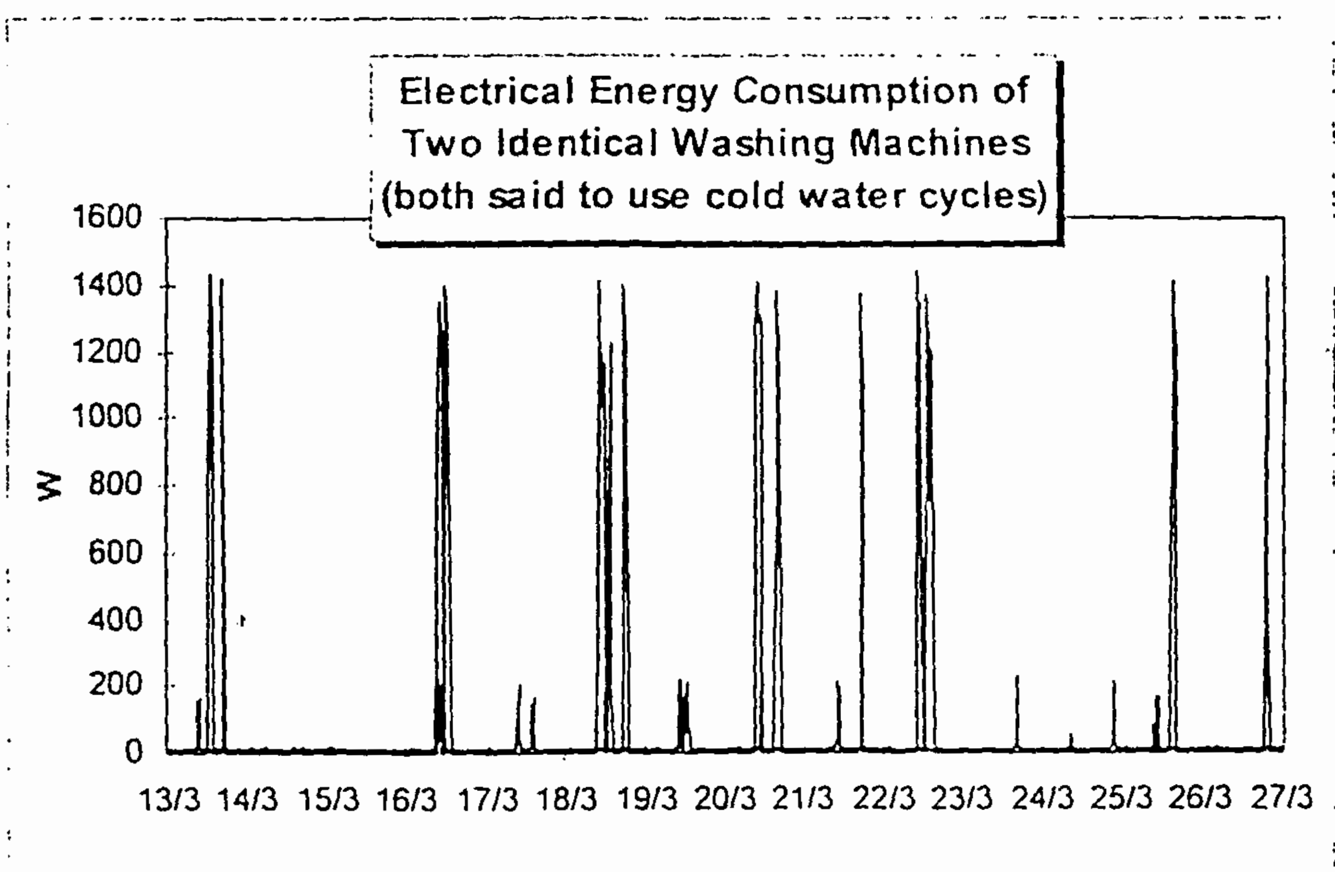

FIGURE 8: Energy consumption profiles of two washing machines with similar specifications. Both operators stated that they would apply cold water washing cycles.

8. Conclusions

The Household Energy End Use Project ("HEEP") is a long-term research programme with the objective of determining and modelling the energy use of residential buildings in New Zealand. Besides various physical determinants, socio/demographic determinants are also included in the analysis and in the model. The model shows potential use for linking socio/demographic and physical energy consumption determinants. It also has considerable potential for forecast scenarios, both at specific determinant or user group level, as well as nationally.

Monitoring and analysis efforts are currently underway in Christchurch and in Wanganui. Initial results are encouraging and already provide useful results at this stage. Statistical analysis of the collected information shows that for some appliance groups more than 100 households have to be logged to collect statistically significant annual energy consumption data.

Variations between annual electrical energy use and total load patterns are significant with domestic hot water heating and space heating generally contributing most to the total energy use.

Houses with night-store heaters tend to have larger total electrical heating energy consumptions. No reduction of evening heating loads could be detected in houses with night-store heaters.

The electrical energy use patterns of an old and a new fridge/freezer combination were analysed. The energy label did not provide a precise indication of the actual energy use of the refrigerator. The measurement of an old chest freezer showed that the cycling was faulty leading to almost continuous running of the compressor. The analysis of the energy use of two almost identical washing machines showed that the user guideline was not clear enough. In one of the two cases the user mistakenly assumed to be washing with cold water.

These results indicate energy saving potential through both technological improvements and educational programmes.

The currently collected information lays the foundation for a range of further aspects of analysis. Some of the aspects which will be investigated are:

- How reliable are surveyed statements versus the actual behaviour? For example: do occupants who state that they do five loads of washing per week really do five loads?
- What is the fraction of standing losses in the hot water energy use?
- How does the amount of space heating installed and space heating energy consumed compare to actual room temperatures.
- What is the relation between connected electrical load and peak load?
- Does the kitchen room temperature affect the fridge/freezer energy consumption?

9. Acknowledgments

We gratefully acknowledge the contributions of the Energy Efficiency and Conservation Authority, the Building Research Association of New Zealand though the Building Research Levy, Industrial Research Ltd., Fitzgerald Applied Sociology, Trans Power New Zealand Ltd., the Public Good Science Fund of the Foundation for Research, Science and Technology, and Powerco.

10. References

1. Hitchcock, G. 1993. An integrated framework for energy use and behaviour in the domestic sector. *Energy and Buildings, 20* : 151-157.
2. Norford, L., Socolow, R., Hsieh, E., Spadaro, G. 1994. Two-to-one discrepancy between measured and predicted performance of a 'low-energy' office building: insights from a reconciliation based on the DOE-2 model. *Energy and Buildings, 21*: 121-131.
3. Rossouw, P., Lermit, J., James, B. 1996. Quantifying past, present and future energy efficiency uptake rates and potential. IPENZ Conference, Dunedin.
4. Ryan, G. and Willink, R. 1997. Domestic electricity logging options and strategies. Submitted to IEEE Transactions of Power Systems.

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