BUILDING ON KNOWLEDGE

CI/SfB			
Date: July 2002			

CONFERENCE PAPER

No. 99 (2002)

An Initial Investigation into New Zealand's Residential Hot Water Energy Usage

A.R. Pollard, A.A. Stoecklein, M.T. Camilleri, L.J. Amitrano, N.P. Isaacs

Presented at the IRHACE Technical Conference,
Palmerston North, March 2001.

Funding for the work reported here was provided by the Public Good Science Fund of the Foundation for Research, Science and Technology, the Building Research Levy, the Energy Efficiency and Conservation Authority (EECA), Trans Power New Zealand Ltd, and The WEL Energy Trust.

SUPPORTED BY THE BUILDING RESEARCH LEVY

ISSN: 0111-7505

An Initial Investigation into New Zealand's Residential Hot Water Energy Usage

Andrew Pollard, Albrecht Stoecklein, Michael Camilleri, Lynda Amitrano, Nigel Isaacs.

Building Research Association of New Zealand (BRANZ)

Hot water energy use is a large component of New Zealand's total residential energy use. Accurate estimates of the future demand for hot water energy use require an accurate understanding of the social drivers and physical processes involved with hot water usage and storage. Changes in society (such as an aging population) and changes in the physical properties of hot water systems (such as increasing the insulation level of hot water cylinders) will impact on the energy used for hot water in households.

This paper undertakes a preliminary examination of New Zealand's residential hot water usage. Results from the initial stages of the Household Energy End-Use Project (HEEP) are used to derive standing losses and hot water usage from measurement. The analysis of the physical properties of the hot water systems allow comparisons of theoretical assumptions from standards and other guidelines concerning the standing losses, thermostat settings and usage frequency with actually measured data. The collection and analysis of socio-demographic data allows for the study of hot water demand which has implications in a wide range of areas such as the sizing of hot water systems and pricing options. Further analysis will be undertaken as the HEEP work progresses.

Keywords: *Residential Energy Use, Hot Water Usage, Water Heaters*

1. Introduction

Water heating is a major component of New Zealand's residential energy use. Hot water systems consume about 20 PJ or 30% of New Zealand's residential energy. (EECA, 2000). A majority of hot water systems use electricity; 91% of households have electricity as an energy source for water heating. (Statistics New Zealand, 1997) while 8% have gas, 16% have solid fuel (commonly as 'wet-backs' contributing to the heating in an electric water cylinder.) and 4% having other energy sources such as solar energy. Presently hot water systems in New Zealand are generally not very efficient with only about 5% meeting the "A" Grade according to NZS 4602:1988 and NZS 4606:1989 (CAE, 1996). Consequently the potential for national energy savings, and Greenhouse Gas emission reductions, from improvements in hot water systems is likely to be large.

2. Hot Water Energy Usage

Buildings do not use energy rather it is the people inside them who use energy. However people do not choose to use energy, rather they choose to use "services" that have an energy consumption associated with them. Hot water service is delivered via a hot water system, however the energy consumption of the hot water system is not simply related to the amount of delivered hot water as the physical properties of the hot water system (for example - volume of the stored water, amount of insulation, thermostat temperatures, presence of tempering valves) will affect the energy consumption of the hot water system.

Accurate modelling of residential hot water energy usage requires the consideration of both hot water demand and the physical properties of the hot water systems. Different disciplines approach these considerations in different ways. Lutzenhiser (1992) (quoted in Bell, Lowe and Roberts, 1996) suggests four classes of models (Physics/Engineering, Economic, Psychological and Social/Anthropological) for general energy consumption modelling. In modelling national residential hot water energy consumption, it may be advantageous to emphasise a Physics/Engineering approach to describe the energy consumption of the hot water system while emphasising a Sociology/Anthropology approach to determine the amount and timing of the hot water demand.

Any type of energy model requires extensive data to construct, validate and implement the model. Good sources of data are therefore critical to produce accurate models. National surveys, specifically focusing on energy, are frequently employed overseas as a primary data source. Examples of these energy surveys would be the Residential Energy Consumption Survey (RECS) (EIA, 1995) for the USA and the Survey of Household Energy Use (SHEU) (NRCan, 1994) for Canada. While these surveys have a good sample size, the energy consumption information is based on monthly billing records and only collects the total energy usage rather than for component energy end-uses.

In New Zealand, a large electricity energy end-use study was carried out in 1971/1972 (New Zealand Department of Statistics, 1973) and included sub-metering of up to four energy end-uses (Water Heating, Portable Appliances and Lights, Range and Fixed Wired Heating.). This 1971/72 study has been frequently used in New Zealand energy modelling however the data is somewhat old and the new data logging methods are now able to collect significantly more detailed information than was possible than in 1971/1972.

Other studies that have collected information relevant to hot water usage in New Zealand are;

- Carrington, et. al (1984,1985) who performed a detailed investigation over at least six months of seven household's (in Dunedin and Auckland) use of hot water and performance of their hot water systems including the performance of six heat pump hot water systems.
- Hendtlass (1982) who examined hot water demand through surveyed 248 Christchurch households, having the occupants record each usage of hot water to individual hot water end-uses over the course of a week.
- Phillips (1976) who surveyed 9868 households throughout the country, asking a range of attitudinal questions concerning energy use.
- Many health reports, reporting on the thermostat settings and tap water temperatures from samples of households. See, for example, Tustin (1991).

In 1996 measurements began for the Household Energy End-Use Project (HEEP), which is a long-term research effort to create a scientifically and technically rigorous, up-to-date public knowledge database of energy use and end-uses, energy services provision and key occupant, building and appliance determinants of energy use in residential buildings. Further information on HEEP can be found in the annual HEEP reports (Stoecklein et al. 1997, Bishop et al. 1998, Camilleri et al. 1999, Camilleri, et al. 2000).

3. Physical Properties of Hot Water Systems

Simplistically, hot water systems heat cold water to produce hot water that is then used for a variety of purposes, at a variety of temperatures. A number of energy types, such as, electricity, natural gas, LPG gas, solid fuel (wet backs) and solar energy can be used to heat the water. The heating abilities of most systems are too limited to heat the incoming cold water to the delivery temperature instantaneously. Only about 3% of the new market of water heaters are of this instantaneous heating type (CAE, 1996). For the remaining systems, storage of preheated water is required, which is the case for the common hot water cylinder.

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 the water that is actually used or consumed by the occupants. A simplistic example of the difference between the two components is seen by the occupants, when they leave the house unoccupied for the holiday period: the hot water in the cylinder still is maintained at the temperature at which the thermostat is set and depending on the insulation level of the cylinder the energy to replace heat losses can be significant, i.e. this energy component is "lost". Whatever surplus energy for water heating is required, once the occupants are actually occupying the building, is deemed to be "used" energy.

It is plausible that the "lost" component of the hot water energy is mainly correlated with the physical properties of the cylinder and pipes and its location in the building, the "used" component is conceivably more closely linked to the occupants' hot water usage behaviour.

In order to develop a more generalised model of hot water energy consumption ("used" energy) 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:

"Lost" hot water energy as a function of physical parameters of the cylinder and house.

"Used" hot water energy as a function of the reported behaviour of the household occupants.

"Used" hot water energy as a function of the socio-demographic characteristics of the household.

The first step in the analysis must be the separation of the "lost" and "used" components of the hot water energy consumption. The method applied in HEEP is described in the HEEP Year 2 Report (Bishop, et. al, 1998). To separate these types of energy use, the energy use for each 10- or 15-minute period was averaged over the logging periods of each house.

Periods of standing loss were assumed to be the flatter areas, found typically in the early morning when no water is drawn from the cylinder (marked with a oval in FIGURE 1). The average standing loss was calculated for this period, extrapolated for the full 24 hour day, and then subtracted from the total energy use to give the average used energy.

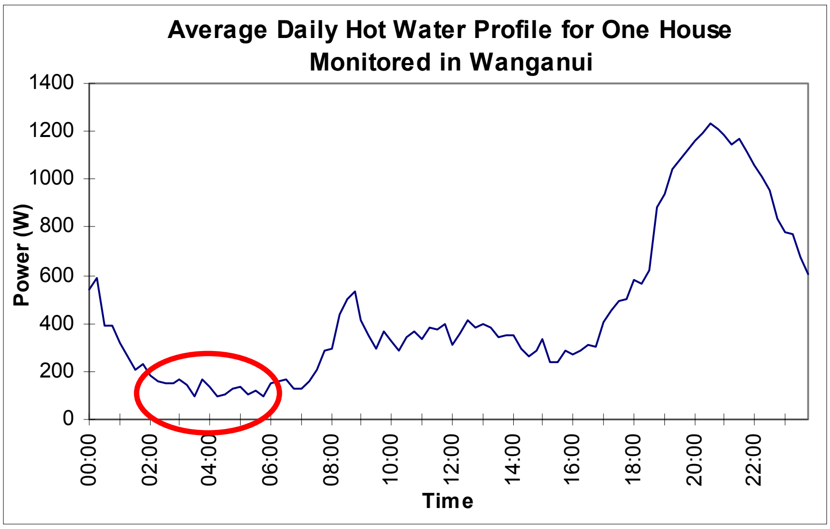

FIGURE 1: Average daily hot water energy use profile for determination of "lost" and "used" hot water energy consumption.

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. (Pratt, et. al, 1993).

The results of the separation of the hot water energy into Lost (Standing Losses) and Used (Consumed) Energy for a number of randomly selected HEEP houses are shown in TABLE 1 and in FIGURE 2. From TABLE 1 it is seen that the electric hot water cylinders are losing about 42% of their energy in standing losses. This compares with a figure of about 30% found by Carrington (1985) for a sample of five cylinders. About 18.3 PJ of New Zealand's electricity is consumed by water heaters (EECA, 2000). Assuming that 42% 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 7.7 PJ .

Type	Lost (kWh/day)	Used (kWh/day)	Percent (%)	Count (n)
Electricity Hot Water	3.56	4.82	42%	28
Nat. Gas Hot Water	3.90	14.82	21%	6
Nat. Gas Instant Hot Water	0.00	9.25	0%	2

TABLE 1. Average standing losses and consumed energy for randomly selected HEEP houses.

Clearly the energy lost in standing losses is large so the immediate question is how these standing losses can be reduced. The heat loss from the cylinder that makes up the standing losses can be reduced by

- Increasing the insulation levels of the insulation surrounding the hot water cylinder
- Reducing the temperature of the water inside the cylinder.
- Increasing the pipe insulation and installing heat traps

Progress has been made to improve the insulation levels of hot water cylinders. The New Zealand Building Code (NZBC) Clause H1 has been recently revised (see BIA 2000) and now includes a requirement that new hot water cylinders installed should perform better than or equal to "B" grade (see NZS4205:1996). Gas cylinders also have a maximum gas consumption rate while recovering from standing losses.

Unfortunately with the demise of the Electrical Development Association (EDA), the WaterMark labelling scheme which the EDA promoted for electric hot water cylinders, is no longer being conducted. Under the WaterMark scheme, hot water cylinders were given a label indicating the grading of the cylinder, which encouraged consumers to purchase cylinders with a high level of insulation.

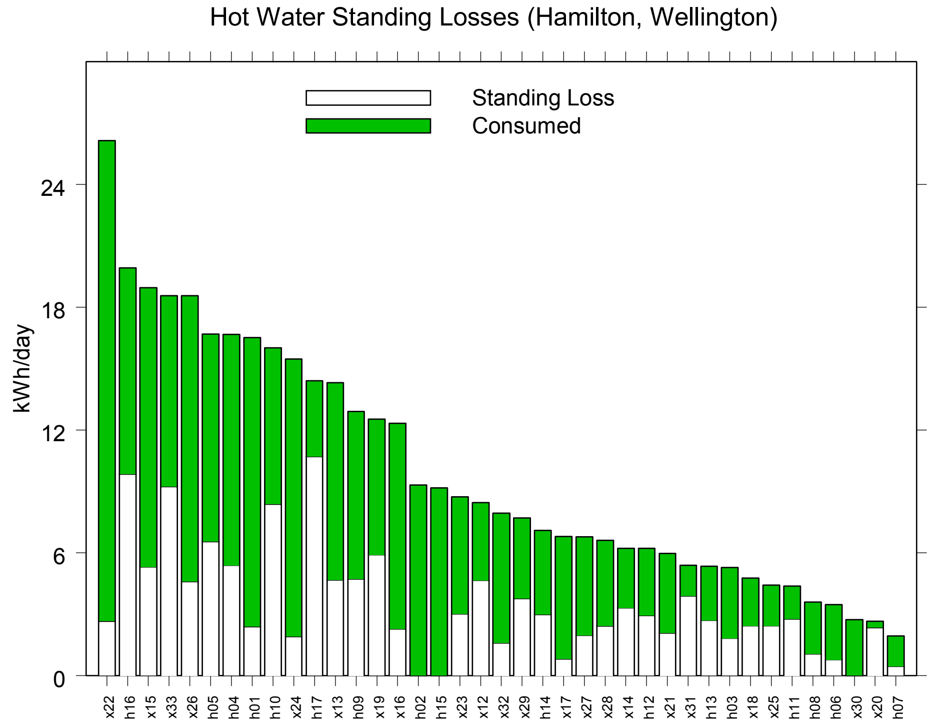

FIGURE 2 Standing losses for randomly selected HEEP houses.

Standing losses can also be significantly reduced for existing electric hot water cylinders by the addition of a cylinder wrap (CAE, 1996). The simple payback period for these cylinder wraps is frequently less than three years.

Another way of reducing standing losses is to reduce the temperature of the water stored within the hot water cylinder. However it is not simply a case of turning down the thermostats of all hot water cylinders. People don't like to run out of hot water and HEEP has found that about 20% of households report that they sometimes run out of hot water. A simple method to reduce the chances of running out of hot water is to turn the thermostat on the cylinder up so that the water within the cylinder is heated to a higher temperature. More warm water is available for showering, as less hot water is needed from the cylinder to be mixed with the cold water to get water of showering temperature. Tustin (1991) reports on a project in Whakatane concerned with safe water temperatures, where twelve households were provided with consumer adjustable thermostats on their hot water systems. At the time of installation these were set to 55°C and the residents were told about safe water temperatures. On returning to the houses after one year it was found that 25% of households had adjusted the thermostat upwards (greater than 60°C) to prevent running out of hot water.

Another way to reduce the chance of running out of hot water is to appropriately match the size of the hot water cylinder to the expected demand for hot water. An indication of whether this matching has not been successful (assuming that people have turned down their cylinders as much as they feel reasonable) is to examine the thermostat settings for the cylinders to see if there are a sizable number greater than 60°C. FIGURE 3 shows the thermostat settings and resulting nearest tap water temperatures for a number of the HEEP houses recorded at the time of installation of the HEEP monitoring equipment for each house (see Carrington et. al. (1984) for comments on adjusting spot readings of water temperature). The angled line in FIGURE 3 shows a one-to-one correspondence. The number of data points above this line are cause for concern. The reasons for this could be due to broken thermostats (for example the cylinder set to 45°C produced water at 75°C) or simply due to inaccuracies in the thermostats. The nearest tap temperatures could be expected to be lower than the thermostat setting on the cylinder when a tempering valve is present on the cylinder or that the cylinder is on a controlled (nightrate) tariff and the thermostat hasn't been operational for some time. The grey area in FIGURE 3 is the area for safe storage and delivery of hot water. The water in the cylinder should be kept at greater than 60°C to kill legionella, but the tap temperature should be less than 55°C (and less than 45°C where the elderly or young are likely to use it). The target area therefore for energy efficiency and safety is the left hand side of the grey area showed with a dotted line.

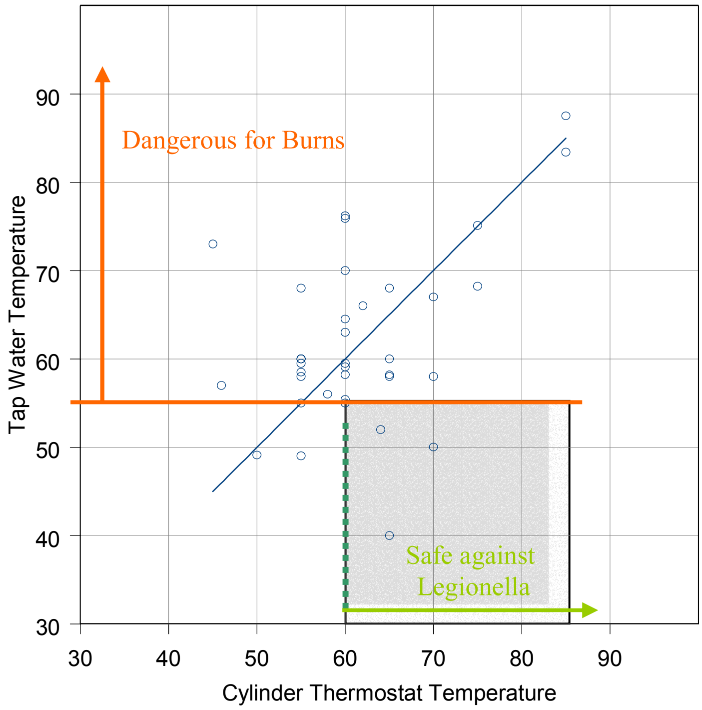

FIGURE 3. Cylinder thermostat setting and the resulting nearest tap water temperature.

Another area of energy efficiency to examine is the method used to heat water. Heat pumps have been seen to be effective to heat water (Carrington et. al, 1984) as have solar energy systems (CAE, 1996). Unfortunately the initial capital costs of these technologies have limited their uptake.

The energy consumption of a hot water system is a physical process and can be accurately modelled using sophisticated models, such as WHATSIM (Hiller et. al, 1992) for electric cylinders and TANK (Paul, et. al, 1993) for gas cylinders, however if only the consumption information is required other than detailed performance then a model such as WHAM (Lutz, 1998) could be used. All of these models require assumptions of the amount of hot water demand in order to predict the energy consumption of the water heater. In the next section hot water demand will be investigated.

4. Social Drivers of Hot Water Demand

Hot water demand, like energy consumption, is made up of a number of distinct end-uses (Koomey et. al, 1994) such as showers, baths, sink use, dish washing and clothes washing. In examining this demand, it is flow-rate or delivered volume of water and the required temperature of the water that is of interest (see Hendtlass, 1982). The estimate of the used (consumed) hot water energy of the hot water system is related to the total demand for hot water. Both the total hot water energy consumption and the used hot water energy consumption (where it is available) are used subsequently in this paper to explore the relationship of hot water demand with other socio-demographic factors.

FIGURE 4 shows the average total hot water profile from 44 of the randomly selected houses from the HEEP database. The data from each house has been standardised (so that it has a mean of zero and a standard deviation of one) as the graph is to be used to examine when hot water is being used. The most striking impression of this graph is the variation in time of use of various hot water systems. Morning and evening peaks are frequent however some show high use during the night or during the day. Classification of the profiles using an Artificial Neural Network similar to those used by Stoecklein (Camilleri, et. al, 2000), to be undertaken later for HEEP, may highlight relationships between time of demand and socio-demographic factors. Earlier HEEP research (Bishop, et. al, 1998) found that 36% of the peak demand from households is due to hot water energy consumption which suggests that load shifting (ripple control) of hot water cylinders may be an effective load control strategy.

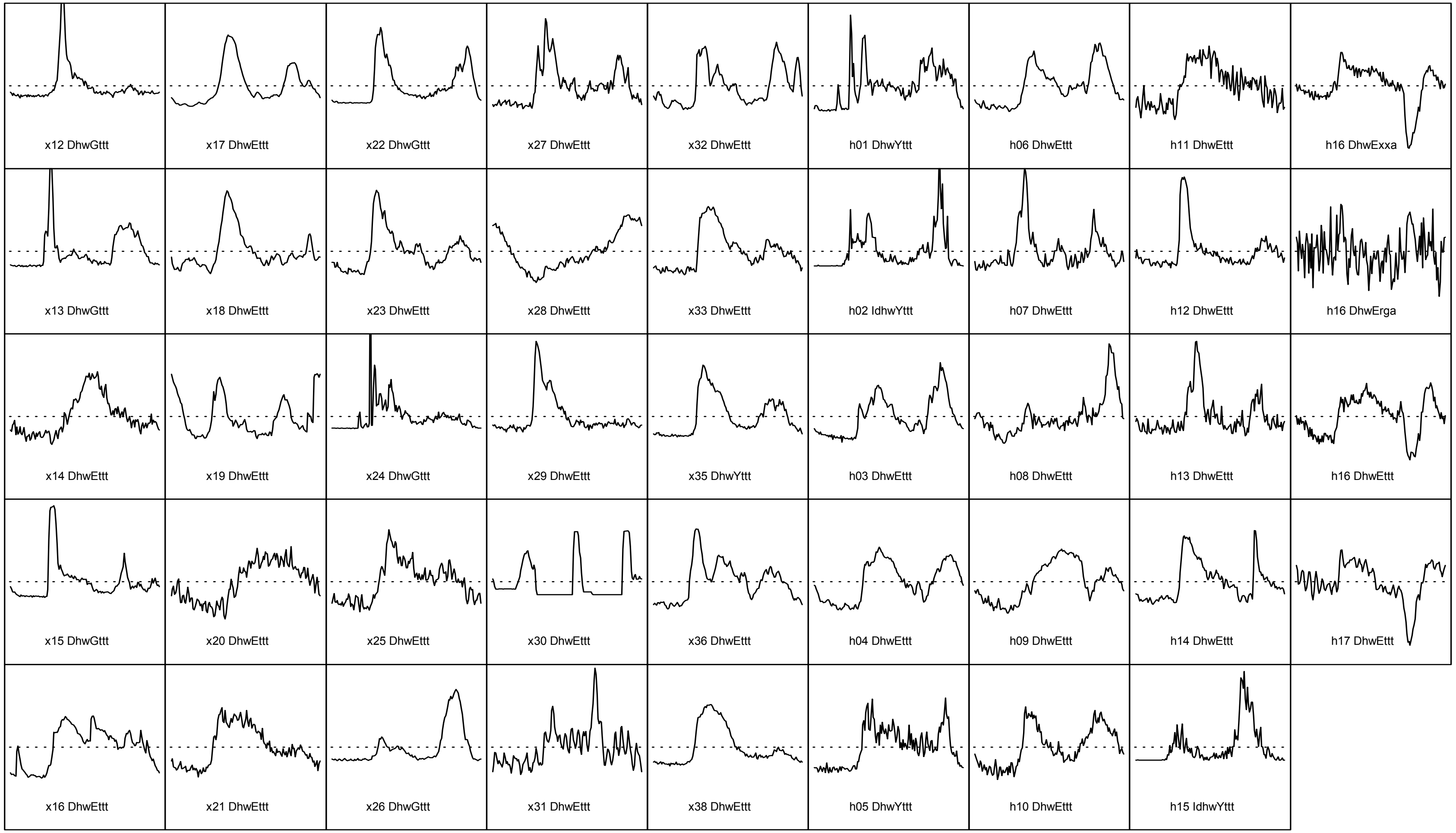

FIGURE 4 Average total hot water energy profiles for a number of randomly selected HEEP houses in Wellington (X) and Hamilton (H). The x-axis ranges from midnight to midnight in each graph. Each profile has been standardised.

While the profiles of FIGURE 4 have shown the variation in the timing of hot water use, nothing has yet been said about the overall total demand for hot water. Fitzgerald and Ryan (1996) examined a small sample of ten Christchurch households measured for electrical end-use consumption by Industrial Research Limited and compared the total electric water heating use for each house with the following factors

- Proportion of household members usually at home in the day [daypropn],
- Number of children in the household [totkids],
- Number of teenagers [totteen],
- Number of adults [totadult],
- Number of elderly [totolds],
- Household income bracket [income],
- Minutes of shower time per person per week [showrati],
- Number of warm or hot loads of washing per person per week [warmrati],
- Number of baths per person per week [bathrati],
- Use of wetback or not [wetback],
- Whether the household was on a concessionary water heating tariff or not [wtariff],
- Whether the household used a dish washer or not [dishwash]

A stepwise linear regression model was used and preceded as shown in TABLE 2.

TABLE 2: Factor coefficients for hot water energy use

Step	Variable	R^2
1	Minutes of shower per person per week [showrati]	.39
2	Number of teenagers [totteen]	.62
3	Proportion of people home during day [daypropn]	.78
4	Household Income bracket [Income]	.90
5	Household on concessionary water tariff [wtariff]	.99
6	Number of warm or hot loads of washing [warmrati]	.99

Finally arriving at the following linear model

$$\text{Water heating} = -156.9 + (1.35 * \text{showrati}) + (138.2 * \text{totalteen}) + (200.1 * \text{daypropn}) + (63.1 * \text{income}) + (199.6 * \text{wtariff}) - (26.6 * \text{warmrati})$$

So the total showering time, the total number of teenagers, the proportion of adults home during the day and the household income are important factors. Fitzgerald and Ryan note that whether the household had a separate hot water tariff [wtariff] and the number of warm washes [warmrati] variables add little improvement to the model and that the small sample size was very much a limiting factor. Fitzgerald and Ryan also note that for a larger sample size, the number of occupants is likely to be a factor.

The 1971-72 Survey of Household Electricity Consumption (New Zealand Department of Statisitics, 1973), included measurements of total electric water heating consumption and the number of occupants for 1984 randomly selected New Zealand households, shown in FIGURE 5. A linear regression line shows a positive, but weak correlation.

The water heating information from the HEEP database was examined against a number of factors as part of a standard linear model. As suggested earlier, most success was encountered when examining the used hot water energy consumption along with the ages of the occupants, type of hot water system, and the reported shower and bath usage. TABLE 3 provides the output terms of a linear model against a wide range of factors. Data from 53 cases within the HEEP database could be examined. Overall the multiple-R^2 for the model was 0.85. It can be seen that the variables of significance are the number of female teenagers within the household, whether the hot water cylinder was electric, and the total number of showers per week. It is interesting to note that the total shower time is less significant than the total number of showers which is surprising as it would be expected that the total shower time would be more closely related to the hot water used The total shower time per week is based on the residents estimates of number of showers per week multiplied by their estimate of the average length of showers. The figure for the total showering time is comprised of two estimates whereas the number of showers per week would only have one estimate. Another reason may be that people are perhaps better at estimating the number of showers per week they have rather than the average length of their showers.

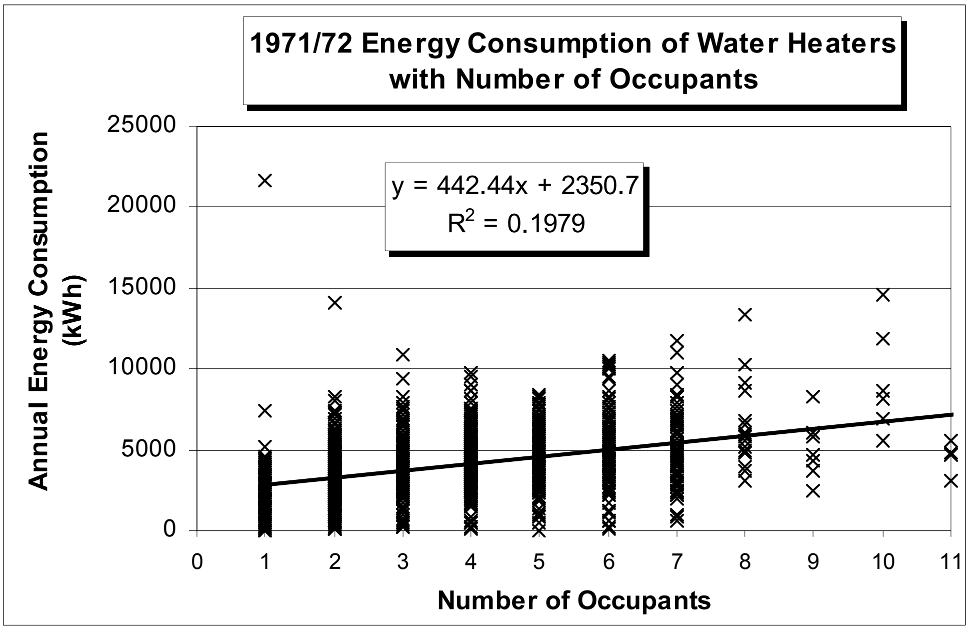

FIGURE 5: 1971/72 Correlation of hat water energy usage with number of occupants

A simpler linear model was constructed from the number of female teenagers in the household, whether the household had an electric water cylinder and the number of showers per week. A total of 64 cases could be considered as fewer cases than the previous model had to be removed due to missing values. TABLE 4 gives the output terms of the shortened linear model Overall the multiple-R^2 for the model was 0.75. Including the number of occupants as an additional term only increased the multiple-R^2 to 0.78. The database has a dominance of houses that have an electric hot water cylinder. The term indicating the presence of a natural gas hot water cylinder or an instantaneous natural hot water system have large standard errors so the model may not have sufficient cases of gas hot water systems to accurately model.

A weakness of linear models is that they work best when the variables used in the regression are not correlated. Unfortunately a considerable number of socio-demographic variables are interrelated and hence are strongly correlated. Factor Analysis is a technique that is not sensitive to the correlation between input variables and results in linear combinations (factors) that sometimes can be interpreted as the underlying categorisation of the data. This will be applied to the data in the later years if HEEP.

TABLE 3 Linear Model Terms Against the Used Hot Water Consumption

Term	Value	Standard Error	t value	Pr(>|t|)
(Intercept)	5.707	1.029	5.547	0.000
Male.Kid	0.366	0.759	0.483	0.632
Female.Kid	-0.122	0.630	-0.194	0.847
Male.Teen	-0.304	1.327	-0.229	0.820
Female.Teen	4.142	1.001	4.137	0.000
Male.Adult	0.434	0.583	0.745	0.461
Female.Adult	-0.119	0.913	-0.131	0.897
Male.Aged	-0.598	0.727	-0.822	0.416
Female.Aged	-0.531	0.859	-0.618	0.540
Appliance (Nat Gas)	-0.192	0.724	-0.265	0.792
Appliance (Electric)	2.641	0.399	6.618	0.000
Appliance (Nat Gas Instant)	0.645	0.528	1.222	0.229
ShowersPerWeek	0.172	0.071	2.415	0.021
BathsPerWeek	-0.007	0.094	-0.071	0.944
Total.Shower.Time	-0.003	0.004	-0.865	0.392

TABLE 4 Simplified Linear Model against Used Hot Water Consumption

Term	Value	Standard Error	t value	Pr(>|t|)
(Intercept)	5.631	0.838	6.723	0.000
Female.Teen	3.838	1.006	3.815	0.000
Appliance (Nat. Gas)	-0.437	0.871	-0.502	0.618
Appliance (Electric.)	2.565	0.413	6.205	0.000
Appliance (Nat. Gas Instant)	0.840	0.625	1.344	0.184
ShowersPerWeek	0.129	0.032	4.014	0.000

5. Conclusions

Previous estimates of the electric hot water cylinder standing losses (Carrington, et. al, 1984,1985) of about 30% appear to be low when compared to a random sample of HEEP houses, which have an average standing loss of about 42%. Standing losses for all of New Zealand's electric hot water cylinders could be as high as 7.7 PJ. New performance requirements under NZBC Clause H1 which became mandatory on 29th December 2000 (better than 'B' grade) will improve the overall performance of New Zealand's electric hot water cylinders, as will retrofitting of insulation wraps to existing cylinders. Re-introducing labels for hot water cylinders may help promote the up-take of cylinders of higher grades.

Hot water demand is driven by a number of factors and work is still being undertaken to examine these. At this intermediate stage, the number of female teenagers appears to be a factor as is the number of showers per week. The total number of occupants may have some influence on the hot water demand. Sufficient data has yet to be collected on households with gas hot water cylinders to examine the hot water demand of these households.

6. Acknowledgements

We gratefully acknowledge the contributions of the Public Good Science Fund of the Foundation for Research, Science and Technology, the Building Research Association of New Zealand though the Building Research Levy, the Energy Efficiency and Conservation Authority, Trans Power New Zealand Ltd., and The WEL Energy Trust.

7. References

1. Bell, M., Lowe, R. J., and Roberts P. W., 1996 Energy Efficiency in Housing, Urban and Regional Planning and Development Series, Avebury, Aldershot, England.

2. BIA, 2000. *Approved Document for New Zealand Building Code Energy Efficiency Clause H1 Second Edition.* Building Industry Authority, Wellington.

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

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

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

6. Carrington, C. G., Sandle, W. J., Warrington, D. M., and Bradford R. A., 1984 *Demonstration of a Hot Water Heat Pump System* NZERDC Report 102, University of Auckland.

7. Carrington, C. G., Warrington, D. M., and Yak, Y. C., 1985 *Structure of Domestic Hot Water Consumption* International Journal of Energy Research Vol. 9, pp 65-75, 1985.

8. CAE, 1996. *Energy Efficiency: A Guide to Current and Emerging Technologies, Volume 1 Buildings and Transport,* Centre for Advanced Engineering, University of Canterbury.

9. EECA 2000. *Energy Efficiency Trends in New Zealand: A compendium of Energy End-Use Analysis and Statistics, 2000 edition.* Energy Efficiency and Conservation Authority, Wellington.

10. Energy Information Administration, 1995. *Household Energy Consumption and Expenditures 1993* US Department of Energy, Washington DC, USA.

11. Fitzgerald, G. and Ryan, G. 1996, *Factors in Appliance- Circuit Level Domestic Electricity Consumption: A Report on Research.* IRL Report, Christchurch.

12. Hendtlass, C. A., 1981 *Report on a survey into hot water usage patterns in residential dwellings* Joint Centre for Environmental Sciences ; Christchurch

13. Hiller, C. C., Lowenstein, A. I., and Merriam, R. L., 1992. *WHATSIM User's Manual, Version 1.0: EPRI Detailed Water Heating Simulation Model User's Manual.* TR- 101702. Palo Alto, Calif.: Electric Power Research Institute.

14. Koomey, J. G., Dunham, C., and Lutz, J. D., 1994. *The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the US: A Detailed End-use Treatment* Report LBL-35475 Lawrence Berkeley Laboratory, Berkeley, USA.

15. Lutz, J., Whitehead, C., Lekov, A., Winiarski, D., and Rosenquist, G., 1998 *WHAM: A Simplified Energy Consumption Equation for Water Heaters* Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings, pp 1.171-1.183, Pacific Grove, USA.

16. Lutzenhiser, L., 1992. *A Cultural Model of Household Energy Consumption,* Energy, vol. 17 (1), pp 47-60

17. Natural Resources Canada, 1994. *1993 Survey of Household Energy Use: National Results* Ottawa. Canada.

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

19. Paul, D. D., Whitacre, G. R., Crisafulli J. J., Fischer R. D., Rutz A. L., Murray J. G., and Holderbaum, G. S., 1993. *TANK Computer Program User's Manual with Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters.* GRI-*93101 86.*Columbus, Ohio: Battelle.

20. Pratt, R. G., Ross, B. A., and Sandusky, W. F., 1993. *Analysis of water heater standby energy consumption from ELCAP homes*, Energy and Buildings, 19 (1993), pp. 221-234.

21. Standards New Zealand, 1988 *NZS 4602: 1988 Low Pressure Copper Thermal Storage Electric Water Heaters,* Wellington.

22. Standards New Zealand, 1989 *NZS 4606.1:1989 Storage Water Heaters, General Requirements,* Wellington.

23. Standards New Zealand, 1996 *NZS 4305:1996 Energy Efficiency – Domestic Type Hot Water Systems,* Wellington.

24. Statistics New Zealand 1997, *1996 Census of Population and Dwellings: Housing*, Statistics New Zealand, Wellington.

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

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

27. Tustin, R., 1991. *Too Hot to Handle: An Examination of Strategies to Reduce Hot Water Injuries to Young Children* Wellington School of Medicine, University of Otago.