Space Heating in New Zealand Houses

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Abstract

The monitored space heating energy consumption in 398 houses in New Zealand is analysed to determine the effect of various drivers such as climate, house characteristics, occupant characteristics, and other factors. At best the statistical models could explain about 50% of the variation in space heating, with the remainder being of unknown cause or random noise. The heating temperatures, schedules and zones were important determinants of the space heating energy, however only a small amount of the variation in these variables could be explained with statistical models. It appears that households choose their heating temperatures, schedules, and zones by a process that was not captured in this study, and may reflect underlying attitudes or behavioural or cultural practices that defy rigorous analysis. The implications for future energy demand with the recent rapid uptake of heat pumps, and changing comfort expectations are discussed.

Keywords: Space heating, comfort, fuel poverty, energy efficiency, HEEP

1. Introduction

The Household Energy End-use Project (HEEP) is a nationwide study of energy use and temperatures in New Zealand houses. Monitoring began in 1999 and was completed for 398 houses in mid-2005, with each house monitored for about one year (Isaacs, Camilleri, French et al, 2010). This study used a random selection of all New Zealand houses and is statistically representative. The sampling design was for a random selection of houses from the major cities and towns with a population of more than ~50,000 (representing about half the population), then cluster samples of 9 or 10 houses in each of 19 smaller geographical areas (small towns, rural areas) chosen on a random basis to represent the rest of the country. This strategy was used as monitoring a random selection of households outside of the major cities and towns would have been too difficult and expensive.

This methodology was carefully designed and implemented to ensure that the sample was representative of the New Zealand population (Isaacs, Camilleri, French et al, 2010). Special care was taken in the household selection process to avoid bias caused by households choosing not to participate in the survey. Overall, 24% of households approached agreed to participate in the study.

All fuels were monitored (electricity, reticulated gas, LPG, solid fuel, oil and solar water heating). Major circuit loads (total electricity, hot water) were monitored in all houses. Other circuit loads (cooking range, lights, fixed gas and electric heaters etc) were monitored in 100 houses, as well as individual appliances (2-3 randomly selected appliances per house rotated on a monthly basis). All solid fuel burners, portable LPG heaters, solid fuel hot water connections and solar water heaters were monitored. Indoor temperatures were also measured (typically three per house). The installation included a detailed occupant survey, house plans and audit details, and inventory of all electrical appliances.

2. Review of models

In the UK a model of domestic space heating energy consumption has been developed (Shorrock and Utley, 2003). Survey data from the BREHOMES model (Shorrock, Henderson and Brown, 1991) and the English House Condition Survey (DETR, 2000) were used to estimate the indoor temperatures, heating schedules, and house thermal properties, which in turn supported the development of the BREHOMES thermal model to estimate space heating energy.

Total domestic energy consumption in the UK is modelled by BREDEM-12 (Anderson, Chapman, Cutland et al., 2002), including individual end-uses such as lighting, cooking, and appliances. Despite having a complex breakdown of end-uses, and models based on the occupancy, the actual formulas that relate energy use to occupancy and other factors are based on a combination of limited data from other sources or assumptions. For example the formula that relates hot water demand to the number of occupants is ($38 + 25 \times$ Number of Occupants) litres per day, and was based on an unpublished formula derived by British Gas.

The Energy Efficiency and Resource Assessment (EERA) Model is a stock based model of energy end-uses for New Zealand (Rossouw, 1997). It has recently been upgraded to take into account information from HEEP, with revised model algorithms that account for the effects of the number of occupants and household characteristic. These algorithms are based on actual monitored energy and temperature data, and surveyed occupant and house characteristics.

3. Data

Data on the occupants was collected using a questionnaire, which included socio-demographic characteristics, heating appliances and usage. A physical audit of the house was conducted, including a detailed house plan, with information on the physical structure, insulation, and windows. Information on space heating appliances was also collected, including the type and heat output. This information was used to develop thermal models in the ALF3 program (Stoecklein and Bassett, 1999).

HEEP temperature data was recorded using single channel battery powered temperature loggers: two in the main living area, and one in the main bedroom. Some houses also had extra temperature loggers for outdoor temperature, otherwise data from a nearby NZ Meteorological Service station was used (CliDB National Climate Database).

The HEEP space heating data consists of the monitored energy consumption of individual space heating appliances including solid fuel burners, LPG cabinet heaters, gas heating systems, and estimates of all other winter space heating derived from total electricity and gas consumption.

Solid fuel burners were monitored using thermocouples, and estimates of their heating output derived from a calibration process using the other monitored energy loads and temperatures and house ALF models to do a heat balance calculation. This process is described in Isaacs, Camilleri, French et al (2010) and has an estimated accuracy or ±20%. These estimates are of the heat released to the room, so do not depend on the efficiency of the solid fuel burner, which varies from ~10% for open fires to 60-70% for enclosed double burners.

LPG cabinet heaters were monitored using thermocouples to detect which panels were lit, and the rate of burn for each panel calibrated by measuring the rate of gas burnt. They are assumed to have an efficiency of 80%. Gas heaters was monitoring directly using gas meters, and the energy input calculated using gas pressure, elevation, and seasonal calorific values supplied by the distribution companies. They are assumed to have an efficiency of 80%.

The method for the estimation of the remaining annual space heating load is described in the HEEP final report (Isaacs, Camilleri, French et al, 2010). The basic process is to compare the summer electricity and gas energy use (excluding water heating and directly monitored heaters) with the winter energy use, with the difference assumed to be primarily space heating. This is known to slightly overestimate space heating, as some of the increase in winter is due to increases in lighting and cooking load, however most of this energy ends up as heat in the building, and most of it is used during times when the building is heated, and so makes a useful contribution to space heating.

4. Heating patterns in New Zealand

The heating patterns in New Zealand houses observed in HEEP were usually intermittent, localised, and often poorly controlled. Whole house, 24 hour heating was very uncommon (<5% of houses), with evening only heating in only the living area the most common heating pattern. Temperature control was also usually not good, as many heating systems (e.g. solid fuel burners) do not have thermostatic or timer controls, and with intermittent heating there is considerable warm up time. Typically, it takes some time for a room to be heated to the desired temperature, then the temperature may or may not be controlled well, then the temperature drops after the heater is turned off. With this type of heating behaviour the concept of a heating set-point is perhaps not appropriate. Instead, the *living room heating temperature* is used, which is defined as the average temperature measured in the living room during winter (Jun-Aug) during the evening (5-11 pm). This room and period was chosen to represent the temperature as approximately 90% of the HEEP households do heat this room during this period.

The New Zealand climate is mild compared to parts of North America and Europe. Average winter evening external air temperatures for the monitored HEEP houses ranged from 4.7°C to 12.5°C, with most of the major populated areas between 8°C and 11°C. The average living room heating temperature was 17.9°C, so the average difference from the outside temperatures is typically 6-9°C. Since this difference is fairly small the amount of heating energy required, and the number of months where heating is needed, are expected to be very sensitive to the living room heating temperature. ALF3 simulations typically show the heating energy doubling for each 2°C increase in heating set-point.

Since heating is often intermittent and localised it is difficult to describe the heating pattern of the whole house quantitatively. Two ways of doing this were used: 1) estimating the area of the house that was heated from the occupant questionnaire information and building floor plan; and 2) A 'Heating Index' synthesised from the occupant questionnaire information on heated zones (e.g. living, bedroom, utility) and heating schedules. Each heating schedule (evening only, morning and evening, all day, 24 hours) is given a weighting, based on the annual loss factors used in ALF3. For each zone and day the heating index multiplier is applied, then multiplied by the number of days of the week that schedule is used. These are then summed for all zones, and the sum of these for all zones gives the heating index. For example, heating living rooms only in the evening gives a Heating Index of 7 (a weight of 1 for 7 days for 1 zone), while heating all zones (living, bedroom, utility) 24 hours a day gives a Heating Index of 84 (a weight of 4 for 7 days for 3 zones).

5. Variations in space heating

The space heating analysed is the *net space heating*, defined as the net energy output to the room from heating appliances. Gross energy input (as measured by gas or electricity meters) is not used, as a lot of space heating is done by solid fuel burners (56% of total gross space heating energy (Isaacs, Camilleri, French et al, 2010)) which have widely ranging efficiencies. The efficiency factors used were 100% for electricity (most heating was resistive), 80% for LPG and reticulated gas, and for solid fuel the net space heating was the quantity measured so no efficiency assumptions were needed.

There are regional variations in net space heating, as shown in Table 1. However net space heating is roughly the same in Auckland, Wellington and Christchurch (the 3 largest cities) despite the large difference in heating degree days. There are major differences in the net space heating energy consumption for the most used heater type (Table 2) and different types of fuels (Table 3). Note that the energy reported is for all fuel types used in the house, not just the fuel of the most used heater. It can be seen that households with natural gas or solid fuel as the most used heater fuel have higher average space heating consumption than houses heated with electricity or portable LPG. This is not necessarily a causative relationship – households using gas or solid fuel may have made a choice to use that fuel to gain comfort, while the data shows that households in colder climates are more likely to have a solid fuel burner.

Table 1: Net space heating energy (all fuels) by climatic region

Region	*Gross Space Heating (kWh/yr)*	*SE*	*Net Space Heating (kWh/yr)*	*SE*	*Degree Days (15°C base)*
Auckland	*3,240*	*500*	*2,370*	*290*	*670*
Hamilton/Tauranga	*3,790*	*730*	*2,820*	*470*	*930*
Wellington	*2,920*	*500*	*2,390*	*420*	*1,120*
Dunedin/Invercargill	*6,200*	*930*	*5,020*	*740*	*1,730*
Warm Clusters[1]	*3,660*	*480*	*2,340*	*280*	*670*
Cool Clusters	*6,920*	*920*	*4,700*	*560*	*1,240*

Table 2. Total space heating energy by most used heater type

Most Used Heater Type	*Gross Space Heating (kWh/yr)*	*SE*	*Net Space Heating (kWh/yr)*	*SE*
Open Fire	*5,050*	*1,840*	*1,520*	*410*
LPG (portable cabinet)	*2,090*	*440*	*1,690*	*300*
Electric	*2,390*	*320*	*2,050*	*230*
Heat Pump	*2,610*	*2,390*	*2,590*	*2,400*
Fixed Electric	*4,100*	*890*	*3,870*	*860*
Gas	*5,450*	*1,180*	*3,870*	*640*
Enclosed Solid Fuel	*6,790*	*630*	*4,420*	*380*
Gas Central	*7,830*	*2,180*	*6,420*	*1,760*

[1] Climatically similar cities and towns have been combined into regions, and the clusters (small towns and rural areas) grouped based on Degree Days into ‘warm’ (≤620 15°C DD) and ‘cool’ (> 620 15°C DD).

Table 3. Net space heating energy (all fuels) by most used heater fuel

Most Used Heater Fuel	*Gross Space Heating (kWh/yr)*	*SE*	*Net Space Heating (kWh/yr)*	*SE*
LPG	*2,090*	*440*	*1,690*	*300*
Electricity	*2,640*	*300*	*2,330*	*250*
Natural Gas	*6,020*	*1,040*	*4,480*	*660*
Solid Fuel	*6,600*	*590*	*4,160*	*350*

5.1 Correlations with single factors

A range of graphs are used to show how the net space heating correlates with a range of single factors. The net space heating ranges widely, from zero or near zero (~5% of households), to nearly 25,000 kWh per year.

Net space heating tends to increase with the living room heating temperature (*Figure 1*, r^2=0.4) and to decrease with external temperature (*Figure 2*, r^2=-0.29), although the scatter is very large. Net space heating energy use tends to increase with the total floor area (Figure 3 , r^2=0.18) and the floor area that is heated (*Figure 4*, r^2=0.27). More space heating tends to be required for houses that heat more extensively, as described by the Heating Index (*Figure 5*, r^2=0.35). The thermal performance of the house also has an influence, with houses with higher total whole building heat losses requiring more heating (*Figure 6*, r^2=0.17).

The one common characteristic in all these figures is the large scatter – although the variables are correlated with the net space heating energy consumption, individually they do not explain much of the variation. Statistical models are used to further explore these influences.

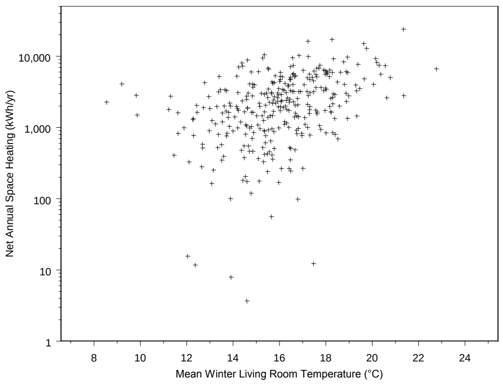

Figure 1. Net space heating by living room heating temperature.

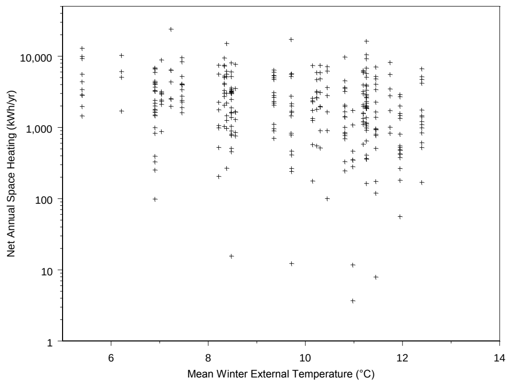

Figure 2. Net space heating by mean winter external temperature.

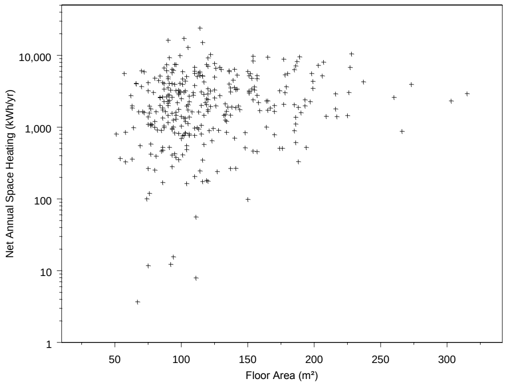

Figure 3. Net space heating by floor area.

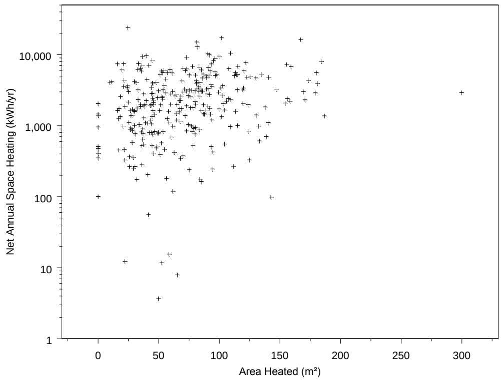

Figure 4. Net space heating by area heated.

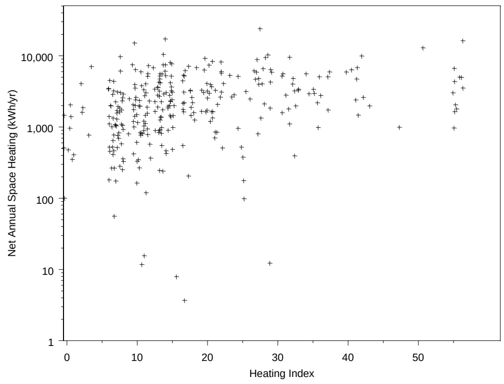

Figure 5. Net space heating by heating index.

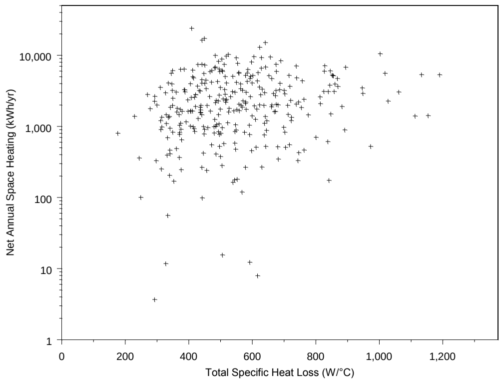

Figure 6. Net space heating by total heat loss.

6. Statistical models of space heating

Generalised linear models were used to explore how the various factors affect space heating energy consumption. This approach was chosen as there are several features of the data that make the use of simple linear models problematic. The residuals (the difference between the actual value and the model prediction) are larger for higher heating energy consumption and they are not normally distributed, and the sample variance increases with the energy consumption. These features fail to meet two of the major criteria for the application of a linear model, which are normally distributed sample measurements and constant variance. Generalised Linear Models (GLM) can deal with these problems[2].

GLMs work in the same general way as linear models, but the underlying statistical distributions are different. For example, a GLM can use a non-normal distribution for the sample measurements (e.g. a logarithmic or gamma distribution). They can also fit the data in a non-linear sense by using link functions such as logarithm, inverse or others. These features of the GLM allow the actual underlying

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[2] “An Introduction to Generalised Linear Models” – 2nd Edition, by A. J. Dobson, ISBN 1-58488-165-8.

structure of the data to be considered in the model and can resolve the previous problems noted with the residuals.

The particular choice of GLM is a matter of finding which type represents the structure of the data best, often by trial and error. The models used for this analysis use the gamma link function for the statistical distribution of errors, and a logarithmic function to link the predictor to the response. The logarithmic function causes the factors to be multiplicative, not additive as is usual with simple linear models. Overall these were found to best deal with the non-normal distribution of the residuals and the skewed distribution of the space heating energy consumption.

6.1 Net space heating models

After initial screening of independent variables it was found that normalising net space heating by the floor area (MJ/m^2) as the dependent variable gave better model representations than net space heating, as the variation introduced by differences in floor area was reduced. Normalisation using further variables (e.g. degree days) gave no further improvement.

There are some complex correlations and interactions between variables. For example, the type of heating system affects (or is affected by) the living room heating temperature, with higher capacity heaters associated with higher temperatures. The living room heating temperature is, in turn, related to the length of the heating season, as to maintain higher temperatures the heating system must be turned on earlier in the season and be used for longer.

There are a variety of occupant factors that could be expected to be related to space heating, such as the type of household. Rather than include them directly in the model as predictors of space heating energy consumption, they have been used to model the occupant-controlled parameters such as heating living room heating temperature, heating index, most used heater group, and heating season length.

6.1.1 Space heating energy model using physical factors

A base statistical model using only physical factors was developed (occupant factors are considered in separate models). The model was formulated as a generalized linear model with a Gamma family with logarithmic link function (Table 4). This model explained 50% of the variation in net space heating per unit floor area as a function of the variables Heating Index, Living Room Heating Temperature, Heating Degree Days (base 15°C), Heating Season Length, Heat Loss per m^2, and Most Used Heater Group[3].

It is important to understand that in New Zealand, space heating tends to be intermittent (often evening only) and usually only parts of whole houses are heated (often only the living room). In

[3] Most Used Heater Group is a factor variable indicating which type of heating appliance is used the most.

combination with the mild climate and short heating season in many areas, this may contribute to the large amount of unexplained variation. The space heating energy will be more sensitive to set-points and schedules than would be the case where a whole house is centrally heated in a cold climate (e.g. as would be the case in colder parts of North America and Europe).

This statistical model clearly shows the importance of the physical factors such as the heating temperature, house heat losses, and heating season.

Table 4. Summary of model terms for space heating energy model (Physical factors only)

Independent Variable	*Factor Category*	*Value*	*Std. Error*	*t-value*
(Intercept)		*-2.551*	*0.479*	*-5.322*
Heating Index		*0.012*	*0.005*	*2.476*
Mean Living room evening temperature		*0.147*	*0.022*	*6.653*
Degree Days (/1000)		*0.565*	*0.157*	*3.590*
Length of heating season		*0.152*	*0.033*	*4.535*
Loss per m²		*0.240*	*0.037*	*6.493*
Most Use Heater Group:	*Portable Electric*	*0.000*	*-*	*-*
	Enclosed Solid Fuel	*0.447*	*0.139*	*3.217*
	Fixed Electric	*0.570*	*0.243*	*2.349*
	Gas	*0.167*	*0.216*	*0.775*
	Gas Central	*1.071*	*0.370*	*2.899*
	Heat Pump	*-0.446*	*0.457*	*-0.978*
	LPG cabinet heater	*-0.113*	*0.163*	*-0.694*
	Open Solid Fuel	*0.139*	*0.265*	*0.523*

The ranked importance of the variables in terms of how much variation they explain was determined using single term deletions from the model. The living room heating temperature and total specific loss per m² are the two most important terms, explaining roughly 20% of the variation each. The length of the heating season, heater group, and degree days each explain less variation (5-9%), however the correlation between degree days and the heating season length reduce the importance of the degree days. The Heating Index explains only a small amount of variation (3%), however it is still worthwhile including.

The Most Used Heater Group variable is interesting. Its presence may in part be reflecting efficiency differences for some heating types. The use of net space heating does account for the conversion efficiency of gas and solid fuel burners, however it does not account for the distribution efficiency of central heating systems nor the co-efficient of performance (COP) of the heat pumps (although both these heating types are very uncommon in the HEEP sample, but heat pumps have since undergone a rapid uptake). For gas central heating, the factor of 1.071 corresponds to a multiplicative factor of 2.91, which could account for an efficiency of 34%. The calculated average overall efficiency of gas central heating systems monitored in HEEP was 36%, which is very low, and perhaps is due to poor installation or a lack of maintenance (Isaacs, Camilleri, French et al, 2010). For heat pumps the factor of -0.446 corresponds to a decrease in net space heating of ~35%, which would correspond to a COP of 1.6[4]. For portable electric, portable LPG, gas, and solid fuel heater types where the efficiency has been fully corrected for, the parameters are not significantly different from 0 (which corresponds to a multiplier of 1).

6.2 Living room heating temperature Model

A model of the living room heating temperature was created (Table 5). Variables included in the model were Heating Degree Days, loss per m², life stage, most used heater group, the household type, and the floor area. This model explains 27% of the variation in the living room heating temperature, which clearly leaves a lot of unexplained variation. There appear to be significant regional variations, which might reflect some underlying attitudes to space heating in particular areas, however no hypothesis has been found that can explain these differences. No association between equivalised income (Atkinson, Rainwater and Smeeding, 1995) and living room heating temperatures was found. There may be other underlying reasons why particular households choose to heat how they do, however this is not revealed by this analysis of the HEEP data and survey information.

The ranked importance of the variables in terms of how much variation they explain was determined using single term deletions from the model. The most used heater group explains the largest amount of variation, followed by the type of household. The other variables, although statistically significant in the model, each explain <2% of the variation.

The most used heater group explains the most variation and has a large effect giving differences in living room heating temperatures. For example, using an enclosed solid fuel burner as the most used heater is associated with living room heating temperatures 1.778°C higher than using portable electric heaters.

The household type was an important factor, with one person households were found to be associated with an average 1.9 °C lower living room heating temperature. This is of concern as many of these households are retired people living alone, and low temperatures have been shown to have negative outcomes for health, especially for vulnerable groups such as the very young, the elderly, and the infirm (Howden-Chapman, Matheson, Crane, Viggers et al, 2007).

The life stage variable shows that working age households have lower living room heating temperature than other households, possibly reflecting occupancy patterns. The living room heating temperature decreases with increasing heating degree days, by about 1 °C per 1,000 Degree Days (approximately the range of permanently inhabited locations). Larger floor areas were associated with slightly lower living room heating temperatures, at a rate of -0.5 °C per 100 m² of floor area. This is

[4] The heat pumps were monitored at various times over the period 2000 to 2005, and some were old units.

perhaps due to larger houses requiring larger heating systems, and might reflect some under-sizing in heating systems.

Living room heating temperatures are lower in houses with higher heat losses. In uninsulated houses these were about 0.8 °C lower than in houses insulated to the current Building Code requirements at the time of monitoring. This term explained the least variation in living room heating temperatures, which is curious as it might have expected that this would have been a major influence, given that a fully insulated house would have a total heat loss that is less than half that of an uninsulated house.

Table 5. Summary of model terms for living room heating temperature model

Independent Variable	*Factor Category*	*Value*	*Std.Error*	*t-value*	*Pr(>|t|)*
(Intercept)		*20.539*	*0.869*	*23.635*	*0.000*
Degree Days (/1000)		*-0.900*	*0.300*	*-2.633*	*0.009*
Loss per m²		*-0.195*	*0.099*	*-1.967*	*0.050*
Life Stage	*pre-school age (0-5 years)*	*0.000*	-	-	-
	school age (5-14 years)	*-0.440*	*0.409*	*-1.077*	*0.282*
	working age (15-64 years)	*-0.633*	*0.373*	*-1.696*	*0.091*
	retired (65+ years)	*0.389*	*0.452*	*0.861*	*0.390*
Most Use Heater Group	*Portable Electric*	*0.000*	-	-	-
	Enclosed Solid Fuel	*1.778*	*0.312*	*5.704*	*0.000*
	Fixed Electric	*0.691*	*0.575*	*1.202*	*0.230*
	Gas	*1.112*	*0.475*	*2.341*	*0.020*
	Gas Central	*1.022*	*0.917*	*1.114*	*0.266*
	Heat Pump	*0.697*	*1.108*	*0.629*	*0.530*
	LPG cabinet heater	*0.054*	*0.384*	*0.142*	*0.887*
	Open Solid Fuel	*-1.141*	*0.699*	*-1.633*	*0.103*
	Solid/Liquid Fuel Central	*1.011*	*2.176*	*0.465*	*0.643*
Household Type:	*one family*	*0.000*	-	-	-
	one family with others	*-0.968*	*0.483*	*-2.004*	*0.046*
	more than one family/household	*-1.965*	*1.289*	*-1.525*	*0.128*
	non family (e.g. flatmates)	*-1.327*	*0.717*	*-1.851*	*0.065*
	one person household	*-1.854*	*0.386*	*-4.802*	*0.000*
Floor Area		*-0.008*	*0.003*	*-2.494*	*0.013*

6.3 Discussion

The two models are used in sequence with the living room heating temperature model as input to the net space heating model, and together starts to reveal the underlying behavioural and physical influences. The living room heating temperature is the most important behavioural factor, and the envelope loss per square metre of floor area the most important physical factor. The living room heating temperature, although a behavioural choice, is affected by both behavioural and physical factors, the two most important of these being the type of household and the type of heating system.

So why does a particular house with a particular set of occupants choose a particular heating system? In many cases the type of heating system is determined by what heating system already exists. With about 25-30% of households in New Zealand renting, these people have little or no influence on the type of heating system (Statistics New Zealand, 2006). New Zealand houses also have a high turnover rate, with the average occupation time for owner-occupied dwellings at about 7 years, and shorter for rented dwellings. This means that a lot of households inherit their heating system (or lack of one) from the previous or even original occupants. There are major differences in the type of heating systems used around New Zealand, with solid fuel burners being more common in the colder climates and outside the major cities. This perhaps reflects both the greater need for heating and high heat output in colder climates, and the availability of cheap firewood (often self-harvested or collected) outside the main cities, along with other factors such as the lack of gas supply, high electricity cost, and the frequency of weather related power cuts in isolated rural areas. A level of security can be offered by a solid fuel burner which can supply heat, hot water if connected, and sometimes even cooking.

Although the heat loss per square metre of floor area is a physical characteristic of the house and is affected by the house age, the association of a household with a particular type of house is affected to some degree by the occupant behaviour and characteristics. In New Zealand, post-1978 houses were required to be insulated to comply with the building code and have lower heat losses than earlier houses. Post-1978 houses are more likely to be occupied by households with above average incomes, and this is one example of how a behavioural or occupant factor can influence a physical factor that might at first appear to be independent of the occupants.

Heating patterns and behaviour have been changing rapidly since the HEEP study was conducted. The biggest chance has been a rapid uptake of heat pumps (reverse cycle air conditioners) in response to clean air campaigns (the phasing out of open fires and polluting wood burners) but also in response to consumer demand for more efficient and effective heating. In the HEEP study, only 4% of households had heat pumps – by 2008 this had grown to 19% (French, 2008), and is still growing rapidly. French (2008) found that when people got heat pumps they tended to heat to higher temperatures, for longer periods, over a larger area of the house. Although heat pumps are very efficient heaters, these changes in behaviour are expected to take up most or all of the potential energy savings. Also, since many of the heat pumps are replacing solid fuel burners or gas heaters, this will place additional demand on the electricity network at peak winter times, when fossil fuel generation is at its peak. Research is underway to study the recent changes in heating patterns and the effect on the electricity network.

7. Conclusions

The relationship between space heating energy consumption and the climate, house, and occupants has been shown to be complex. About half of the variation in space heating energy consumption per m² of floor area can be explained by physical factors such as climate (heating degree days), heating zone, schedules and set-point, heating season, type of heating system, and house envelope thermal losses. This is a very successful result given that the amount and extent of space heating in New Zealand houses is highly variable compared to cold climates in North America and Europe climates where 24 hour, whole house heating is common. However trying to explain why a particular household chooses to heat their house the way they do is not nearly as successful. Living room heating temperature models were poor, explaining at most 26% of the variation. It appears plausible that there are underlying attitudes or behaviours that may not be related to socio-demographic factors that determine space heating behaviour. Attitudes to comfort, energy conservation, expenditure, and health may be important influences on occupant behaviour, and the recent rapid uptake of heat pumps shows how quickly these attitudes can change.

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