# AN ANALYSIS OF LIFESTYLE EFFECTS ON RESIDENTIAL ENERGY USE

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## ABSTRACT

A large data set was analysed to identify the effect of lifestyle trends or relationships on residential energy consumption. Seven utilities collected data from about 30 homes in each of 7 locations. For all of these homes, energy consumption data, including submetered space conditioning and water heating energy use, were recorded on a 15 minute basis. Some of the utilities also measured indoor temperature. The utilities collected an assortment of survey information such as family size, house size, and house type.

Results from an examination of data from the Hood River Conservation Project are also included. This data represents 320 homes where submetered energy use and indoor temperature data is also available on a 15 minute basis. The extensive surveys included in this project have enabled us to address a large number of lifestyle effects. However, because this analysis is still in progress, the results presented here are preliminary and far from complete.

Indoor temperature and heating and air conditioning energy use were examined with respect to outdoor temperature, heating system type, family size, house size, and house type. Hot water energy use was similarly examined.

Several trends associated with these variables were identified: homes with central thermostats are more likely to use nighttime temperature setback during the winter than those with individual room controllers; outdoor temperature affects thermostat management during the winter; and hot water use varies seasonally with the variation being most noticeable during the fall months.

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*Operated by Martin Marietta Energy Systems, Inc. under Contract DE-AC05-84OR21400 with the U.S. Department of Energy.

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## INTRODUCTION

Data sets useful in residential conservation research are available with varying degrees of information. One such data set was generated as the result of a thermal energy storage (TES) test funded jointly by the Department of Energy (DOE) and seven utilities: Arkansas Power and Light (APL), Long Island Lighting (LILCO), Pacific Gas and Electric (PG&E), Wisconsin Electric Power (WEPCO), Public Service Electric and Gas (PSE&G), United Power Association (UPA), and Virginia Electric and Power (VEPCO). This test included both storage and control homes at each utility. The storage homes were equipped with modified heating and cooling systems for load control research. The control homes were equipped with conventional heating and cooling equipment and were monitored to permit comparison with the storage homes.

The research presented in this paper is based on the conventionally heated and cooled control homes. There were about 30 control homes at each utility, each monitored to provide total as well as space heat or air conditioning energy use. Some utilities also measured water heater load and indoor temperature. Several utilities collected limited lifestyle information such as family size, house size, and house type. One of the utilities compared room heating units with central heating units.

Our analysis of this data examined indoor temperature, water heating use, and heating and air conditioning use as related to outdoor temperature, heating system type, family size, house size, and house type. The average energy use or temperature of homes with common attributes were plotted against time-of-day or outdoor temperature to portray the differences, or lack of differences, between such groups of homes. The results show some interesting variations that are not always statistically measurable using other techniques, such as multiple regression (Ref. 1).

Another data set useful for lifestyle examination is currently being created as part of the Hood River Conservation Project (HRCP), funded by the Bonneville Power Administration, Pacific Power and Light, and other participants. One part of this project includes monitoring approximately 320 homes in Hood River, Oregon on a 15 minute basis over a 2-year period. The data collected

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includes electric space-heating use, indoor temperature, total electrical use, and either water heater use or wood stove heat output. Extensive survey information is also available for these 320 homes. The analysis of this data is currently underway and preliminary results have been included in this paper where possible.

## ANALYSIS METHODS

### *Regression Analysis*

Data from the load storage tests were available at Oak Ridge National Laboratory as a result of an analysis of the load management data funded by the Electric Power Research Institute (Ref. 2). We performed statistical regression analysis of these data sets to examine the influence of the known lifestyle variables. The regression analysis eliminated time-of-day variations by using daily totals or averages for energy use or indoor temperature and correlating these values with lifestyle variables such as house size, number of occupants, and house type. We also tried hourly regression models but the results were poorer than those based on daily values, reflecting the wide fluctuations in hourly use from one day to the next in any individual home.

The regression results tend to be inconclusive for this analysis for several reasons. First, these lifestyle variables, while important, are not the dominant determinants of household energy use. Obviously, it is not possible to predict the heating energy use of a home based on the number of occupants without consideration of house construction (such as building materials, number of windows, degree of leakiness, etc.) and outdoor weather variables that vary from day to day within the analysis period. Second, though quite large, the overall data set represents several different groups of only about 30 homes in each location. When these groups of 30 are further subdivided according to family size or house type, the sample size shrinks to about 10 for each size or type category. For the same reason, subgroups based on two variables, such as house size and family size, were not made because the resulting subsets would nave represented only three or four homes. Both of these reasons lead to very small correlation coefficients, indicating that energy use cannot be calculated without the consideration of many contributing factors.

Spectral analysis was also used to examine the lifestyle effects on customer load profiles. Spectral analysis converts the load profile (a time series) into a series of sine and cosine terms (a Fourier series). This Fourier series is then used to identify the underlying frequencies of the load and the contributions of these frequencies to the total load profile. For example, a spectral analysis of total house load for a group of houses shows lifestyle patterns with fundamental frequencies of 24 h (daily activities), 12 h (morning and evening activity periods), 4 to 6 h (cooking and cleanup), and a host of other frequencies, depending on the electricity-consuming activities engaged in at the group of houses.

This technique was used in a limited way to look at the load management data and seemed to be able to discern between weather-driven and lifestyle-driven space heating loads. Fig. 1 shows the spectral density plot for a 2-member household with baseboard heating. This plot is clearly dominated by a 24-h cycle driven by daily weather patterns. Another, but much smaller 12-h cycle shows that the morning and evening activity periods have a lesser effect on heating loads in this house. In contrast, Fig. 2 shows a spectral density plot for a 6-member household where the 12-h activity periods dominate, the secondary peak reflects a 6-h cooking cycle, and the weather-related peak at 24 h is very small.

The spectral analysis technique was applied to each individual customer in the HRCP data set in an attempt to group together customers with similar energy use patterns. This analysis covered each customers total energy use time series during the month of November, 1984. Customers were assigned to groups based on their two highest spectral density peaks. The largest group of customers, almost 200, was dominated by 12 and 24 hour cycles. A second group of about 50 customers was distinguished by the dominance of cycles longer than 24 hours. The last group of about 40 members showed a tendency toward shorter cycles of 6 hours or less. The average (over the month of November) space heat and total energy use profiles were then calculated for each group. These profiles, shown in Figs. 3 & 4, reflect the trends identified by the spectral analysis. Group 1's curve is a relatively smooth, double humped curve showing the early morning heating load and the morning and evening activity periods. Group 2's curve is noticeably flatter than the others, with shallower troughs and smaller peaks. The last group's curve is exceptionally peaky and rough. Load curves that average at least 30 randomly chosen homes are generally much smoother than this curve. Because this curve represents the average of about 40 homes over a month's time, the roughness must actually reflect the fluctuating nature of these customers' energy use.

Regression analyses (using 4 periods: week days, week nights, weekend days, and weekend nights) on these groups of customers have so far produced results less satisfactory than the regression analyses for the total group of customers, where regression coefficients as high as .97 have been achieved. This could mean that these groups are not as similar as we hoped, or it could mean that the regression models tried to date have excluded some pertinent variable(s).

The lifestyle effect conclusions in this paper are therefore based on graphical display and visual examination of energy use trends within groups chosen to represent similar lifestyle characteristics identified from survey data. Each figure from the load-management data analysis represents an entire season's data unless the curve is expressly labeled otherwise (some curves represent specific months). For example, a curve that plots energy use against time of day represents the mean energy use for that time of day over the entire heating or cooling season. These curves should be interpreted as indicative of trends because each curve represents the mean of a data subset and there is undoubtedly some overlap among the data subsets.

Analysis of pre-retrofit energy use data (1984-85 winter) from the HRCP has allowed us to compare 1) wood heat users and electric heat users, 2) homes with and without portable space heaters, and 3) single family homes vs multiple family homes. This analysis is on-going and the results presented here should be regarded as preliminary.

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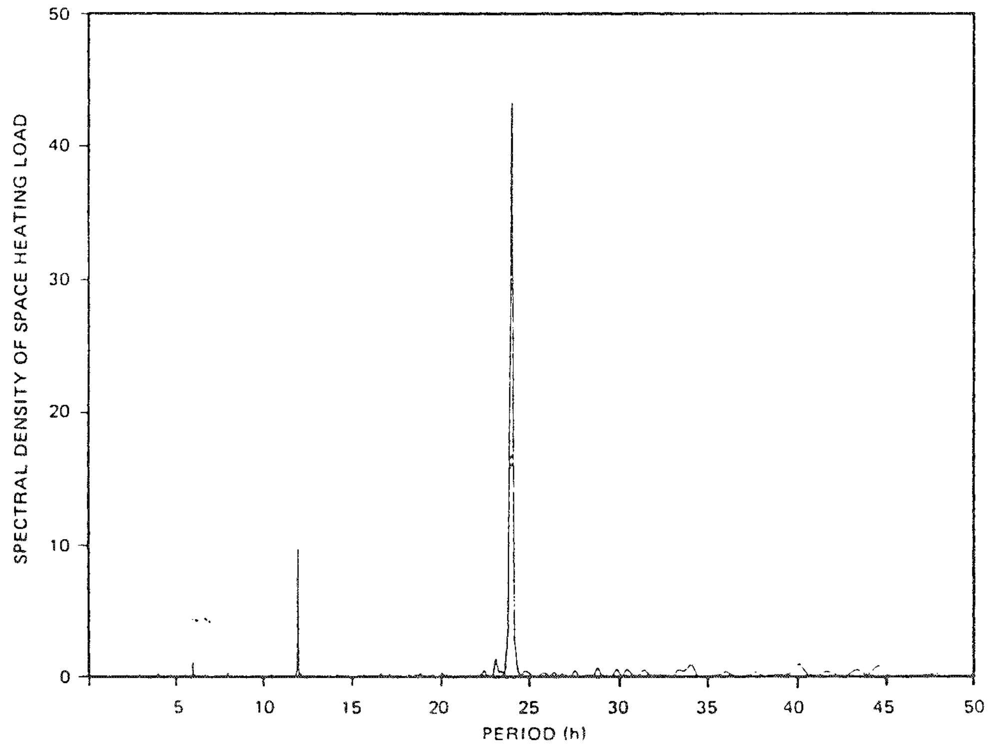


FIGURE 1. UPA HOUSE 24 SPACE HEATING LOAD

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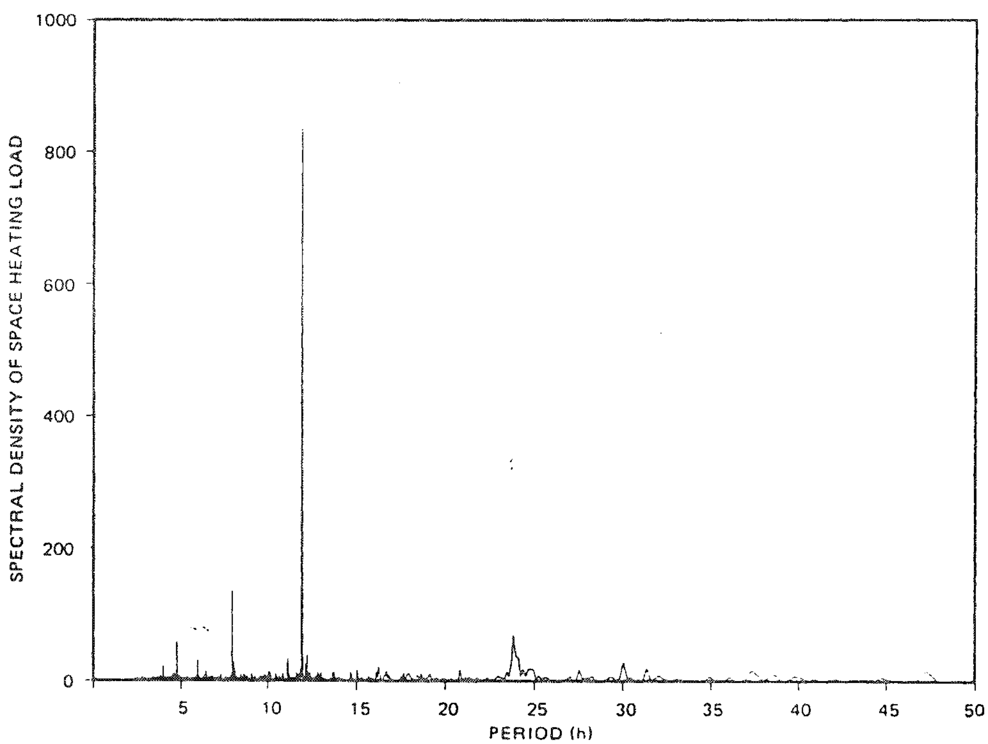


FIGURE 2. UPA HOUSE 26 SPACE HEATING LOAD

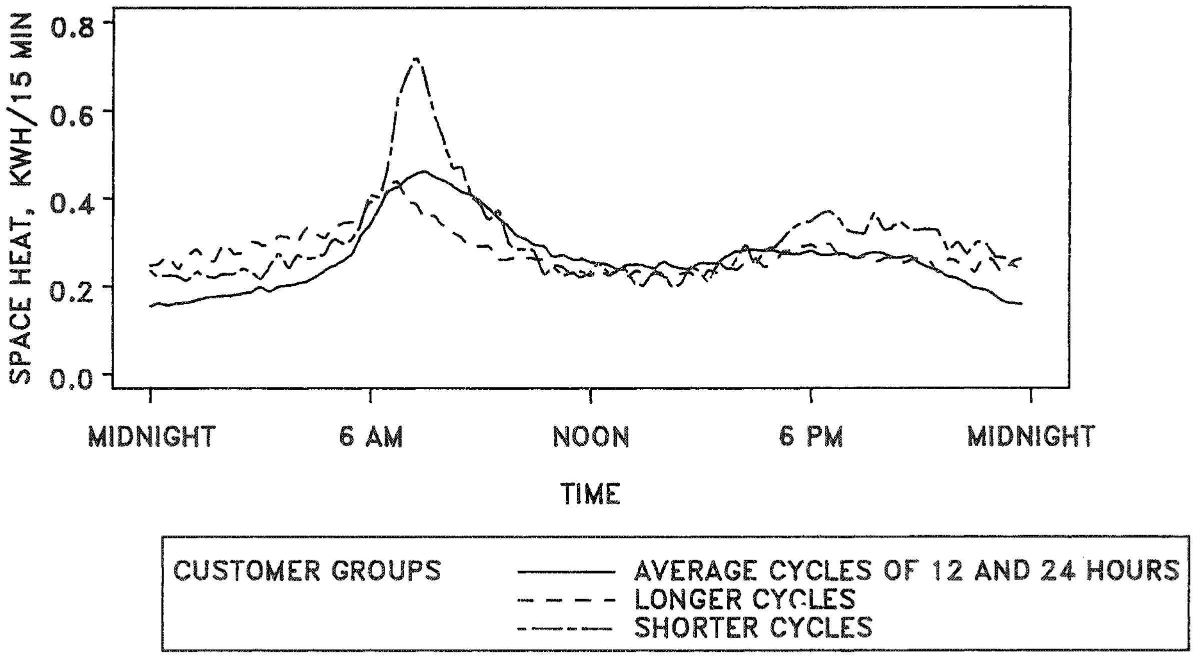


FIGURE 3. HOOD RIVER NOVEMBER 1984 SPACE HEAT ENERGY USE
CUSTOMERS CLUSTERED USING SPECTRAL ANALYSIS

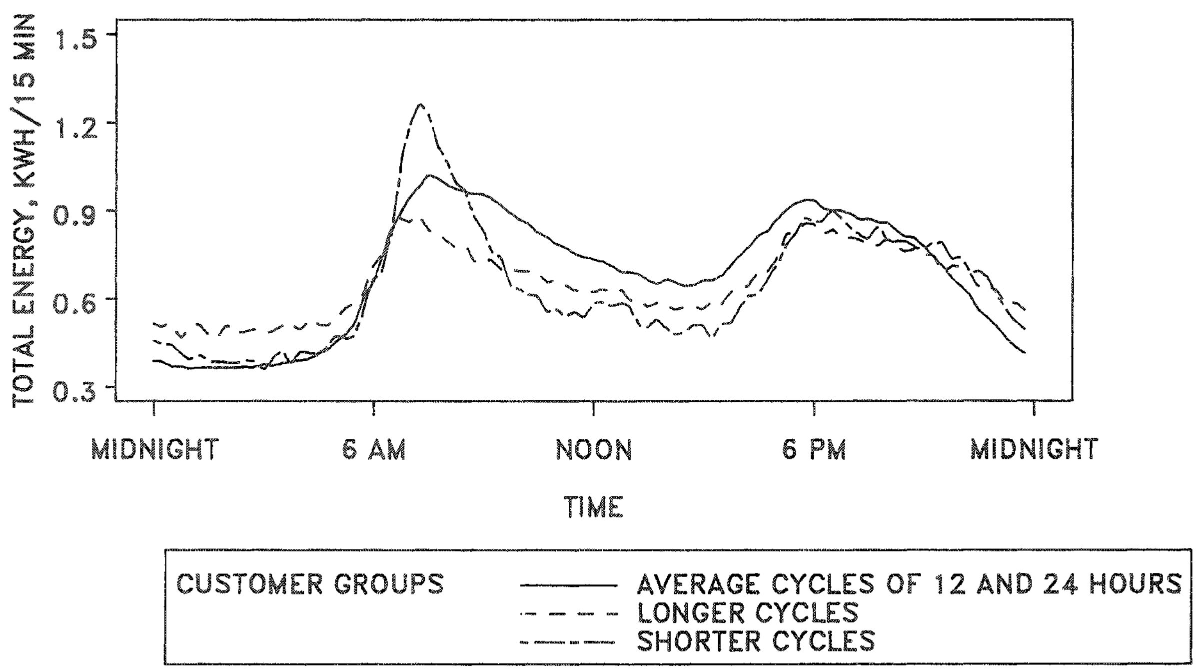


FIGURE 4. HOOD RIVER NOVEMBER 1984 TOTAL ENERGY USE
CUSTOMERS CLUSTERED USING SPECTRAL ANALYSIS

## RESULTS

### *Heating Season*

*Comparison of Room and Central Heating Systems.* A test of heating systems at UPA compared 10 centrally heated homes with 10 homes equipped with room heaters in the cold Minnesota climate. The average load profiles for these two groups are shown in Fig. 5. The load profile for homeowners with central systems shows a clear morning heating peak and a midday valley, while that for the homeowners with room heaters is relatively flat. One possible cause for this difference could be an inclination to practice daytime and nighttime setback among those homeowners with central controls. Such setback practices among homeowners with room heaters would be more difficult because a numbered dial would have to be adjusted in each room.

Portable heater use in Hood River, Oregon is shown to differ significantly from room heater use (see Fig. 6). The average total energy use in homes with only one portable heater (64 homes) is only slightly greater and not noticeably different in shape from homes without any such heaters (231 homes). However, homes with two or more portable heaters (19 homes) apparently use them to displace their central heating systems and conserve energy by turning them off, or very low, at nighttime. The indoor temperature profiles in Fig. 6 show this trend more clearly. (The distribution of portable heaters is similar for wood- and electrically-heated homes).

*Comparison of Wood and Electric Heat Users.* The average electrical space heating energy use for 121 customers in HRCP who claim that their main heating fuel is wood is predictably less than the average space heating energy use of 193 customers whose main heating fuel is electricity (see Fig. 7). The shapes of the space heating use curves are also very different with 2 distinct peaks and troughs on the electric heat curve and a rather flat 1-peak profile for the wood heat curve.

However, the total energy use profile of the wood heat user's group in Fig. 8 is very similar, although smaller in magnitude, to that of the electrically heated homes. This would seem to indicate that non-space heating energy uses are equally important in determining hourly load variations. The comparison of these two figures seems to indicate that non-space heating uses are very important in determining the early evening peak level. Also note that wood heat users tend to supplement their wood heat with electrical space heat more in the morning hours than at any other time during the day.

*Indoor Temperature Management.* PSE&G's (located in New Jersey) indoor temperature data in Fig. 9 represent a 30-home winter average and show a pronounced shift in acceptable indoor temperature as the outdoor temperature gets colder. (Because thermostat set points are not directly available, they must be inferred from the measured indoor temperature of the house.) Both the degree to which night setback is practiced (as shown by the greater variation in day and night temperatures) and the daytime thermostat set point (as indicated by the flat part of the curve) are altered in response to the weather. This trend shows that colder temperatures are more acceptable with colder weather. The small change between the 17°F and the 4°F curves shows

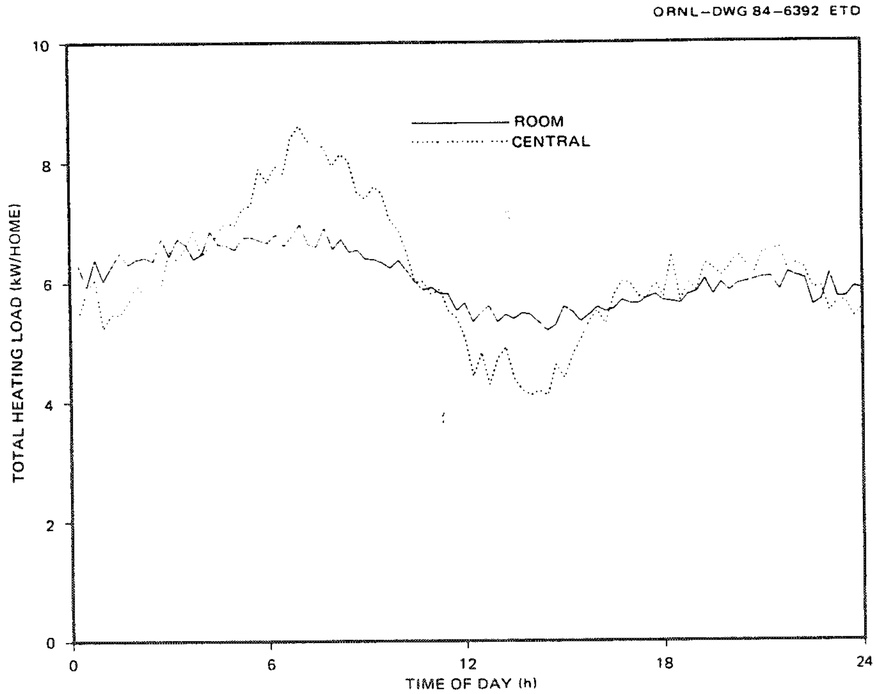


FIGURE 5. UPA HEATING LOAD PROFILE

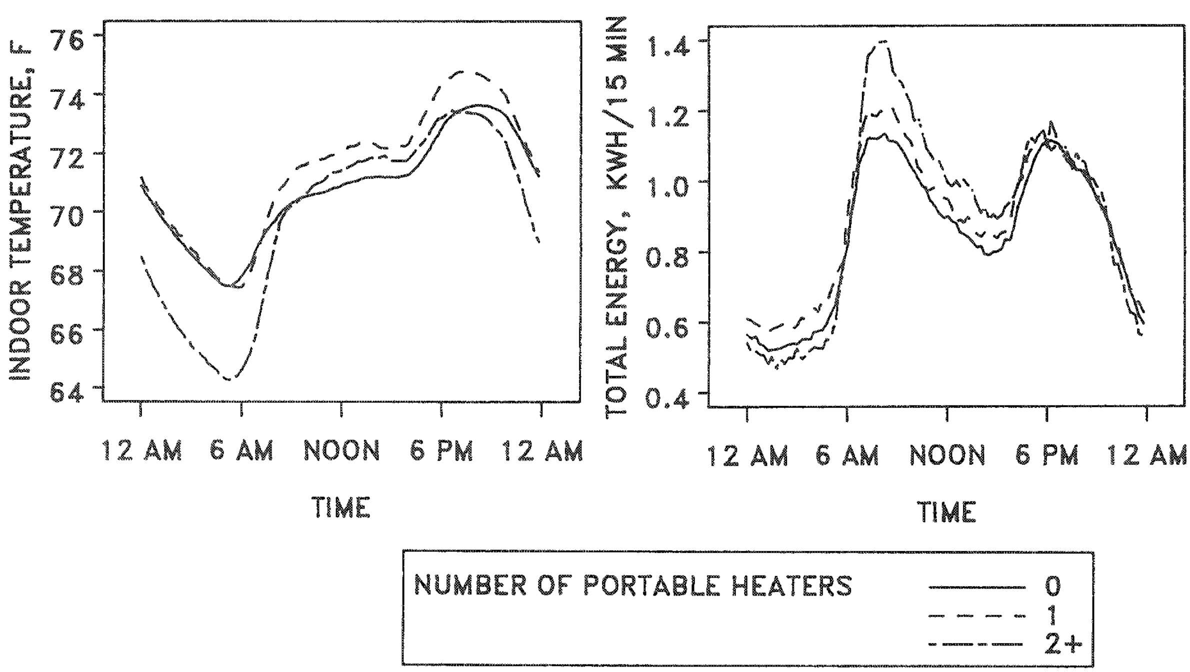


FIGURE 6. HOOD RIVER DECEMBER 1984 TOTAL ENERGY USE AND INDOOR TEMPERATURES, EFFECT OF PORTABLE HEATERS

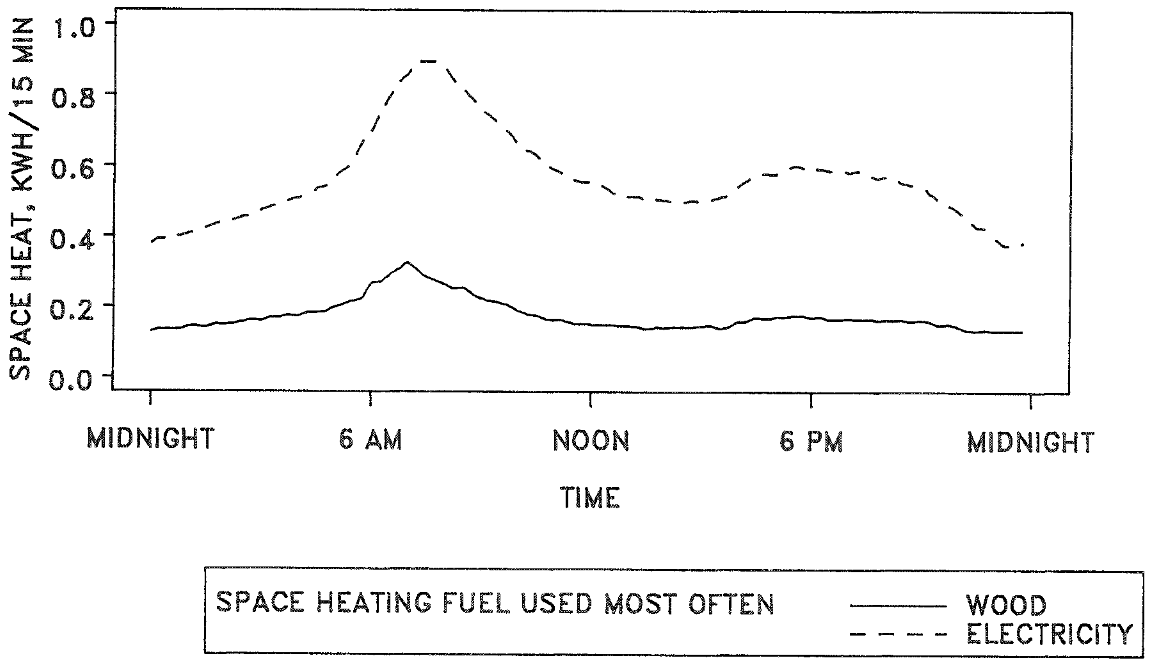


FIGURE 7. HOOD RIVER SPACE HEATING ENERGY FOR WOOD- AND ELECTRICALLY-HEATED HOMES, JANUARY AND FEBRUARY 1985

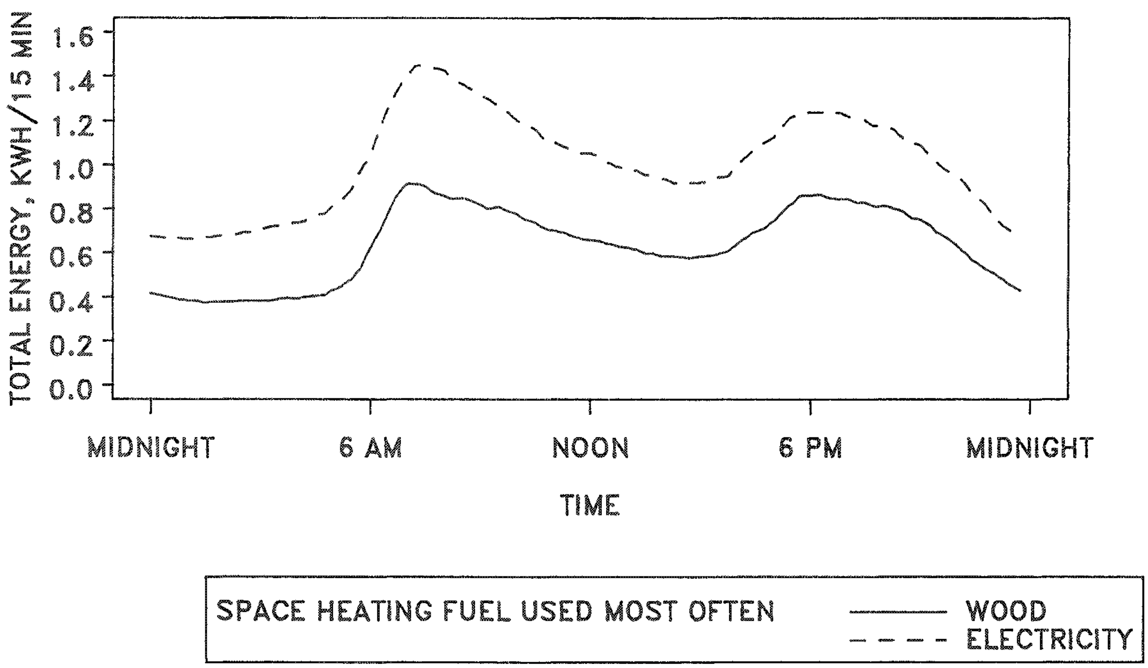


FIGURE 8. HOOD RIVER TOTAL ENERGY FOR WOOD- AND ELECTRICALLY-HEATED HOMES, JANUARY AND FEBRUARY 1985

that there is a limit to this trend and that occupants are unwilling to lower their thermostats beyond a certain point. This small change also shows that the furnaces were not operating at maximum capacity at 17°F or there would have been a much larger drop in indoor temperature when the outdoor temperature decreased to 4°F.

This thermostat control behavior may be attributable to conservation motives; that is, the customer may deliberately turn down the thermostat to save energy and money during colder weather. It might also be due in part to an acclimatization effect; that is, the colder weather may occur later in the winter when the occupants have become accustomed to the colder temperatures and perhaps adjusted their clothing habits.

The HRCP data set was examined to see if this behavior was also exhibited by a larger sample in a different climate. The HRCP indoor temperature data from September, 1984 through March, 1985 is shown in Fig. 10 for 6 temperature bins. Although this data does show the trend to colder indoor temperatures as the outdoor temperature decreases, it does not reflect the increased degree of setback or the compression at extreme cold temperatures (likely because the Hood River weather was relatively mild with only a few days of average outdoor temperatures below 20°F).

To test whether this is an acclimatization effect and to examine the impact of wood heat users (almost 40% of the HRCP users report that wood heat is used more than electric heat), the indoor temperature was averaged for each month for both wood and electric heat users. The results are shown in Figs. 11 and 12. The September profiles in both groups are about the same, indicating that little heating was required. The profiles from October through March, however, are very different. The electrically-heated homes show a nighttime temperature drop with each successive month, but the daytime temperature behavior seems to be relatively constant from November through March. This could indicate that nighttime setback is practiced by more electrically-heated customers as the winter progresses. The wood-heated homes, on the other hand, were kept warmer than electrically-heated homes and show a wider variability in temperature control during the winter. The nighttime temperatures in these homes are relatively constant from December through February and are at their warmest in November when they first begin to use their wood stoves. March appears to be their coldest month. So again, an acclimatization on the part of the residents may occur, or perhaps they just get tired of fooling with the wood stove but still avoid turning on their electric heat.

Other researchers have reported that homeowners raise their thermostat set points as outdoor temperatures decrease, leading to speculation that temperature measurement characteristics may be influencing the results (Ref. 3).

*Water Heating*

The use of hot water, examined in the load management data, was found to vary by time of day, day of the week, and season. Smaller variations were noted due to number of occupants and outdoor temperature.

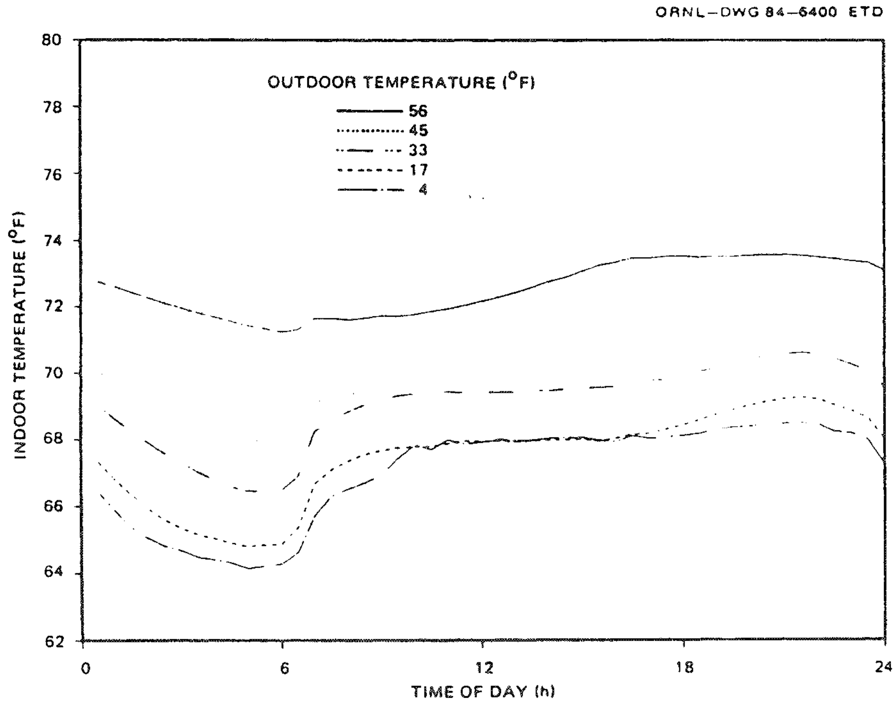


FIGURE 9. PSE&G INDOOR TEMPERATURE FOR OUTDOOR TEMPERATURE BINS

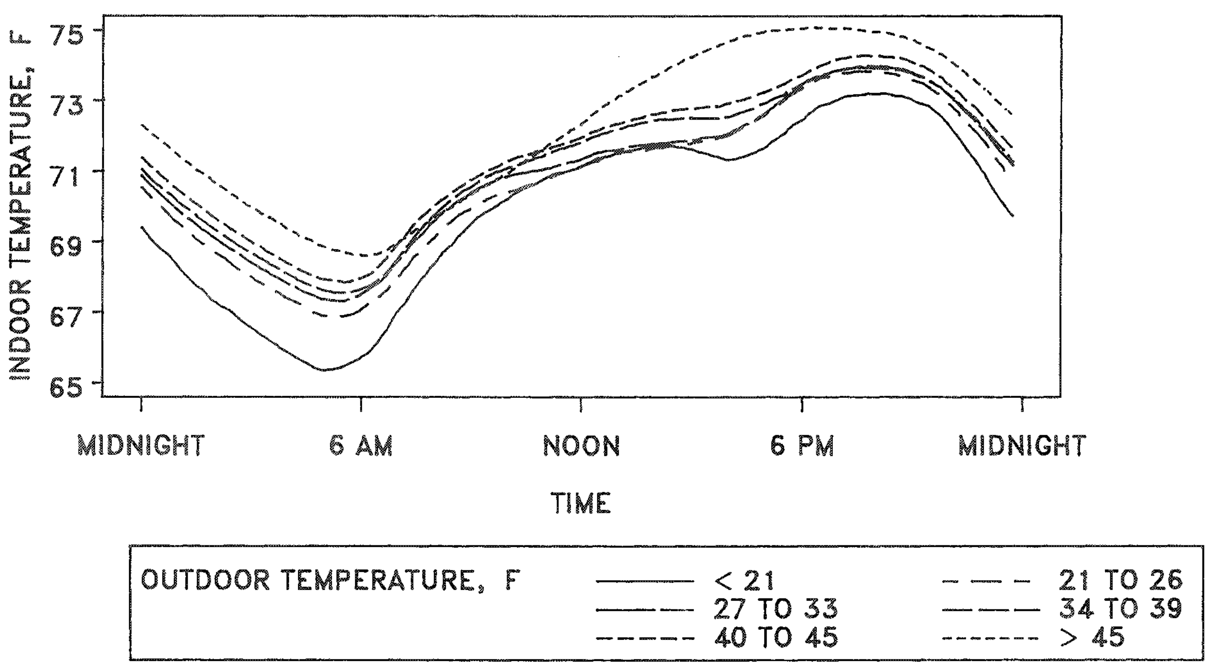


FIGURE 10. HOOD RIVER INDOOR TEMPERATURES , WINTER 1985, GROUPED ACCORDING TO AVERAGE OUTSIDE DAILY TEMPERATURE

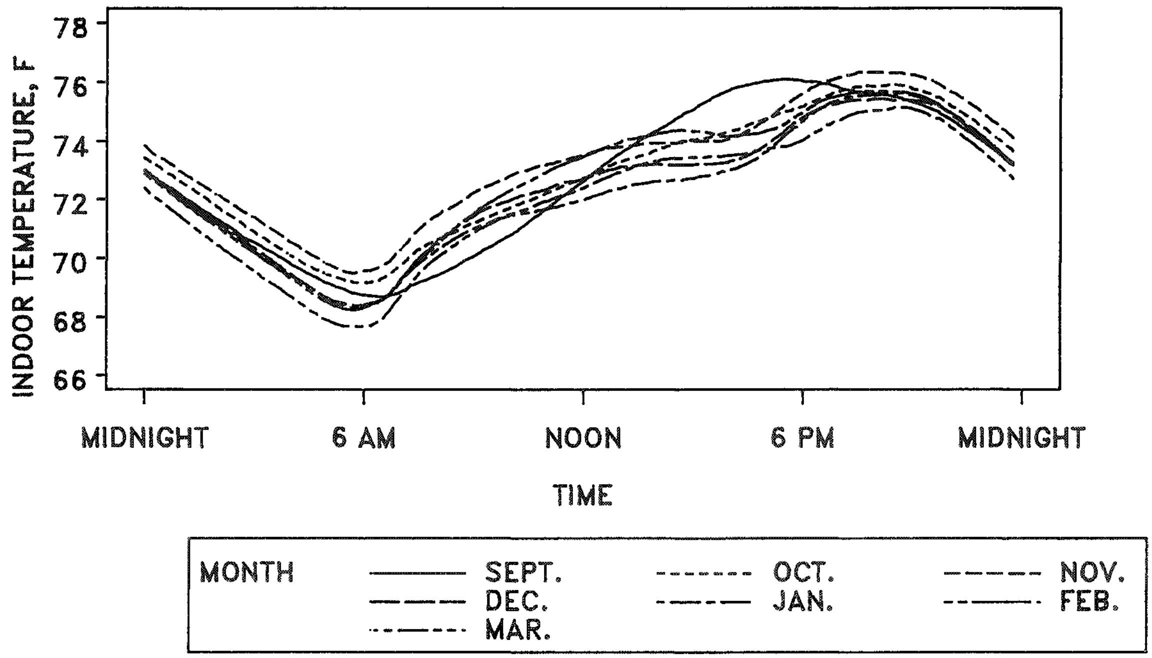


FIGURE 11. HOOD RIVER INDOOR TEMPERATURES FOR ELECTRICALLY HEATED HOMES, SEPTEMBER 1985 TO MARCH 1985

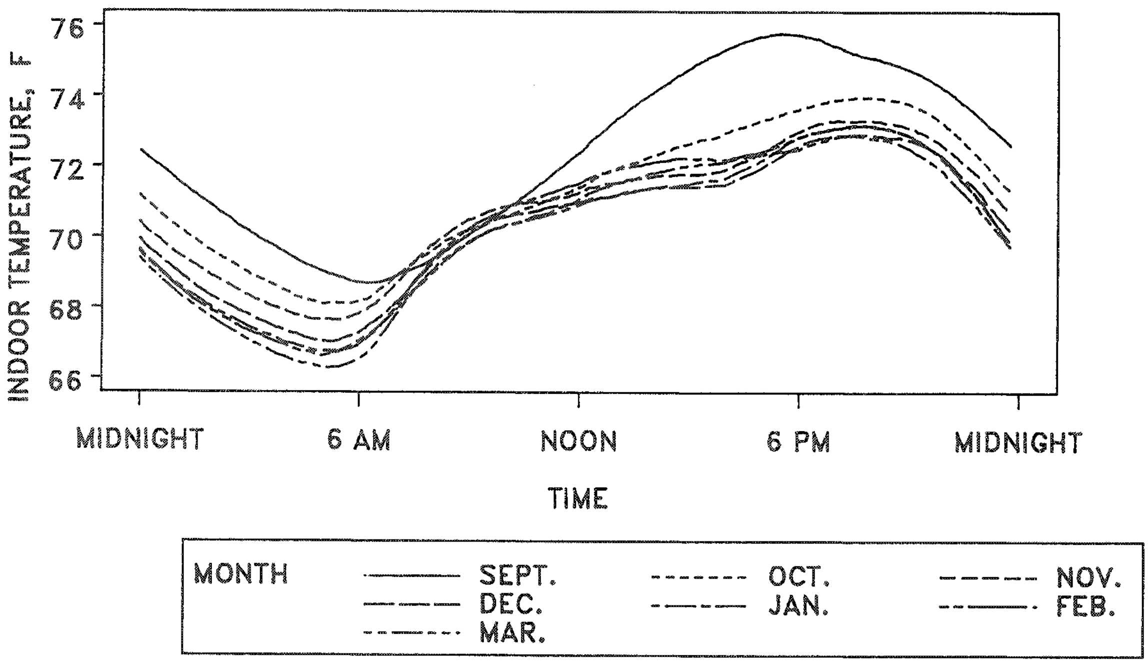


FIGURE 12. HOOD RIVER INDOOR TEMPERATURES FOR WOOD HEATED HOMES, SEPTEMBER 1985 TO MARCH 1985

Hot water use and energy use were also found to vary seasonally. At PSE&G, during the months of October-December, both the amount of hot water and the energy used to heat it increased. This behavior was also found at UPA and VEPCO. The extent to which changes in supply water temperature contribute to higher water heater load in the winter is unknown. However, the water use characteristics shown in Fig. 13 indicate that customer habits also play a major role. Perhaps lower groundwater temperatures cause customers to increase the proportion of hot water in any hot/cold water mixtu[illegible] as showers) to obtain the same mixed water temperature.

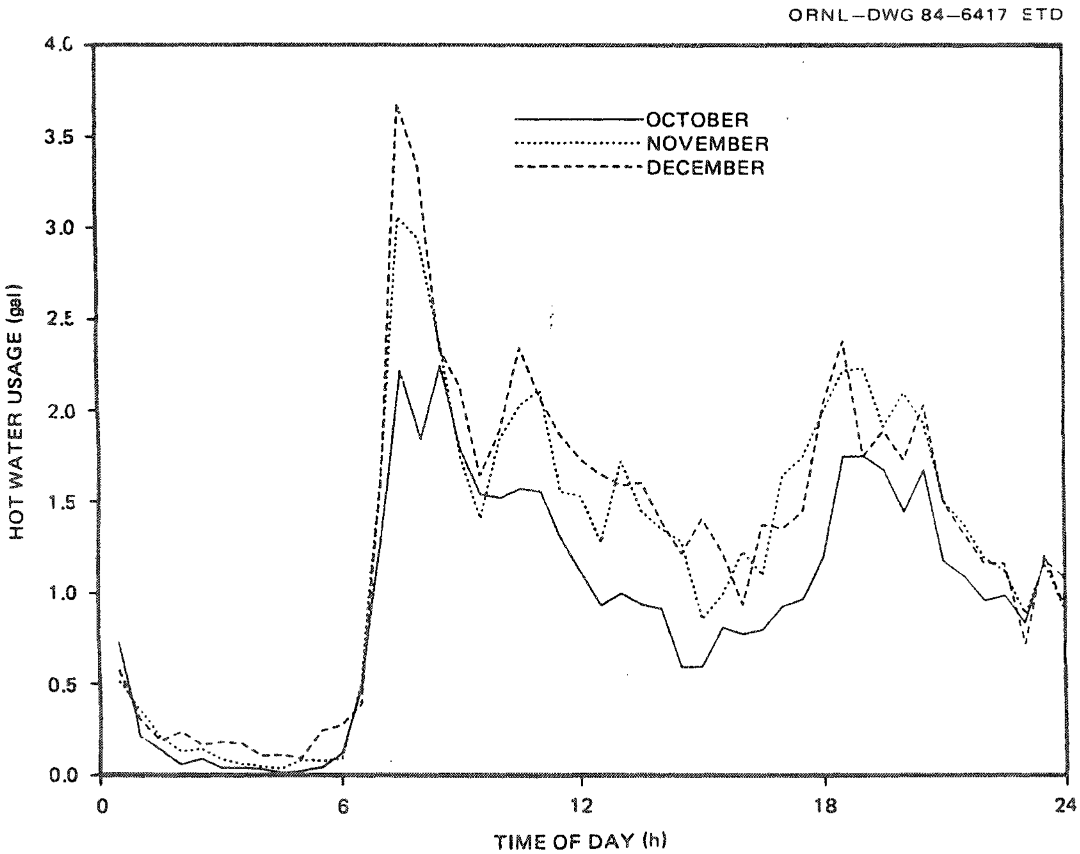


FIGURE 13. PSE&G CONTROL HOME HOT WATER USE: OCTOBER, NOVEMBER, AND DECEMBER

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3. W. Kempton, Letter to T. K. Stovall. January 29, 1986.