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Assessment of Princeton Scorekeeping Method Space-Heating Estimates Using End-Use Data from the Hood River Conservation Project

Ho-Ling Hwang

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ABSTRACT

The Princeton Scorekeeping Method (PRISM) has been widely used in energy conservation studies. PRISM produces weather-adjusted estimates of energy consumption which enables researchers to monitor and evaluate changes over time. The model generally provides stable and reliable estimates for the total energy consumption. However, the accuracy of its space heating estimates has been questioned.

In this research, data collected from the Hood River Conservation Project (HRCP) during 1984-86 were used to investigate possible improvements for the PRISM estimates of space heating electricity use. After a series of data screening processes on the 320 houses available from HRCP, 148 households were selected as the sample for analyses. PRISM was used to estimate electricity consumption for each household in the pre-retrofit (July 1984 - June 1985) and the post-retrofit (July 1985 - June 1986) years. The actual end-use data was used to evaluate the accuracy of PRISM and to obtain possible adjustment factors for PRISM estimates of space heating consumption.

It was found that the performance of PRISM was generally consistent between the two-year study period. PRISM overestimated space heating electricity use by an average of 19% in both years for the 148 Hood River homes. A constant adjustment factor of 0.81, obtained from a simple regression model approach, was found to have attractive potentials in improving the PRISM space-heating estimates for houses located in the Hood River area. Additional investigation will be needed to further understand and generalize this method.

Summary

The PRInceton Scorekeeping Method (PRISM) has been widely used in energy conservation studies. This method employs a simple statistical model and readily available data to produce a weather-adjusted measure of annual energy consumption. PRISM generates a Normalized Annual Consumption (NAC) for each household in each year and employs it as an index of energy consumption. Through the use of PRISM, researchers can evaluate and monitor changes in energy consumption over time. Consequently, the effectiveness of a conservation program can be examined.

Although PRISM provides stable and reliable estimates for the total annual energy consumption, the accuracy of its estimates for space heating energy use has been questioned. The research effort reported here was sponsored by the Bonneville Power Administration (Bonneville) to investigate ways to correct PRISM space heating parameters. Submetered end-use data collected from the Hood River Conservation Project (HRCP) for both pre- and post-retrofit years were analyzed in this project. Thus, comparisons of PRISM performance, in terms of how well it estimates the space heating consumption for houses before and after retrofits, could also be made.

HRCP was a five-year (1983-87), $20 million research and demonstration project which provided information on market penetration, logistics, and savings in a community-based weatherization program. HRCP employed high levels of weatherization measures. The project contained two parts. The first component, conducted between fall 1983 and the end of 1985, was to weatherize all Hood River homes. The second part was the extensive research and supporting data collection. This effort began a year before the field activity started and continued for three years after retrofits were installed.

A random sample of 320 Hood River homes was selected in early 1984 from the project participants to receive load-research meters (submeters). These submeters measured electricity consumption for specific end uses, including space heating, at 15-minute intervals. Detailed on-site home interviews were conducted with occupants of these homes in July 1984 to obtain demographic and appliance data.

Of these 320 Hood River submetered homes, 148 were selected, following a series of data screening processes, and used as the sample for the present analyses. PRISM was used to estimate the pre-retrofit (July 1984 to June 1985) and post-retrofit (July 1985 to June 1986) electricity consumption. Comparisons of PRISM performance for these two years, as well as electricity savings over this two-year period, were examined. The submetered data were then compared with the corresponding PRISM estimates for each household. Finally, several different approaches for adjusting PRISM estimates of space heating electricity use were tested.

The key findings from this research were:

1. The performance of PRISM was generally consistent between the pre- and post-retrofit years, 1984-85 and 1985-86. No significant difference in model performance was identified between results for the two years. Contrary to findings reported by other researchers, this study showed that bias does not increase with the increased tightness of homes in the Hood River area. This could be a result of the fact that water-heater retrofits were included in the HRCP.

2. Based on these 148 Hood River households, PRISM-estimated average for whole-house annual electricity savings over this two-year period was 2350 kWh, 11% of pre-retrofit year electricity use. PRISM-estimated average space heating savings were 2100 kWh, or 20% over the two years. In comparison with the submetered data, PRISM overestimated space heating electricity use by 19% in both years. The average overestimate of space heating was 1800 kWh in 1984-85 and 1500 kWh in 1985-86.

3. Based on a simple regression model with PRISM estimates of space heating (SPACE) as the independent variable and the actual submetered space heating data (HEAT) as the dependent variable, adjustment factors for the PRISM space heating estimates were examined for various subgroups of the 148 homes. This simple method is quite accurate in adjusting PRISM estimates for various groups of Hood River homes.

4. The coefficients of the no-intercept simple regression model were remarkably stable among most of the subgroups examined in this study. The adjustment factors obtained from those households who used wood as the secondary fuel were not significantly different from those who used only electricity in both years. However, in order to correct for greater bias, the primary wood-use homes required smaller adjustment factors than the group that used electricity as the primary heating resource. On the average, the factors were found to be 0.73 (with a standard deviation of 0.06) for the former and 0.81 (with a standard deviation of 0.02) for the latter when 1984-85 data was used. The adjustment factors were slightly changed when 1985-86 data was used; they are 0.80 (with a standard deviation of 0.02) and 0.74 (with a standard deviation of 0.06), respectively.

5. Multiplying PRISM-estimated space heating electricity use by 0.81, at an aggregated level, will yield a close estimate for homes that are not primarily wood-heated in the Hood River area. In other words, for these homes,

   Adjusted PRISM estimate for space-heating electricity use
   = 0.81 * (PRISM-estimated space heating electricity use)
   ≅ Actual submeter data for space heat.

A more accurate estimate can be provided by using 0.73 as the adjustment factor to correct the PRISM space heating parameters for the primarily wood-heated homes in the Hood River area. Surprisingly, however, the adjusted PRISM estimates obtained from using 0.81 were not significantly different from the actual data even for the primarily wood-heated house group.

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List of Acronyms

a	PRISM estimate of base load consumption (kWh/day)
AC	Annual Consumption, non-normalized, (kWh/year)
b	PRISM estimate of space heating energy use per unit change in HDD (kWh/HDD)
e	Regression error term
HDD	Heating Degree Days (°F)
HEAT	Actual submetered space heating electricity use (kWh/year)
HRCP	Hood River Conservation Project
LOAD	Actual whole-house total electricity use (kWh/year)
NAC	Normalized Annual Consumption (kWh/year)
NOAA	National Oceanic and Atmospheric Administration
ORNL	Oak Ridge National Laboratory
PRISM	Princeton Scorekeeping Method
SPACE	PRISM-estimated space heating electricity use (kWh/year)
Tref	Reference Temperature (^{O}F)

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1. INTRODUCTION

1.1 General Background

For over a decade, many utilities in the United States have made great efforts to obtain energy savings through numerous conservation programs. One of the main methods of promoting conservation programs is to provide financial incentives for residential weatherization. In order for the utilities to evaluate these conservation programs properly, a reliable and adequate measurement of energy savings is vital.

The analyst generally is confronted by many difficulties when measuring the energy savings directly attributed to a given conservation program. The randomness of human behavior involved in energy-use decision processes and the relationships between weather variables and energy usages are two examples. These factors are known to be important but have not yet been fully understood. Models such as the PRInceton Scorekeeping Method (PRISM) were developed to better understand some of these issues and to statistically estimate the energy savings through conservation.

In evaluating weatherization programs, energy savings can be estimated conceptually by comparing energy use for each household before and after the program was implemented. However, since the weather conditions in these time periods are sometimes different, a direct comparison could be misleading. A method to adjust space heating energy use for changes in weather is, therefore, essential for valid comparisons.

PRISM has been the method of choice for a number of energy conservation evaluators (Fels, 1986 and Fels, et al., 1985). It has proven to be a valuable research tool for evaluating residential energy conservation programs. The most appealing aspect of PRISM is that reasonably accurate estimates of energy use can be obtained without the expense of installing special end-use meters. PRISM uses a simple statistical model that yields meaningful physical interpretations. It uses the readily available energy billing data collected by utilities and daily average temperature information provided by weather stations. The method produces weather-adjusted measures of energy use which enable researchers to monitor and evaluate changes in energy consumption over time. In addition, PRISM allows researchers to compare a conservation program's potential and effectiveness across various geographical locations and among different periods of time.

In general, PRISM provides a reliable basis for measuring energy savings. It calculates a Normalized Annual Consumption (NAC) for individual houses and employs this as an index of consumption. Typical standard errors of NAC are normally less than

3 - 4% of the estimates (Fels, 1986 and Rachlin, et al., 1986). However, PRISM estimates of space heating energy use and base load consumption require further investigation.

Based on submetered data obtained from the Hood River Conservation Project (HRCP) during 1984-85, Hirst and Goeltz (1986) showed that PRISM overestimated space heating electricity use by at least 6% for homes relying primarily on electric heat. Because of the large amount of wood burning in the Hood River sample, the average overestimate was much higher, approximately 29%, when wood heated homes were included. Bronfman, Horowitz, and Lerman (1987) reported a similar finding in their evaluation of the Tacoma Early Adopter Program. Rachlin, Fels and Socolow (1986) showed that there are physical reasons for the overestimate. While most researchers found that PRISM overestimates space heating consumption, Lee and Englin (1988) reported that PRISM underestimated space heating energy consumption in their study of a subset of manufactured (mobile) homes in the HRCP. Whereas this inconsistency might be due to the use of a small sample size (only 10 homes were used by Lee and Englin), it is clear that the PRISM estimates of space heating are not accurate.

The inaccuracy of PRISM estimates for space heating occurs partly because the model was originally developed for houses using natual gas for space heating as their main source of energy. With electricity, however, the weather-sensitive component given in PRISM is no longer a simple term to reflect space heating energy use. A significant portion of non-heating uses, such as water heating and lighting, is also sensitive to temperature and seasonal variations. Use of supplemental fuels such as wood and portable heaters further complicates the issue. It was found by Tonn and White (1987) that wood-burning homes use from 1.7 to 4.5 times more energy for space heating by wood than by electricity. Moreover, Tonn and White (1988) indicated that nearly 50% of the households in the Pacific Northwest had the ability to use wood for some or all of their space heating needs. Therefore, simply interpreting the weather-sensitive component in PRISM as the space heating electricity use is not adequate.

Recently, Bonneville asked researchers at Oak Ridge National Laboratory (ORNL) to evaluate PRISM estimates. The main objective of this study is to develop adjustment factors that can be used to correct PRISM estimates of space heating electricity use for the Hood River area; i.e., equations of the form Adjusted_SPACE = f(SPACE, ...), where SPACE is the PRISM-estimated space heating electricity use and Adjusted_SPACE is a more accurate estimate of actual space heating, namely, HEAT. The comprehensive set of information collected from HRCP during 1984-86 was utilized in this study.

The findings from this research effort are organized into six sections. As just discussed, Section One contains a general background on the project. A summary of the PRISM method and a description of HRCP data resources are included. Section describes the data screening and sample selection processes used in the research. A comparison of household demographic characteristics between the sample and those who were not selected is also presented. PRISM estimates of pre- and post-retrofit energy consumption, as well as energy savings, computed from the 1984-86 HRCP submetered data, are summarized in Section Three. Comparisons of PRISM estimates with the actual submetered data are given in Section Four. Efforts to improve PRISM space heating estimates, as well as preliminary investigations of other possible alternatives, are reported in Section Five. Section Six presents findings and conclusions from this research, and recommendations for future work.

1.2 Princeton Scorekeeping Method (PRISM)

There are two important features of PRISM that make it popular. First, the method uses a simple statistical model that contains only three parameters, each with a distinct physical interpretation. Second, the model has a weather correction component which utilizes outdoor temperature to normalize energy use so that comparisons of energy use across areas and time periods are possible.

The PRISM model assumes a linear relationship between energy use and heating degree-days (HDD). It decomposes the total energy consumption of a given household into two parts: the base load (nonweather-sensitive), and the space heating component (weather-sensitive). That is, for each household:

$$Y_j = a + b * HDD_j(Tref) + e_j, \quad j = 1, 2, ..., p \qquad (1)$$

where

Y_j = total energy used (kWh) in time period j
a = base load consumption (kWh)
b = unit space heating energy use per degree increase in HDD (kWh)
Tref = reference temperature (°F)
$HDD_j(Tref)$ = heating degree-days computed to reference temperature Tref in time interval j
e_j = regression error term in period j
p = number of time intervals (e.g., 12 months)

For each household, "Tref" is the outdoor air temperature above which electricity use is insensitive to temperature variations; "a" represents the weather-insensitive energy use per time interval; and, "b * HDD_j(Tref)" represents the weather-sensitive use per time interval. The model residuals, e_j, are assumed to be normally distributed with zero means and constant variances. PRISM uses Newton's method to obtain the optimum reference temperature while using the ordinary least square (OLS) method to estimate a and b for each household (Goldberg, 1982). Standard errors associated with each parameter are computed and also provided in the standard output generated by PRISM and its microcomputer version PRISMonPC (Fels, et al., 1986). These software packages can be obtained from The Center for Energy and Environmental Studies (CEES) at Princeton University.

Generally, the most reliable results from PRISM are obtained from a year's data (Rachlin, et al., 1986). When daily average electricity consumption is available, the total annual consumption of household i, denoted as AC can be calculated as:

$$AC_i = 365 * a_i + b_i * \quad [HDD_j(Tref_i)], \qquad (2)$$

where a_i and b_i are estimates obtained from (1). To perform a valid comparison among conservation programs conducted in different years or locations, weather-adjustments to the above equation are required. By replacing the $HDD_j(Tref_i)$ in equation (2) with a long-term annual average of heating degree days, $HDD_o(Tref_i)$, a Normalized Annual Consumption (NAC) is produced as an index of consumption for each individual house. That is, for household i,

$$NAC_i = 365 * a_i + b_i * HDD_o(Tref_i), \qquad i = 1, 2, ..., N. \qquad (3)$$

As stated in many studies, NAC generally provides a stable and reliable consumption index from which energy savings and conservation trends can be accurately estimated (Fels, 1986). The stability of NAC, in terms of small average standard errors, is the most significant feature of PRISM.

1.3 Data Resources

A detailed description of all data collected under the HRCP was reported by Hirst (1987). The HRCP was a five-year, multi-million dollar retrofit demonstration project. It was funded by Bonneville and conducted by Pacific Power & Light Company, in cooperation with the Hood River Electric Cooperative in Hood River, Oregon. The project included the weatherization of almost 3,000 Hood River homes during 1983-85, and an extensive research and data collection effort from 1982 through 1988. A randomly selected sample of 320 Hood River homes had load meters installed to measure their specific electricity uses at 15-minute intervals. The following is a brief description of data sets that are relevant to this project:

a. Hood River Submetered Data

The data associated with the HRCP project are extensive and detailed. The information collected includes detailed electricity end-use data for 320 homes in Hood River from July 1984 to June 1988. Data on total electricity use, space heating electricity use, and water heating electricity use as well as indoor temperatures were gathered at 15-minute intervals during the study period. Wood heat sensors were installed (replacing the water-heater channel) to monitor wood stoves in 100 of the 320 homes that participated in the project. Since all 320 homes received retrofits in mid-1985, this data set provides a valuable opportunity for researchers to compare pre- (July 1984-June 1985) and post-retrofit (July 1985-June 1986) energy consumption. Moreover, the comparisons of PRISM estimates with actual measurements allow researchers to determine how PRISM parameters performed. This was the most important issue examined in the current research.

b. Temperature Data

A set of 15-minute-interval climate data was collected at three weather stations in Hood River. The daily temperature data from the National Oceanic and Atmospheric Administration (NOAA) at the Hood River Experiment Station were also available. In this project, only NOAA daily temperature data for the period from July 1984 to June 1986 were used.

c. Demographics and Dwelling Unit Characteristics Data

Detailed information on the demographic characteristics of the HRCP participants, their dwelling units and appliances, primary and supplemental heating fuels, as well as other energy-related attributes, were also accessible. These data were collected through an on-site home survey done in July 1984 with the Hood River submetered households. The data base contains useful behavioral information which enables researchers to carry out cross-sectional analyses at an individual household level. Information contained in this data base was utilized during the investigation of possible adjustment factors for PRISM parameters.

2. DATA SCREENING AND SAMPLE SELECTION

2.1 Data Screening Process

Considerable efforts were made in the initial stage of this project to examine data quality. One of the 320 Hood River houses was identified as a non-residential building by Hirst and Goeltz (1986) and was eliminated from the data base. Data from the remaining 319 homes were then examined. The 15-minute interval submetered load data were first aggregated to the daily level. If more than 20 intervals (of 96) were missing from a given day, the energy consumption for that day was then coded as missing. Otherwise, the daily consumption was calculated by taking the average of all available 15-minute load data for that day and multiplying it by 96 (the total number of intervals in a day). The daily submetered data were further aggregated into monthly load data. Hirst and Goeltz (1986) combined their data according to each billing period to allow comparisons with the actual electricity bills. Since no billing data were utilized in the current study, using calender months to calculate monthly totals was sufficient.

Table 1 shows the results from the data screening process based on this monthly data set. Two out of the original 319 homes did not have information available for the post-retrofit year. Six houses lacked home survey data. Five homes shared meters with other families. The initial screening also revealed certain problems in the data. Among the 319 in 1984-85, 40 homes contained more than 35 "missing days" in either whole-house total or space heating channels. The number of such homes increases to 63 for 1985-86. Note that a "missing day" is defined as a day in which no submetered data was available. The zero whole-house total consumption is also doubful, especially when a long period was presented. Among the 319 households, six homes have more than five days of zero whole-house consumption, whereas in 1985-86, four homes were found from 317 households. Removal of these records resulted in a data set containing 266 homes in the 1984-85 year and 245 homes in the 1985-86 year. Among these households, 230 homes were found to be in both years (i.e., included two years of information).

Because PRISM was designed to analyze the primary space heating fuel, Hirst and Goeltz (1986) chose only those households which used 2,000 kWh or more per year for space heating. The same criterion was applied in the sample selection reported here. Among the remaining 266 houses in 1984-85, 74 homes used less than 2,000 kWh for space heating as measured from the monitored channel. Seventy-eight such homes were found in the 1985-86 year (from a total of 245 homes). Fifty-five of these homes used less than 2,000 kWh for space heating in both years. Close examination of the 1984 on-site home surveys indicated that 45 of the 55 homes (82%) reported that wood was their primary fuel for heating. PRISM output of these 55 homes were further analyzed. As expected, PRISM did not perform well on most of these houses. No significant relationship could be found among PRISM parameters, R^2, and the amount of actual

Table 1. Data Screening Results

	Pre-retrofit	Post-retrofit	both years
Total No. of Homes	319	317	317
Lack of Survey	6	6	6
Share Meter	5	5	5
More than 5 days of zero total	6	4	0
More than 35 days of missing total or heat channel	40	63	25
TOTAL[a]	266	245	230
No. of homes that used < 2,000 kWh/year for space heating	74	78	55
No. of homes that used >= 2,000 kWh/year for space heating	192	167	148

[a] some homes satisfied more than one criteria. i.e., the numbers of homes reported in different rows are overlapping.

space heating electricity usage of the house, however. The PRISM R^2 values range from 2% to 98% with a nearly uniform distribution for these 55 households. Since PRISM will not provide reliable results if used to estimate non-primary fuel consumption, and the objective here is to derive adjustment factors for PRISM parameters under a circumstance that is suitable for PRISM applications, it is reasonable to exclude these low-heating (low-kWh) homes.

By eliminating those households who used less than 2,000 kWh per year for space heating from the study, the screening process resulted in 192 homes for 1984-85 and 167 homes for 1985-86. To compare PRISM results on the individual household level, such as comparison of pre- and post-retrofit energy consumption, the "matching" 148 homes were used in the subsequent studies and are referred to as "the sample." In other words, the sample includes those households which had complete (or nearly complete) data and used more than 2,000 kWh for space heating in both years. The elimination of households who used less than 2,000 kWh per year for space heating did not exclude all wood using homes from the study. The sample (148 homes) still includes some houses with substantial wood heating.

The sample size resulting from the abovementioned selection criteria was smaller than the 189 homes reported in Hirst and Goeltz (1986). This was mainly due to the elimination of households that did not satisfy certain conditions for either pre- or post-retrofit years, especially the minimum space heating usage of 2,000 kWh or more. Some discrepancies were also due to the use of billing data and aggregated monthly totals according to billing periods (instead of calendar months) in Hirst and Goeltz. Over 90% of the 148 homes in this study, however, were included in the Hirst and Goeltz (1986) study.

2.2 Comparisons of Demographic Characteristics Between Selected And Non-selected Homes

The first step in the analysis was to examine differences between the sample (148 homes) and the remaining 166 households to determine if a bias is present in the sample households. The on-site home survey data collected in HRCP were examined to determine dwelling characteristics. Results from this comparison are presented in Appendix A. Overall, no significant differences were found between these two groups for:

type of dwelling,
ownership of the house,
size of the dwelling,
size of the household, and
household income.

The level of education for the head of each household showed a similar distribution between the two groups, with exceptions in categories of "some college" and "college graduate and over."

Significant differences were found only in space heating (Table 2). The minimum requirement of 2,000 kWh for space heating, used as one of the criteria in the selection of the sample, is the main cause of the discrepancies between these two groups. Most of the households in the sample used electricity as their primary (or only) heating source while most of the households in the other group were primarily wood users. Fewer households in the sample, however, used air conditioners in the summer (see Appendix A).

Table 2. Comparisons of Space Heating Use for Homes Included in The Sample (148 homes) with Those Who Were Excluded (166 homes)

Type	Included	Excluded	Total
Electricity Only	60(41%)	22(13%)	82(26%)
Elec. & Wood suppl.	60(41%)	49(30%)	109(35%)
Wood & Elec. suppl.	25(17%)	84(51%)	109(35%)
Wood Only[a]	1(1%)	11(7%)	12(4%)
Elec. & Elec. suppl.[b]	2(1%)	0(0%)	2(1%)
TOTAL	148	166	314

[a] The on-site home survey indicated that this is a moble home using wood as the primary fuel for heating but using no other supplemental fuels. However, based on the submetered data, the actual space heating was 2,900 kWh in 1984-85 and 4,300 kWh in 1985-86 for this house.

[b] Two homes reported electricity as their primary space heating fuel as well as the supplemental heating (probably portable heaters). These were not included in the "electricity only" group.

The above comparisons suggest that the sample (148 homes) well represents the population (314 homes) in terms of general household and dwelling characteristics. Results based on this sample should be applicable to all of the 314 Hood River homes. The impact of wood use behavior on PRISM estimates, and the adjustment of these estimates, is an important issue which deserves further study.

2.3 Analysis of actual space heating data for the sample

Because the selection of heating fuel played an important part in determining whether a house was included in the sample (see Table 2 in section 2.2), the actual space heating submetered data was again examined. The single wood-only home found in the sample was combined with the wood-and-electricity subgroup (25 homes) as a new subgroup (wood-primary). Table 3 summarizes the means and medians of actual space heating consumption under this breakdown. No statistical significance could be found for the first two groups, namely "electricity only" and "electricity with wood as

Table 3. Comparisons of Actual Space Heating Consumption (kWh) for Different Fuel-Used Groups

	Pre-retrofit 1984-85		Post-retrofit 1985-86	
Group	Mean	Median	Mean	Median
Elec. only (60 homes)	9400	8700	7800	7100
Elec. with Wood suppl. (60 homes)	11000	10100	8500	8500
Wood prim. (26 homes)	5800	4500	6100	4700

supplemental fuel." The space heating electricity use for the primary wood using homes (26 homes) was significantly lower than that for the other two groups for both pre- and post-retrofit years. Statistical procedures for multiple comparisons also strongly indicated a significant difference between the "wood-primary" group and the others.

Although the average space heating electricity consumption for these 26 homes was relatively low, 5,800 kWh in 1984-85 and 6,100 kWh in 1985-86, one should be cautious in generalizing this result. The actual submetered data collected from the space heating channel installed in these wood-primary homes showed a very wide range, from approximately 2,400 kWh to 29,700 kWh in 1984-85 and 2,100 kWh to 23,300 kWh in 1985-86. This might indicate that there is a possibility of inconsistency among information provided in different data bases. For example, as shown in Table 2, one home reported as "wood-only" used 2,900 kWh for space heating in 1984-85 and 4,300 kWh in 1985-86.

In an in-depth study of the impact of retrofits on energy use for five Hood River homes, Meier, Nordman, Miller, and Hadley (1988) stated that the HRCP submetered data revealed that non-space heating energy use was surprisely high. They indicated that much of the appliance energy was attributed to space heating because the end use breakdown was not accurately known prior to the HRCP. This could be one reason why high electricity readings were collected by the space heating end-use meter in some wood-use homes.

3. PRISM RESULTS

3.1 PRISM Estimates of Pre- and Post-retrofit Energy Consumption

PRISM was used to estimate space heating electricity use, base load consumption, NAC, and reference temperature for each of the 148 Hood River homes. Standard long-term HDDs, based on temperature data from 1976 to 1986, were used in the model. As stated previously, this normalization (or weather-adjustment) aids comparisons of energy consumption over the two-year study period without possible influence caused by the difference in temperature. Consequently, energy savings directly contributed by the retrofits can then be more accurately estimated.

Examination of the R-square values shows that PRISM performed well in both years (see Figure 1). Almost half of the 148 homes had R-square values of 0.95 or more in both years. The model performance (when measured by R-square) was generally consistent between pre- and post-retrofit years. In other words, a good pre-retrofit model normally corresponded to a good post-retrofit model. This can be seen from the cross-tabulation of R-squares in Table 4. The mean and median values of R-squares were almost identical for the two years.

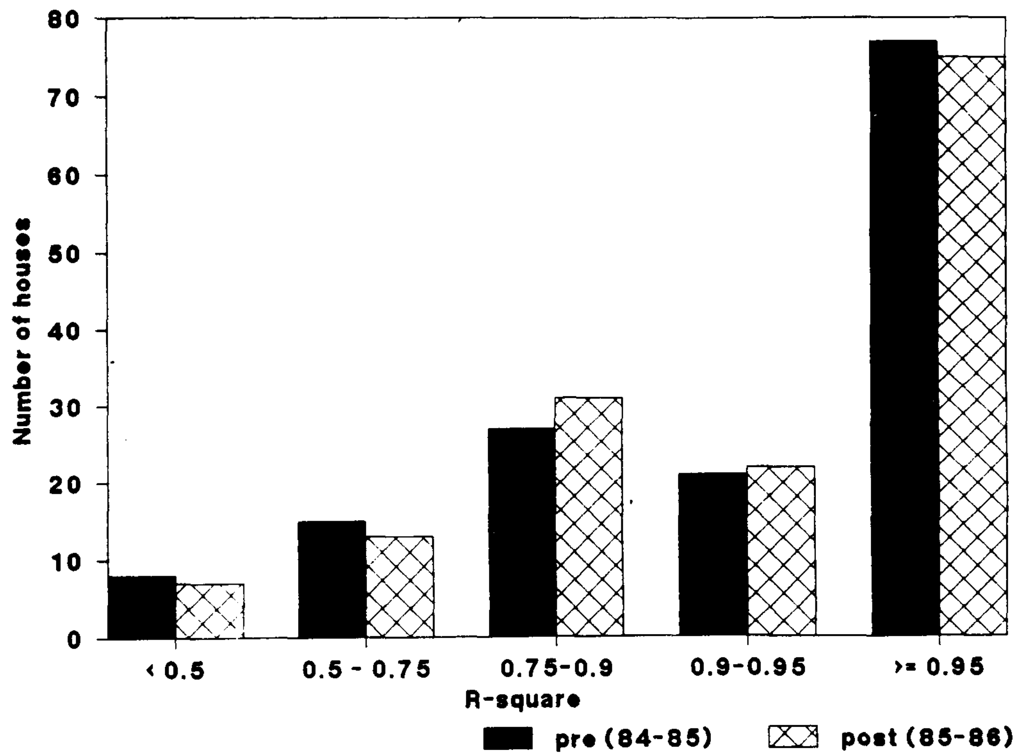

Figure 1. R-squares from the PRISM model based on aggregated monthly electricity totals for the 148 Hood River homes in both pre- and post-retrofit years.

Table 4. Cross-tabulation of PRISM R-squares for Hood River homes in Pre-retrofit and Post-retrofit years.

1985-86	1984-85					
	<0.5	0.5-0.75	0.75-0.9	0.9-0.95	0.95-0.975	>=0.975
<0.5	3	1	1	1	0	1
0.5-0.75	1	5	2	1	1	2
0.75-0.9	2	4	11	5	5	4
0.9-0.95	0	2	3	1	8	4
0.95-0.975	1	1	6	3	6	18
>=0.975	1	2	3	8	6	25

R-square >= .95 for both years (55)

R-square >= .90 for both years (79)

The standard error for NAC agrees with the findings of other researchers, 1% to 16% of corresponding NACs in both years. The average standard error was 4% for both pre- and post-retrofit years. The mean and median values for PRISM estimates of NAC and space heating energy use (SPACE) are listed in Table 5. Figure 2 shows scatter plots of PRISM space heating estimates over the two years along with the means and medians of these estimates for the 148 homes. The differences for NACs and SPACEs over the two years are both statistically significant at 0.01 level. In addition, both NAC and SPACE decreased between the two years, indicating an expected savings in energy use due to the retrofit. Table 5 also gives the PRISM estimates for the reference temperatures. Interestingly, the average reference temperature for both pre-retrofit and post-retrofit years was 59 degrees (F). Apparently for homes in Hood River, the behavior of the PRISM model was not influenced by the retrofit performed on the houses.

Table 5. Comparison of PRISM estimates for 148 Hood River homes in both pre- and post-retrofit years. [a]

	Pre-retrofit 84/85		Post-retrofit 85-86	
	Mean	Median	Mean	Median
NAC (kWh)	21600	20200	19200	18300
SPACE (kWh)	10400	9500	8300	7800
Ref. Temp. (°F)	59	57	59	58
R-square	0.88	0.95	0.88	0.95

(a) The mean differences between NACs and SPACEs for the two years are statistically significant at 0.01 level.

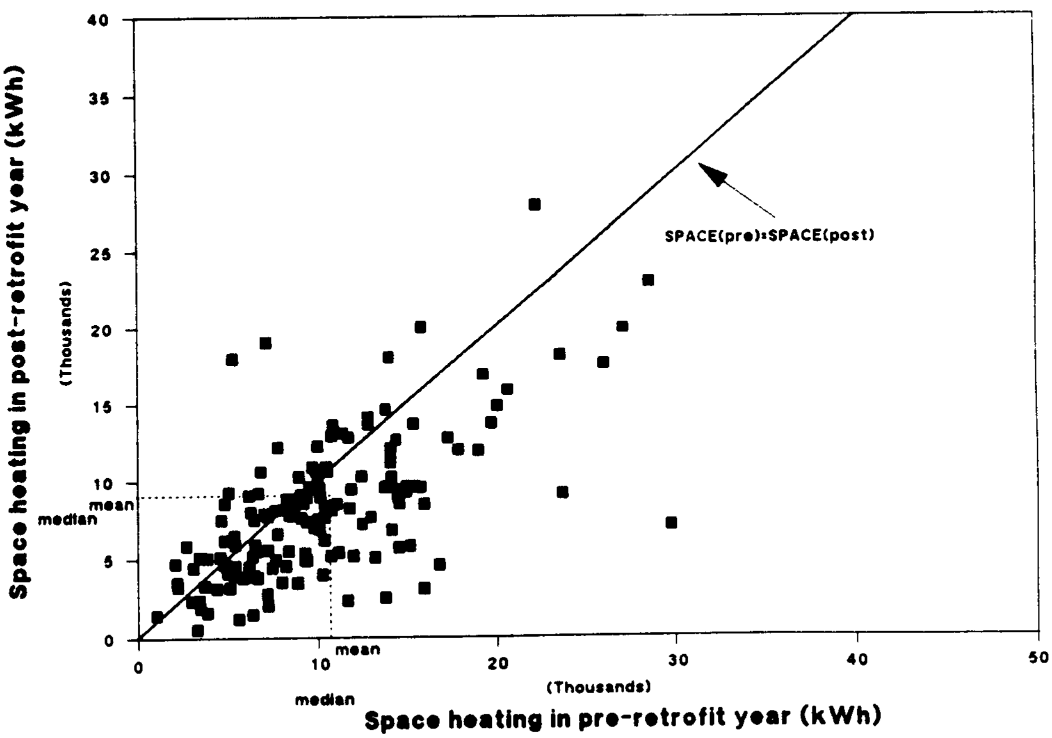

Figure 2. PRISM estimates of space heating electricity use for the 148 Hood River homes in both pre- and post-retrofit years, long-term HDDs were used in the model.

3.2 PRISM Estimate of Energy Savings

Based on the PRISM results, energy savings for each individual household can be calculated as the difference between NAC(pre) and NAC(post):

$$\text{Savings} = \text{NAC(pre)} - \text{NAC(post)}.$$

While the percent savings can be defined as:

$$\%\text{Savings} = \text{Savings} / \text{NAC(pre)}.$$

Similarly, the savings in terms of space heating for each individual household can also be defined. Table 6 gives the distribution of PRISM-estimated savings and %savings for the 148 homes over the two-year study period. More than 50% of the 148 households had total electricity savings ranging from 200 kWh to 4,500 kWh, or 0 to 20%. The estimated average energy savings over the two-year period was 2,350 kWh, or 11% of NAC(pre) (or 1,800 kWh and 9%, if medians are used). The savings were statistically significant at the 1% level. The average savings in space heating over the two years was 2,100 kWh, or 20% of SPACE(pre) which was also statistically significant at the 1% level (Figure 3).

Table 6. Distributions of PRISM-estimated savings and %savings for the 148 homes over the 1984-86 Period.

Quantiles	Savings (kWh)	%Savings (100%)
.01	-8800	-55
.05	-2900	-14
.10	-800	-6
.25	200	1
.50 (Median)	1800	9
.75	4500	20
.90	7600	28
.95	9100	34
.99	14900	50
Mean	2350	11

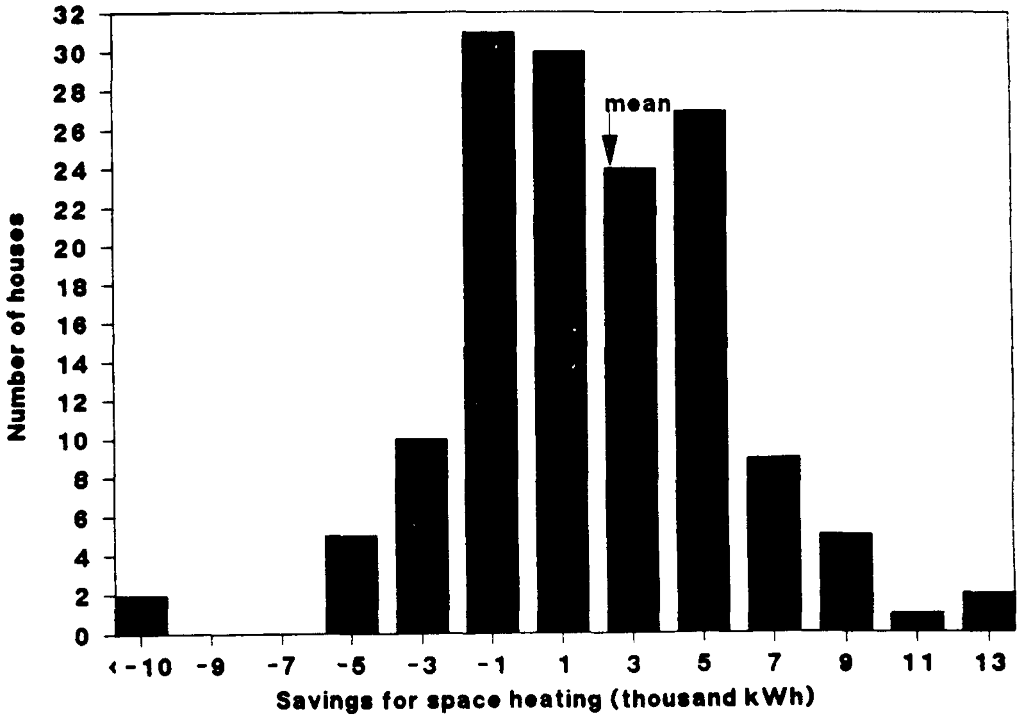

Figure 3. PRISM-estimated space heating savings for 148 Hood River homes over the 1984-86 period (value shown under each bar is the mid-point of the range in thousand kWh).

4. COMPARISONS OF PRISM ESTIMATES WITH SUBMETERED DATA

Comparisons between the submetered data and the PRISM estimates were performed on an individual household basis for the pre- and post-retrofit years. Note that non-normalized HDDs (i.e., the actual HDDs for that year) were used here. Since there is no weather-adjustment on the actual submetered data, use of weather-adjusted (or normalized) PRISM estimates in the comparisons was not appropriate.

The means and medians for the actual submetered data (HEAT), along with the PRISM estimates of space heating electricity use (SPACE), are given in Table 7. PRISM overestimated the space heating electricity use by 19% in both years (or 22% in 1984-85 and 24% in 1985-86, if medians are used). The similarity in PRISM estimates of space-heating for both pre- and post-retrofit years was somewhat surprising. It was expected by some researchers that the PRISM model might be less satisfactory for energy-efficient homes. Bronfman, Horowitz, and Lerman (1987) stated that, in their study, the PRISM methodology misallocated a larger fraction of energy use between base load and heating load for houses that were more energy efficient. The result obtained from this study, however, did not support this.

Table 7. Comparisons of Actual Data with PRISM Estimates of Space Heating Electricity Consumption (kWh). [(a)]

	1984-85		1985-86	
	Mean	Median	Mean	Median
PRISM (SPACE)	11200	10400	9300	9000
Actual (HEAT)	9400	8500	7800	7200
SPACE-HEAT	1800	1200[(b)]	1500	1000[(b)]
SPACE/HEAT	1.19	1.22[(c)]	1.19	1.24[(c)]

(a) To compare with the actual load data, "Non-normalized" HDDs are used in PRISM.

(b) This was calculated as the median of the differences, i.e., median of all (SPACE-HEAT) values.

(c) This was calculated as the median of the ratios, i.e., median of all (SPACE/HEAT) values.

One of the possible reasons could be that water-heater retrofit was conducted in the HRCP but not in other studies. This water-heater retrofit included wraps for water-heaters, as well as pipes, and installations of low-flow showerheads for participating Hood River homes. In general, when one interprets the two PRISM components as base load and space-heating load, some portion of the water-heating energy use may be misallocated into the latter. This misallocation is expected to be larger with well-insulated houses. Because of the water-heater retrofit performed in HRCP, the savings due to the water-heater could have offset the misallocation of space-heating load for Hood River homes. Consequently, the percentage of overestimate in the space-heating component of PRISM model remains approximately the same for the pre- and post-retrofit years.

The means and medians of savings based on actual and estimated results for the two-year period are displayed in Table 8. The actual savings obtained from the submetered data indicated an average of 10% of space-heating use, while PRISM-estimated space heating savings averaged 6% (with non-normalized HDDs). The difference was not statistically significant, which might be due to the large variation among values obtained from individual households. The difference between the two medians was fairly small, however.

Table 8. Comparisons of Actual Savings with PRISM Estimates for Space Heating [a]

	Savings (kWh)		%Savings (100%)	
	Mean	Median	Mean	Median
SPACE	2000	1600	6	16
HEAT	1600	1200	10	15
SPACE-HEAT	300[b]	100[c]	-4	-2[c]

(a) To compare with the actual load data, "Non-normalized" HDDs are used in PRISM.
(b) Round off error due to the number of significant digits used in table.
(c) Median was calculated based on values of SPACE-HEAT (i.e., the differences).

5. ADJUSTMENT OF PRISM SPACE HEATING PARAMETER

5.1 Previous Research Efforts

The comparison given in the previous section clearly shows that PRISM overestimated space heating electricity use by almost 20% of the measured data for the 148 homes. Therefore, to accurately estimate space heating electricity consumption from the PRISM model, certain corrective factors (or multipliers) that could remedy the problem of overestimation are desirable. In an attempt to seek adjustment factors for PRISM estimates of space heating electricity use, Hirst and Goeltz (1986) developed a regression model which used the difference between space heating estimates as the dependent variable (i.e., SPACE - HEAT). Various explanatory variables were examined, including: information from PRISM outputs (such as standard error of heating and reference temperature); data available from the on-site home survey (such as a dummy variable indicating use of wood); and submetered data for the actual space heating electricity use (i.e., HEAT). The intention of this "difference model" was to search for factors that in part might account for the discrepancy between the PRISM estimate and the actual space heating electricity use.

Bronfman, Horowitz, and Lerman (1987) adapted the idea from Hirst and Goeltz and developed four adjustment factors for their Tacoma evaluation samples. Although both studies indicated that approximately 50% of the variation between the PRISM estimates and the actual space heating electricity use could be explained by these models, the use of these models is somewhat limited. Not only is the use of standard errors of certain estimates as independent variables unusual in statistical models, the interpretation of their physical meanings is also difficult. Furthermore, the demographic data are not generally available in a conservation program; therefore, a model that relies on this information will not be useful in most circumstances.

As an initial exploration, however, the "difference model" used by Hirst and Goeltz (1986) was applied to the sample of 148 Hood River households. The model explained only approximately 30% of the variation for the 1984-85 data and about 40% for the 1985-86 data. The PRISM estimate of reference temperature turned out to be the only significant variable in the 1984-85 model. The standard errors of space heating and reference temperature were significant in the 1985-86 model. There was no evidence that further investigations of these models would be useful.

5.2 Possible Approaches to Develop Adjustment Factors for PRISM Estimates

5.2.1 A Simple Regression Approach

Since the objective here is to find techniques to correct PRISM estimates (with the aid of submetered data), it makes sense to directly examine the relationship between the actual measured and the estimated (from PRISM) space heating electricity - in other words, to learn how PRISM estimates can be used to "predict" the actual space heating electricity use. Figures 4 and 5 give scatter plots of the actual and the PRISM-estimated space heating electricity consumption for 1984-85 and 1985-86, respectively. It is clear that a strong positive correlation exists between these two variables (i.e., the estimated and the measured). The correlation coefficient is 0.84 for 1984-85 and 0.79 for 1985-86. These high correlation coefficients indicate that a linear relationship exists.

A simple regression model was examined, with PRISM estimates as the independent variable and the actual submetered data as the dependent variable, i.e.,

$$\text{HEAT} = C_0 + C_1 * \text{SPACE} + \text{error} \qquad (3)$$

where C_0 and C_1 are constants. Results from this regression model are summarized in the top part of Table 9. The "predicted" electricity consumption obtained from this model is the "adjusted" PRISM estimate, and the "residual" is the difference between the adjusted PRISM estimate and the actual measurement.

Note that the regression adjustment method can only provide information for all households under the study as a whole. Because the adjustment factor was calculated based on aggregated information from a group of households, it should only be applied to adjust the mean space heating consumption (or total space heating consumption) for these households. No improvement of individual household estimates could be made through this adjustment process.

To further investigate the relationship between adjustment factors and the time period used to estimate them, the adjustment factor obtained from one year was applied to the other year. For example, the PRISM estimate of the 1985-86 space heating electricity for each home was multiplied by 0.72 and then 1312 was added to this result. The means and medians of these new adjustments are listed in Table 10. The new differences were computed and are also listed in Table 10. Neither one of them is statistically significant. It appears that either model could adjust PRISM estimates as well as the other. This reconfirms that there is no significant difference in PRISM performance between the Hood River pre- and post-retrofit data for this sample.

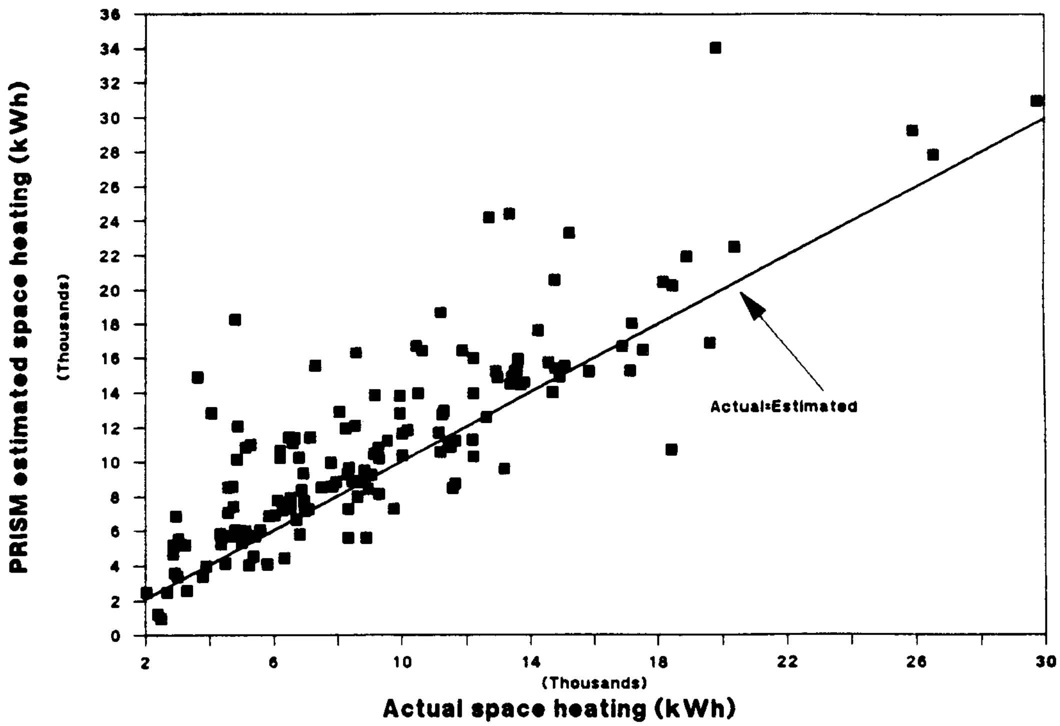

Figure 4. Plot of the actual and PRISM-estimated space heating electricity consumption for the 148 homes in 1984-85.

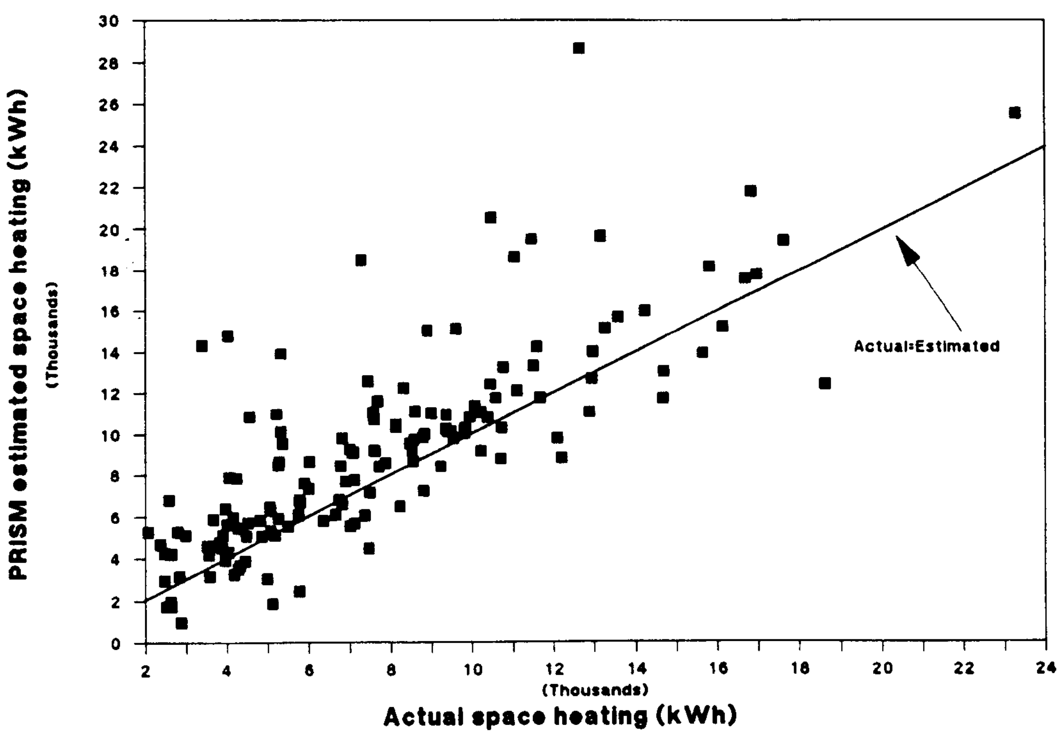

Figure 5. Plot of the actual and PRISM-estimated space heating electricity consumption for the 148 homes in 1985-86.

Table 9. Simple regression estimates for all subgroups (Model: HEAT = $C_0 + C_1$ * SPACE).

Group	Year	N	C_0	std (C_0)	C_1	std (C_1)	Rt MSE	R^2	Note
All homes									
	84/85	148	1311	495	.72	.04	2770	.70	
	85/86	148	1793	436	.65	.04	2448	.62	
Fuel used for heating									
ELEC.	84/85	60	2516	784	.64	.07	2633	.62	
ONLY	85/86	60	2643	670	.57	.07	2419	.56	
USED	84/85	86	579	641	.77	.05	2845	.75	#
WOOD(a)	85/86	86	1150	577	.70	.05	2470	.66	#
ELEC.+	84/85	60	1615	860	.71	.06	2711	.71	#
WOOD(b)	85/86	60	1762	665	.68	.06	2199	.68	#
WOOD	84/85	26	-415	971	.76	.10	2901	.72	#
PRIM.(c)	85/86	26	672	1087	.68	.12	3025	.60	#
House type									
SINGLE	84/85	113	903	576	.72	.04	2833	.72	#
FAMILY	85/86	113	1491	465	.65	.04	2302	.67	
OTHER	84/85	35	1145	996	.85	.10	2264	.69	#
TYPE(d)	85/86	35	2678	1071	.63	.11	2815	.51	#
MOBILE	84/85	27	1476	1228	.83	.17	2466	.67	#
HOME(e)	85/86	27	3892	1441	.53	.14	3092	.39	#
House size									
LARGER	84/85	25	-234	1655	.82	.11	3606	.73	#
HOME(f)	85/86	25	1830	1547	.71	.12	2928	.61	#
SMALLER	84/85	123	1652	514	.69	.04	2581	.68	
HOME(g)	85/86	123	1980	447	.61	.05	2320	.60	

Table 9. (continued)

Group	Year	N	C_0	std (C_0)	C_1	std (C_1)	Rt MSE	R^2	Note
Electricity usage									
HEAVY	84/85	36	7339	1730	.50	.09	3001	.47	
USER(h)	85/86	19	12230	2251	.19	.13	2560	.11	*
NORMAL	84/85	83	4418	615	.40	.06	1702	.36	
USER(i)	85/86	88	4731	536	.35	.05	1645	.34	
LIGHT	84/85	29	2972	263	.13	.04	752	.33	
USER(j)	85/86	41	3276	260	.07	.04	787	.06	*

Note: HEAT: actual space heating consumption
SPACE: PRISM-estimated space heating consumption
std: standard deviation
Rt MSE: root mean square error which is the estimate of standard deviation

(a) Households used wood as the primary or the secondary fuel.
(b) Households used electricity as the primary fuel for heating and used wood as supplement.
(c) Households used wood as the primary fuel for space heating.
(d) Home types other than single-family.
(e) This is a subset of (d).
(f) Number of rooms is greater than or equal to 9.
(g) Number of rooms in living space is less than 9.
(h) Households that used more than 12,500 kWh electricity per year for space heating (based on submetered data).
(i) Households that used no more than 12,500 kWh but used more than 5,000 kWh per year for space heating.
(j) Households that used no more than 5,000 kWh per year for space heating.

: intercept was not statistically significant at 0.01 level.
*: PRISM estimate was not statistically significant.

Table 10. Mean and median of adjusted PRISM estimates (adjusted by the equation obtained for the other year).

	1984-85 (pre-retrofit year) Mean	Median	1985-86 (post-retrofit year) Mean	Median
Actual heating (HEAT)	9400	8500	7800	7200
PRISM (SPACE)	11200	10400	9300	9000
Adjusted PRISM	9100	8500	8000	7800
Adjusted Diff.	-400[a]	-200[b]	200[a]	40[b]
Adjusted Ratio	0.96[a]	1.00[b]	1.03[a]	1.08[b]

[a] Round off errors due to the number of significant digits used in the table.
[b] Medians were calculated based on the individual difference (or ratio) obtained from the above.

5.2.2 Effect on Subgroups of The Sample

The simple regression approach was employed with several subgroups of the 148 homes to evaluate the adjustment technique. This practice could also reveal certain elements that might contribute to the underlying model used in this method. Several categories were considered: (1) use of wood; (2) type of dwelling; (3) size of the house; and (4) amount of electricity used for heating.

Initially, two groups of households were examined for the first category, namely "electric only" and "used wood." Based on the on-site home survey data, 60 homes used electricity with no secondary fuels, while 86 homes used wood either as a primary or as a supplemental fuel (from Table 2). The wood-use group was further broken down into two subgroups. Sixty of the 86 homes that used wood as a supplemental fuel were grouped as "electricity & wood" while the remaining 26 homes were included in the "wood primary" group. In terms of type of dwelling, 113 single-family homes and the remaining 35 homes of other types were grouped first. The 27 mobile homes were then selected from the latter (i.e., other types) to form a third subgroup. For the third category, an arbitrary criterion of nine rooms was selected to categorize the size of a house.

The last category, amount of electricity used for heating, was different in nature from the other categories. The previous categories were all based on demographic characteristics gathered from the 1984 on-site home interviews. For this subgrouping, the amount of electricity used for heating was obtained from submetered data, and therefore, the number of homes within each subgroup may not necessarily stay the same for both years. Three groups were examined for each year. The "heavy electricity users" were those who used more than 12,500 kWh per year for heating; "light electricity users" were those who used less than or equal to 5,000 kWh in a year; and the remaining households form a group of "normal electricity users." These cutoffs (i.e., 12,500 kWh and 5,000 kWh) were arbitrarily selected. The only constraint used in the selection was that the resulting sample sizes for each of the groups should not be too small. The number of homes in the last group was similar for the pre- and post-retrofit years. The change in the number of homes which switched from one group to another, from pre- to post-retrofit, is in the anticipated direction (dropping from 36 to 19 for heavy electricity users and increasing from 29 to 41 for the light electricity users).

For each group in the categories, estimates for the simple regression model are also summarized in Table 9. The PRISM estimates and the associated actual submetered space heating are shown in Appendix B. Because the regression model was calculated based on aggregated information from a group of homes, estimates for individual households could fall above or below the regression line (which represents the mean of these estimates). Applying an adjustment factor derived from the mean does not necessarily adjust individual values in an "improved" direction. Thus, these adjustment factors would only be helpful in adjusting PRISM estimates within the group as a whole.

From Table 9, it is shown that coefficients of these models are quite different among subgroups. A model would not be very practical if it behaved differently according to varying classifications of data. To examine this, the model obtained from the 148 homes in the pre-retrofit year was applied to each of the 10 subgroups for adjustment. The adjusted PRISM outcomes are also displayed in Appendix B under the column heading of "Adj.PRISM." In general, the adjusted PRISM estimates were not significantly different from the measured space heating electricity consumption. Subsequently, the calculation of [1300 + 0.72 * (PRISM estimates)], which was the 1984-85 model for all homes, could be applied to adjust any randomly selected samples for the Hood River community.

Close examination of the parameters in Table 9 shows that the intercept was not significant for approximately half of these groups. Ideally, when the actual space heating use equals zero, PRISM should estimate zero consumption for space heating.

In other words, the regression line should pass through the origin. Therefore, analysis of these models without the intercept term is a logical next step.

5.2.3 Simple Regression Without Intercept

Table 11 presents results from the no-intercept option of the linear regression. Mean and median values of the associated adjusted-PRISM estimates are presented in Appendix C. These coefficients are remarkably stable among most of the groups. In most cases the adjustment factor is close to 0.8, except for some groups with small sample sizes (including the wood-primary subgroup). In fact, the 0.81 obtained from the 148 homes compares favorably to the previous 19% overestimate of PRISM space heating parameters (see Table 7). Overall, the adjusted PRISM estimates performed well in that no significant differences across population subgroups could be identified in comparison to actual space heating. When a constant adjustment factor calculated from the pre-retrofit data of the 148 homes (0.81) was applied to all groups, most of the differences remained statistically insignificant. These new adjusted-PRISM estimates are presented in Appendix C under the heading of "Adj.PRISM2." By plotting both adjusted and non-adjusted PRISM estimates of the space heating against the actual data for the 148 homes, it is clearly shown in Figures 6 and 7 that the adjusted "ellipse" has moved toward the 45-degree line. This 45-degree line represents an ideal condition where all of the estimates equal the actual data. Although it can be seen from these figures that in some cases the adjusted-PRISM estimates are worse than non-adjusted, the overall estimates for the adjusted group are definitely improved.

The no-intercept option implemented on a regression model should be handled with care, however. The interpretation of results from such a model might be grossly misleading if not made with caution. Physically, the model must be meaningful to be forced to go through the origin. The sum of squares of error for the no-intercept regression model should be closedly examined. Because the R-square statistic in the no-intercept model has been redefined, the increase in its value should not be interpreted as an improvement in the model. More precisely, the total sum of squares in a no-intercept model is the "uncorrected" sum of squares, Σy_i^2, for a given dependent variable Y. On the other hand, the total sum of squares for a model with intercept is the "corrected" sum of squares, $\Sigma(y_i - y)^2$, where y is the mean of y_i's. Although the error sum of squares is much larger for the no-intercept model, the difference between the total and error sum of squares is also much larger for the no-intercept model. Thus, a larger value for the R-square statistic results.

Nevertheless, the factor calculated from the 148 Hood River homes in the preretrofit year provides an easy and reliable adjustment of the PRISM-estimated space heating component. A Monte Carlo simulation method applied to the 148 homes indicated that the coefficient of this no-intercept, single parameter, approach is generally

Table 11. No-intercept regression results for all subgroups (Model: HEAT = C_1 * SPACE).

Group	Year	N	C_1	std(C_1)	Rt MSE [a]	R^2 [b]
ALL HOMES	84/85	148	.81	.018	2827	.93
	85/86	148	.80	.020	2577	.91
fuel use for space heating:						
ELEC. ONLY	84/85	60	.83	.030	2833	.93
	85/86	60	.80	.035	2701	.90
USED WOOD(c)	84/85	86	.81	.023	2844	.93
	85/86	86	.80	.026	2513	.92
ELEC. + WOOD(d)	84/85	60	.81	.025	2768	.95
	85/86	60	.83	.027	2308	.94
WOOD PRIM.(e)	84/85	26	.73	.055	2853	.87
	85/86	26	.74	.062	2987	.85
house type:						
SINGLE FAMILY	84/85	113	.79	.020	2851	.93
	85/86	113	.78	.021	2395	.92
OTHER TYPE	84/85	35	.96	.039	2275	.95
	85/86	35	.87	.051	3025	.90
MOBILE HOME(f)	84/85	27	.96	.046	2487	.94
	85/86	27	.86	.062	3446	.88
home size:						
LARGER HOME(g)	84/85	25	.81	.045	3532	.93
	85/86	25	.84	.046	2952	.93
SMALLER HOME(h)	84/85	123	.82	.020	2678	.93
	85/86	123	.78	.023	2490	.91

Table 11. (continued)

Group	Year	N	C_1	std(C_1)	Rt MSE [a]	R^2 [b]
Electricity use:						
HEAVY	84/85	36	.86	.032	3658	.95
USER(i)	85/86	19	.87	.054	4116	.93
NORMAL	84/85	83	.81	.023	2164	.94
USER(j)	85/86	88	.79	.024	2258	.93
LIGHT	84/85	29	.46	.044	1766	.80
USER(k)	85/86	41	.56	.047	1748	.79

(a) Square-root of the mean square error.
(b) These R-squares should not be compared with those presented in Table 9, because R-squares have been redefined in the no-intercept regression model.
(c) Households that used wood as either primary or supplemental fuel for heating.
(d) Households that used wood as the supplemental fuel for heating.
(e) Households that used wood as the primary fuel for space heating.
(f) This is a subset of "OTHER TYPE" in the same category.
(g) Number of rooms is greater than or equal to 9.
(h) Number of rooms in living space is less than 9.
(i) Households that used more than 12,500 kWh electricity per year for space heating (based on submetered data).
(j) Households that used no more than 12,500 kWh but used more than 5,000 kWh per year for space heating.
(k) Households that used no more than 5,000 kWh per year for space heating.

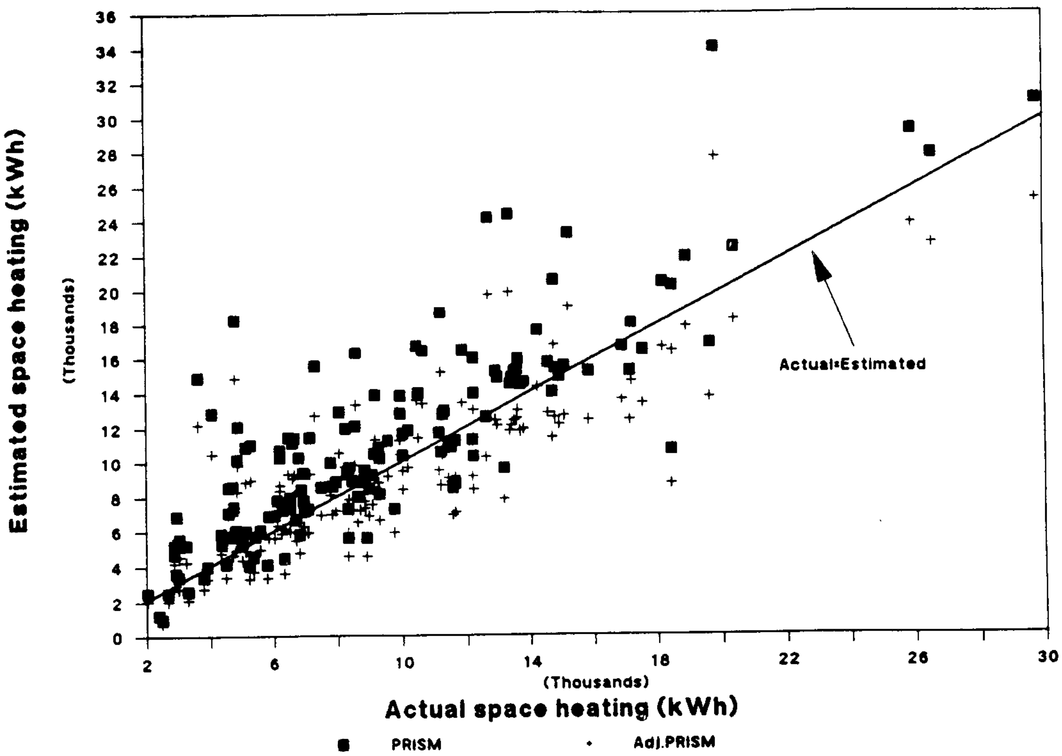

Figure 6. Actual, non-adjusted and adjusted PRISM-estimated space heating electricity use for 148 homes in 1984-85.

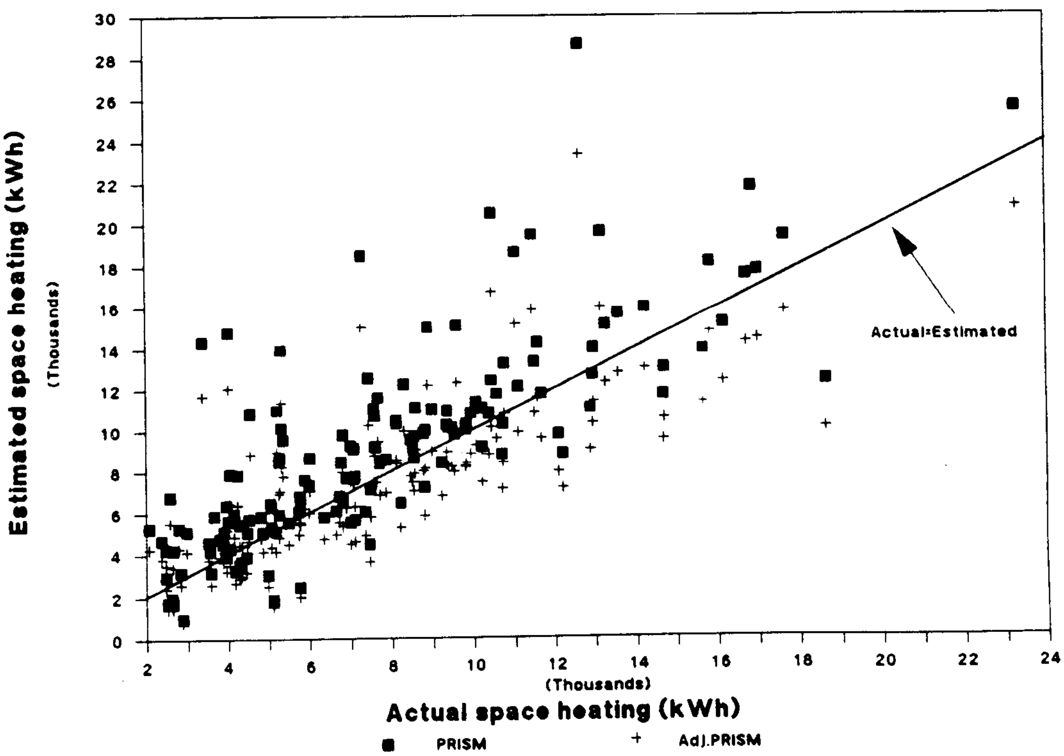

Figure 7. Actual, non-adjusted and adjusted PRISM-estimated space heating electricity use for 148 homes in 1985-86.

very stable. One thousand randomly-generated samples of 50 homes were selected from the 148 homes. The no-intercept, single parameter regression model was used on each of these 1,000 samples. All 1,000 estimated coefficients (the slopes) were recorded and analyzed for each year. A narrow range, 0.7-0.9, was found for each of the 1,000 samples generated from the Hood River homes. This finding reconfirmed the stability of the previously found adjustment factor of 0.81, which was obtained from the 148 Hood River submetered homes. A further examination of this method on other Hood River homes as well as on additional data sets collected from different locations would be highly desirable.

5.3 Implementation of the Adjustment Method

The following illustrates, step by step, how to utilize the above-mentioned adjustment method for the Hood River community.

1. Select a random sample, with sample size n (preferably 50 or more), from houses in Hood River area and collect a year of electricity billing data from these homes.
2. Run PRISM (or PRISMonPC) to obtain estimates of space heating electricity use for all homes in the sample.
3. Compute mean value for these PRISM space heating estimates and multiply this mean by 0.81 to obtain adjusted value of mean, e.g., Adjusted-mean.
4. The total aggregated electricity consumption for the sample can then be computed as "n * Adjusted-mean."
5. The total aggregated electricity consumption for the whole "population" is then estimated by multiplying the above result with N/n, where N is the total number of houses in the study.

For other geographical areas, the adjustment factor (i.e., 0.81 in step 3) can be estimated from certain pilot studies of space heating electricity use in that area (or similar areas). It would not be appropriate to apply the constant derived from Hood River houses to all other geographical locations.

5.4 Multiple Regression Approach

The simple linear regression model approach discussed above yields promising outcomes based on the Hood River data. To further experiment with this regression approach, other explanatory variables were added to the simple model. Recall from section 5.1 that the PRISM-estimated reference temperature was significant in both years. The scatter plots of PRISM-estimated reference temperature and the actual space heating energy use for both years were studied. No obvious trend could be identified from these plots, however. Additional scatter plots of the percentage of NAC used in heating versus the actual space heating electricity use were examined. A positive relationship between these two variables seems to exist.

The percentage of NAC used for heating, denoted as %NAC, was calculated as the ratio of the PRISM-estimated space heating to the NAC. Further examination of plots of %NAC against the PRISM-estimated reference temperature reveals the possibility of interaction between these two variables. Along with PRISM-estimated space heating electricity use, %NAC, and the product of PRISM-estimated reference temperature and %NAC were used as the explanatory variables in the regression model. The intercept of this 3-variable model was not statistically significant. The no-intercept option was then implemented. Table 12 shows results from both models. With two additional variables, the model performance naturally was improved. However, the improvement was so marginal that one might rather use the simpler model in practice.

Table 12. Results from the Multiple Regression Approach.

1. $HEAT = b_0 + b_1 * SPACE + b_2 * (\%NAC*100\%) + b_3 * (\%NAC*100\%*RefTemp) + error$

year	b_0	b_1	b_2	b_3	R^2
84/85	120	.76	210	-3.2	.78
85/86	860	.77	160	-2.7	.71

2. No-intercept option ($b_0 = 0$)

year	b_1	b_2	b_3	R^2
84/85	.76	220	-3.3	.95
85/86	.78	190	-3.0	.94

Note: all parameters, except b_0, are significant at 0.01 level.

6. DISCUSSION AND CONCLUSION

6.1 Findings

Although many analyses using PRISM have been conducted by other researchers, the uniqueness of the Hood River environment (and Bonneville's service area in general) makes it difficult to apply results obtained from other studies. Often, the fuel studied is natural gas, whereas Bonneville's interest is in electricity use. Also, a large number of homes in Bonneville's service area use wood as a supplemental fuel. Therefore, it is important to evaluate these methodologies with the data provided by HRCP.

One of the more exciting prospects of the analysis of post-retrofit data was the opportunity to observe how PRISM reacts to a "super-weatherized home." Prior to the analysis, it was anticipated that PRISM might not perform well on such "tight" houses. Surprisingly, the current study showed that the performance of PRISM models was not significantly different from pre- to post-retrofit years. A possible explanation for this similarity in the PRISM model performance could be the water-heater retrofit that was conducted in the Hood River Project. Further studies are needed to generalize this statement to other conservation programs.

The key result of this research is that a very simple multiplicative factor can be used to correct PRISM-estimated space heating electricity use. Multiplying the PRISM estimates of space heating by 0.81 yields estimates very close to the actual submetered data for the Hood River households. Surprisingly, this factor was nearly invariant among different subgroups of the end-use monitored HRCP homes. This might indicate that the simple multiplier obtained from the regression can be applied to the general population, provided that a well selected random sample of households was used. Note that the "population" here is the set of households within Hood River who used substantial electricity for space heating. In other words, when submetered data are not available, it is likely that 0.81*(PRISM-estimated space heating electricity use) would be within a few hundred kWh of the actual space heating value. Although the group of households who primarily used wood for space heating has smaller correction factors than 0.81, the sample size of 26 was too small to derive any solid conclusions.

It was assumed that no significant differences in energy-use behavior existed for the households during the two-year study period. That is, the on-site survey data collected in July 1984 was applied to the period from July 1984 to June 1986. Although this assumption might not have significant influence on results obtained from the 148 sample homes, outcomes based on subgroups will be changed, especially for those based on different types of fuel for heating. Changes such as increased electricity prices or family income could have important impacts on the energy-use behavior. Therefore, information from a follow-up survey could be useful for improvement of results reported.

6.2 Future Research

Due to the limited project resources, many important issues which might yield improvements for the PRISM estimates were not explored. The weather-dependency of electricity use for water heating would be an important area to investigate. Some portion of water-heater use is probably included in the space heating parameter (Brown, White, and Purucker, 1987). Analysis of water-heating electricity use might provide a possible source of bias for the PRISM parameters. Further investigation of the water-heater use subset may lead to answers to the question of how much of the parameter can be attributed to water heating.

It would also be interesting to employ the reliablity criteria of PRISM estimates, similar to those developed by Reynolds and Fels (1988), to test the weather-adjusted information provided to the Hood River data sets. If successful, this analysis might be useful in identifying individual houses with anomalous behavior in electricity consumption. Utility companies in Hood River would then be able to determine whether a piece of information is sufficiently reliable and could be reported to the customers.

Many researchers have called for more robust estimators for the PRISM parameters. A robust estimator will be less sensitive to extreme values possibly contained within the data collected. Consequently, the resulting model will likely be more stable. It is also anticipated that weighted regression techniques (based on the distribution of the data, or certain functions that smooth the "noise" within the data) instead of the Ordinary Least Square method currently used in PRISM would yield better estimates for space heating electricity use as well as for the base load electricity use.

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APPENDIX A. Comparisons based on Home Survey Data for 148 selected sample and the remaining 166 homes.

A. Type of Dwelling:

Type	148	166	Total(314)
Mobile Home	27(18%)	35(21%)	62(20%)
Single Family	113(76%)	129(78%)	242(77%)
2 - Units	0(0%)	2(1%)	2(1%)
4 - Units	2(1%)	0(0%)	2(1%)
5+ - Units	6(4%)	0(0%)	6(2%)

B. Ownership:

Type	148	166	Total(314)
Own or buying	124(84%)	148(89%)	272(87%)
Rent	22(15%)	17(10%)	39(12%)
Occupied (no rent)	2(1%)	1(1%)	3(1%)

C. No. of Rooms in Living Space:

Number	148	166	Total(314)
Less than 5	14(10%)	11(7%)	25(8%)
5	23(16%)	19(12%)	42(13%)
6	32(22%)	34(21%)	66(21%)
7	27(18%)	44(27%)	71(23%)
8	27(18%)	30(18%)	57(18%)
9	11(8%)	15(9%)	26(8%)
10 or More	14(10%)	13(8%)	27(9%)

APPENDIX A. (continued)

D. Type of Fuel Used Most:

Type	148	166	Total(314)
Wood or Prestologs	26(18%)	95(57%)	121(39%)
Electricity	122(82%)	71(43%)	193(62%)

E. Use Additional Heating Fuels (i.e., use supplement fuels):

	148	166	Total(314)
Yes	87(59%)	133(80%)	220(70%)
No	61(41%)	33(20%)	94(30%)

F. Type of Additional Heating Fuels (for those who said Yes):

Type	87	133	220
Wood	60(69%)	49(37%)	109(50%)
Electricity	27(31%)	84(63%)	111(50%)

G. Used Air Conditioning:

	148	166	Total(314)
Yes	30(20%)	50(30%)	80(26%)
No	118(80%)	116(70%)	234(74%)

APPENDIX A. (continued)

H. Total No. of Residents:

Number	148	166	Total(314)
1	22(15%)	14(8%)	36(12%)
2	54(37%)	62(37%)	116(37%)
3	21(14%)	27(16%)	48(15%)
4	37(25%)	40(24%)	77(25%)
5	10(7%)	14(8%)	24(8%)
6 or more	4(3%)	9(5%)	13(4%)

I. Level of Education for Head of Household:

Education	148	166	Total(314)
Under Highschool or none	9(6%)	10(6%)	19(6%)
Some Highschool	19(13%)	19(11%)	38(12%)
Highschool Grad.	47(32%)	64(39%)	111(35%)
Trade sch. Grad.	10(7%)	7(4%)	17(5%)
Some College	25(17%)	43(26%)	68(22%)
College Grad. and over	38(26%)	22(13%)	60(19%)
Unknown	0(0%)	1(1%)	1(0%)

J. Combined Income for 1982 (x $1000.):

	148	166	Total(314)
Under 10	21(14%)	13(7%)	34(11%)
10 - 14	15(10%)	12(7%)	27(9%)
14+ - 18	14(10%)	18(11%)	32(10%)
18+ - 25	23(16%)	33(20%)	56(18%)
25+ - 30	19(13%)	22(13%)	41(13%)
30+ - 35	15(10%)	19(12%)	34(11%)
35+ - 50	20(14%)	25(15%)	45(14%)
50+	16(11%)	9(5%)	25(8%)
missing(*)	5(0%)	15(9%)	20(6%)

* missing includes those who refused to answer and unknowns.

APPENDIX B. Mean and Median of Adjusted-PRISM Estimates for All Subgroups (based on the simple regression approach).

Group			HEAT[a] (kWh)	SPACE[b] (kWh)	Adj.PRISM[c] (kWh)	Diff [%diff][d] (kWh)
fuel use for space heating:						
ELEC	84/85	Mean	9400	10800	9100	-300 [3]
ONLY		Median	8700	9600	8300	-300[e]
	85/86	Mean	7800	9000	7800	0 [0]
		Median	7200	8100	7200	100
USED	84/85	Mean	9400	11500	9700	200 [2]
WOOD		Median	8300	10900	9200	0
(f)	85/86	Mean	7800	9400	8100	400 [5]
		Median	7200	9500	8200	0
ELEC	84/85	Mean	11000	13200	11000	0 [0]
+ WOOD		Median	10100	13100	10900	-100
(g)	85/86	Mean	8500	9800	8500	0 [0]
		Median	8500	9800	8400	-100
PRIM	84/85	Mean	5800	8200	5800	0 [0]
WOOD		Median	4500	6400	4500	100
(h)	85/86	Mean	6100	7900	6100	0 [0]
		Median	4700	6200	4900	-200
house type:						
	84/85					
SINGLE		Mean	9600	11900	9900	300 [3]
FAMILY		Median	8400	10900	9200	0
	85/86	Mean	7600	9400	8100	500 [7]
		Median	7000	8800	7700	300
	84/85					
OTHER		Mean	9000	9200	8000	-1100 [12]
TYPE		Median	9100	9300	8000	-700
(i)	85/86	Mean	8300	9000	7800	-500 [6]
		Median	8100	9200	7900	-600

APPENDIX B. (continued)

Group			HEAT (kWh)	SPACE (kWh)	Adj.PRISM (kWh)	Diff [%diff] (k W h)
	84/85					
MOBILE		Mean	9500	9700	8300	-1200 [13]
HOME		Median	9500	9700	8300	-1000
(j)	85/86	Mean	9100	9800	8400	-700 [8]
		Median	9200	9800	8400	-1000
House size:						
	84/85					
LARGER		Mean	11400	14200	11600	100 [1]
HOME		Median	9900	13800	11300	-100
(k)	85/86	Mean	10400	12000	10000	-400 [4]
		Median	10400	12200	10100	-800
	84/85					
SMALLER		Mean	9000	10600	9000	0 [0]
HOME		Median	8400	9900	8500	-200
(l)	85/86	Mean	7300	8800	7700	400 [5]
		Median	7000	8500	7400	100
Electricity use:						
	84/85					
HEAVY		Mean	16400	18300	14500	-1900 [12])
USER		Median	14800	15800	12800	-2100
(m)	85/86	Mean	15400	16800	13500	-1900 [12]
		Median	14700	15700	12600	-2500
	84/85					
NORMAL		Mean	8400	9900	8400	100 [1]
USER		Median	8300	9700	8300	-100
(n)	85/86	Mean	8100	9600	8200	100 [1]
		Median	7800	9500	8200	-200
	84/85					
LIGHT		Mean	3800	6400	5900	2100 [55]
USER		Median	3900	5600	5300	1200
(o)	85/86	Mean	3600	5200	5000	1400 [39]
		Median	3900	4800	4800	1000

APPENDIX B. (continued)

Note:

(a) HEAT = actual space heating electricity consumption (kWh).
(b) SPACE = PRISM-estimated space heating electricity consumption (kWh).
(c) Adj.PRISM = $C_0 + C_1$ * SPACE, where C_0 and C_1 are listed in Table 9.
(d) Diff = Adj.PRISM - HEAT; %diff = Abs(Diff) / HEAT,
where Abs() is the absolute value function.
(e) computed as medians of all differences not the difference of two medians.
(f) used wood as the primary or the secondary fuel for space heating.
(g) used wood as the supplemental fuel for space heating.
(h) used wood as the primary fuel for space heating.
(i) other than single families, including mobile homes.
(j) a subset of (i).
(k) No. of rooms in living space is at least 9.
(l) No. of rooms in living space is no more than 9.
(m) used more than 12,500 kWh per year for space heating.
(n) electricity used for space heating per year was between 12,500 kWh and 5,000 kWh.
(o) used no more than 5,000 kWh for space heating.

APPENDIX C. Mean and Median of Space-heating Estimates for All Subgroups (based on the no-intercept simple regression approach).

Group			HEAT[a]	Adj.PRISM[b]	Adj.PRISM2[c]	Diff.[d]	Diff2[e]
ALL	84/85	Mean	9400	9200	9200	-300[f]	-300
HOMES		Median	8500	8500	8500	-600[g]	-600
	85/86	Mean	7800	7400	7600	-400	-200
		Median	7200	7100	7300	-800	-700
fuel use for space heating:							
ELEC	84/85	Mean	9400	9000	8800	-500	-600
ONLY		Median	8700	8000	7800	-600	-700
	85/86	Mean	7800	7200	7300	-600	-500
		Median	7200	6500	6600	-700	-700
USED	84/85	Mean	9400	9300	9400	-100	0
WOOD		Median	8300	8800	8900	-600	-500
(h)	85/86	Mean	7800	7500	7700	-200	-100
		Median	7200	7600	7800	-800	-700
ELEC	84/85	Mean	11000	10700	10800	-300	-200
+ WOOD		Median	10100	10600	10700	-700	-600
(i)	85/86	Mean	8500	8200	8000	-300	-500
		Median	8500	8100	8000	-700	-900
PRIM	84/85	Mean	5800	6000	6700	100	900
WOOD		Median	4500	4700	5200	400	800
(j)	85/86	Mean	6100	5900	6400	-200	300
		Median	4700	4600	5100	-400	100
house type:							
	84/85						
SINGLE		Mean	9600	9400	9700	-200	100
FAMILY		Median	8400	8600	8900	-700	-500
	85/86	Mean	7600	7300	7600	-300	0
		Median	7000	6900	7200	-500	-300
	84/85						
OTHER		Mean	9000	8900	7500	-200	-1500
TYPE		Median	9100	8900	7500	100	-900
(k)	85/86	Mean	8300	7800	7300	-500	-1000
		Median	8100	8000	7500	-700	-1000

APPENDIX C. (continued)

Group			HEAT	Adj.PRISM	Adj.PRISM2	Diff.	Diff2
	84/85						
MOBILE		Mean	9500	9300	7900	-200	-1600
HOME		Median	9500	9200	7900	0	-1500
(l)	85/86	Mean	9100	8500	8000	-700	-1200
		Median	9200	8500	8000	-1100	-1600
house size:							
	84/85						
LARGER		Mean	11400	11500	11600	0	100
HOME		Median	9900	11200	11300	-500	-400
(m)	85/86	Mean	10400	10100	9800	-300	-600
		Median	10400	10300	10000	-600	-1000
	84/85						
SMALLER		Mean	9000	8700	8700	-300	-400
HOME		Median	8400	8100	8100	-600	-600
(n)	85/86	Mean	7300	6800	7100	-400	-200
		Median	7000	6600	6900	-900	-600
electricity use:							
	84/85						
HEAVY		Mean	16400	15800	14900	-600	-1500
USER		Median	14800	13700	12900	-1000	-2000
(o)	85/86	Mean	15400	14600	13700	-800	-1700
		Median	14700	13600	12800	-1200	-2400
	84/85						
NORMAL		Mean	8400	8000	8000	-400	-300
USER		Median	8300	7800	7900	-700	-600
(p)	85/86	Mean	8100	7600	7800	-500	-300
		Median	7800	7500	7800	-900	-700
	84/85						
LIGHT		Mean	3800	2900	5200	-800	1400
USER		Median	3900	2600	4500	-1300	500
(q)	85/86	Mean	3600	2900	4200	-700	600
		Median	3900	2700	3900	-1100	100

APPENDIX C. (continued)

(a) HEAT = actual space heating electricity consumption (kWh).
(b) Adj.PRISM = C_1 * SPACE, where SPACE is the PRISM-estimated space heating consumption and C_1 is from Table 11.
(c) Adj.PRISM2 = 0.814 * SPACE.
(d) Diff = Adj.PRISM - HEAT.
(e) Diff2 = Adj.PRISM2 - HEAT.
(f) round-off errors.
(g) defined as median of all differences, not the difference of two medians.
(h) used wood as primary or secondary fuel for heating.
(i) used wood as supplemental fuel for space heating.
(j) used wood as primary fuel for space heating.
(k) other than the single families, including mobile homes.
(l) a subset of (k).
(m) No. of rooms in living space is at least 9.
(n) No. of rooms in living space is no more than 9.
(o) used more than 12,500 kWh per year for space heating.
(p) annual electricity use for space heating was between 12,500 kWh and 5,000 kWh.
(q) used no more than 5,000 kWh for space heating.

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