A PROPOSED METHOD FOR IMPROVING RESIDENTIAL HEATING ENERGY ESTIMATES BASED ON BILLING DATA

A. D. LEE
Senior Research Scientist
Pacific Northwest Laboratory
Portland, Oregon

D. L HADLEY
Senior Research Scientist
Pacific Northwest Laboratory
Richland, Washington

ABSTRACT

Analyses of residential energy conservation programs frequently require reliable estimates of program effects on space-heating energy consumption. Simulation models are often used to provide such estimates. Recent, large-scale programs to collect empirical energy consumption data, however, provide a basis for alternative ways to estimate program effects that utilize the empirical data. The PRISM methodology uses relatively inexpensive billing and weather data to estimate base and temperature-sensitive (primarily space-heating) loads. We used billing data from over 300 manufactured (mobile) homes in two residential conservation projects to derive PRISM heating energy estimates. Actual heating energy data for a subset of these homes was used to develop a methodology for adjusting the initial PRISM-based heating estimates. We developed the adjustment relying on a theoretical approach and the empirical data. This approach resulted in a correction technique that reduced the average error in the initial PRISM-based space-heating estimates by about 70%. and requires primarily readily available PRISM outputs and limited housing characteristics data.

INTRODUCTION

Manufactured (mobile) homes represent a significant share of new housing starts[1] in the

homes. In other states, nearly 50% of the new single-family homes are manufactured homes (1). Manufactured homes are especially prevalent in the hot and humid Southern states. Few studies, however, have been conducted that analyze the thermal characteristics of manufactured homes and their energy consumption.

Even in the Northwest where manufactured homes are considered a lost conservation opportunity, little is known about the energy consumption characteristics of manufactured homes. For this study we had access to two sets of manufactured home energy consumption data.

[1]Manufactured homes are often called "HUD-code" homes because they are preemptively regulated by the Department of Housing and Urban Development's Manufactured Housing Construction and Safety Standards (MHCSS). This code, in place since June 1976, places requirements, including thermal requirements, on the construction of HUD-code homes that cannot be modified by local regulations.

The Hood River Conservation Project (HRCP) provided extensive information on the characteristics and energy consumption of 594 electrically-heated manufactured homes for the period from 1982 to 1986. HRCP is a residential weatherization program that weatherized nearly 3,000 homes located in Hood River, Oregon. Data were collected on these homes by the Bonneville Power Administration (Bonneville) and Pacific Power. Manufactured home billing data, for four years, and 15-min. measured space-heating data for a subset of homes, for two years, were available to us for analysis.

Data were also available for 34 all-electric, energy-efficient manufactured homes built to the Northwest's Model Conservation Standards (MCS). Weekly space-heating and total electricity consumption data were available for a period of one year starting in June 1986. These homes were located on the Tulalip Indian Reservation and are referred to here as the Tulalip homes.

Our study objective was to utilize the available billing data to estimate the effect of various energy conservation measures on space-heating energy consumption. We initially applied the PRInceton Scorekeeping Method (PRISM) to estimate energy consumption in these homes. PRISM is a commonly used methodology for using billing data to estimate normalized annual energy

derived from PRISM parameters are considerably less accurate than PRISM's estimates of total energy consumption. Our objective was to start with PRISM parameter estimates and develop a technique to improve their prediction of space-heating energy consumption.

This paper presents a brief description of PRISM and the initial PRISM results, and describes the development and application of a method to improve the PRISM-based space-heating estimates.

OVERVIEW OF PRISM METHODOLOGY

PRISM is a statistical procedure for calculating changes in energy consumption over time in response to outdoor temperature (see (2) for a good explanation of PRISM). PRISM requires three readily available pieces of information: 1) monthly utility billing information, 2) daily average temperatures for the period covered by the billing data, and 3) long-term (generally 3 years or more) daily average temperatures or typical weather year temperatures.

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

PRISM results are generated in two steps. The first is to estimate baseload consumption, the reference temperature (T-ref), and the heating slope, based on the performance of the house during the period covered by the billing data. These parameters can be used to estimate the baseload and space-heating energy for the year from which the data come. In the second step, PRISM uses these parameters in conjunction with long-term average weather data (heating degree-days) to estimate the Normalized Annual Consumption (NAC) and a normalized heating component. In this paper, we focus on improving PRISM-based heating estimates prior to normalization.

INITIAL PRISM ANALYSIS AND COMPARISON WITH MEASURED DATA

We applied the PRISM software to generate the parameter estimates for each HRCP manufactured home for which space-heating end-use (and billing) data were available and for the Tulalip homes. The initial PRISM results for each home were then screened using acceptance criteria similar to those used by Bronfman et al. (3) to identify "good-fit" homes. These are homes where PRISM results indicate a robust linear fit to the data. Homes that failed to satisfy these criteria were eliminated from further analysis. The criteria were:

1. R-squared (of the PRISM fit) greater than .75,
2. standard error of the reference temperature less than 25°F, and
3. standard error of the baseload coefficient less than 25 kWh.

Tulalip homes known to use wood to heat any part of the time (based on occupant information and an inspection of the homes) were eliminated from the analysis even though some of their PRISM results may have satisfied the "good-fit" criteria. After screening, 16 Tulalip homes remained in our analysis. No specific information on wood heating or other supplemental heating was available for the Hood River manufactured homes. However, homes whose ratio of heating load to total load (heating component/NAC) was less than 0.25 were considered to be using an abnormally low fraction of their total energy for heating, possibly because of significant supplemental heating with wood or other nonelectric appliances (e.g., kerosene heaters) at least part of the time. These homes were also dropped from further analysis.

COMPARISON OF PRISM ESTIMATES AND MEASURED HEATING LOAD

The ability of PRISM to accurately decompose total residential energy consumption into its heating and baseload components can be tested by comparing measured component load data for a given year to PRISM estimates based on the same year of temperature data as the energy data, instead of normalizing to long-term temperature data. Hirst and Goeltz (4), in a study of site-built, electrically heated Hood River homes, demonstrated that PRISM estimates of the normalized annual consumption (NAC) are extremely accurate. On the other hand, a systematic bias is known to exist in the estimation of the PRISM parameters (3,4,5), resulting typically in an overestimation of the space-heating component (underestimation of the baseload).

We compared PRISM-based space-heating estimates to measured space-heating consumption data to determine how well the PRISM-based estimates matched actual data. The analysis was conducted for a one-year period for the Tulalip homes, and for a period one year before and one year after retrofit for the HRCP homes. Results for all three data sets are summarized in Table 1. Results for the Tulalip homes indicate that the PRISM-based space-heating estimates substantially exceeded actual heating energy consumption. The average overestimate was 52%. At the individual house level the difference ranged from -8% to 102%. For the HRCP homes, for the pre-retrofit period the PRISM-based space-heating estimate was 1% less than the actual heating energy consumption on the average, while the difference ranged from -42% to +33% at the individual house level. After retrofit, the PRISM-based estimate was 9% less than the actual consumption, on the average. The error ranged from +28% to -41%, a smaller range but comparable to the pre-retrofit results.

OBSERVATIONS ABOUT PRISM ERROR

The differences between PRISM-based estimates and actual measurements of space-heating electricity use can be attributed to at least four possible sources:

- inaccurate billing data
- inaccurate load data
- misinterpretation of baseload because of summer peak loads (air conditioning) or
- seasonality of non-space-heating loads.

Based on thorough data quality assurance and the lack of air-conditioning equipment in the homes, the effects of the first three error sources were considered minimal in our study. On the other hand, differences between end-use measurements and PRISM-based estimates of the heating component are likely to be influenced by other non-heating loads that exhibit seasonality. Examples include: 1) interior/exterior lighting in response to shorter and less intense daylight hours during winter and 2) electric hot water heater energy use, which increases because of lower supply water temperatures during the winter.

Comparing the Tulalip and Hood River home results, the average error of the PRISM-based space-heating estimate was positive for the

TABLE 1. PRISM-Based Space-Heating Estimates and Measured Annual Heating Energy Consumption (kWh/year)

	PRISM Estimates			Measured			
	Heating		Total	Heating		Total	Heat
Data Set	kWh	kWh/ft^2	kWh	kWh	kWh/ft^2	kWh	Error[a]
Tulalip Homes							
average	6814	6.9	15262	4513	4.8	15298	0.52
maximum	9277	9.8	22708	5900	5.8	22478	1.02
minimum	3429	4.0	9170	2660	2.2	9333	-0.08
n=16							
Hood River Homes Pre-Retrofit[b]							
average	12370	13.2	23278	12565	13.3	---	-0.01
maximum	17300	26.3	42279	18146	26.3	---	0.33
minimum	4272	3.2	15232	6159	4.6	---	-0.42
n=19							
Hood River Homes Post-Retrofit[b]							
average	10980	10.0	22780	12279	11.0	---	-0.09
maximum	14972	16.6	40885	17987	22.0	---	0.28
minimum	4431	3.3	16708	7505	5.6	---	-0.41
Hood River Homes Post-Retrofit[b]							
average	10980	10.0	22780	12279	11.0	---	-0.09
maximum	14972	16.6	40885	17987	22.0	---	0.28
minimum	4431	3.3	16708	7505	5.6	---	-0.41
n=10							

(a) Heat error = (PRISM heating component - actual heat)/actual heat.
(b) The values of the total measured load were not calculated for this table.

energy-efficient Tulalip homes and negative for the Hood River homes. This suggested that the error in the PRISM-based space-heating estimate might be related to the energy-efficiency of the home and the relative effect of internal and solar gains.

ADJUSTMENT OF PRISM-BASED HEATING COMPONENT WITHIN CLIMATE ZONE

As the results in Table 1 indicated, PRISM-based estimates of the heating component can differ substantially from the metered heating energy consumption. For individualhomes, the errors ranged from -42% to +102% and the mean value of the errors tended to obscure the large variance in the differences. The positive and larger errors for the energy-efficient homes were particularly troubling since our focus was on estimating the performance of energy-efficient homes.

Given the sample of homes available, we examined the relationship between the PRISM-based heating component and the measured heating consumption. We ran a simple regression analysis using the actual heating consumption as the dependent variable and the PRISM-based estimate as the independent variable. Table 2 shows that a significant relationship exists, with the actual average heating consumption about 96% of the PRISM-based estimate. The R-squared was 0.68, which indicated a reasonable correlation between the variables. The predictive power of the PRISM-based heating component was not particularly good, though, as the results in Table 1 confirmed, particularly for the Tulalip, energy-efficient homes.

TABLE 2 Initial Regression Results

Dependent Variable: Actual heating energy consumption

Independent Variable	Estimated Coefficient	t-Statistic
PRISM-based space-heating estimate	0.96	26.4

Number of Observations = 45
R-squared = 0.68

Because of the demonstrated inability of the PRISM-based heating component to provide an adequately accurate estimate of the actual space-heating consumption, we developed a methodology to adjust the PRISM-based estimates of heating consumption and utilized the measured data available in our study. The technique was developed to increase the utility of information from PRISM in estimating heating loads, based on billing data, within a given climate zone. Lee et al. (6) presents a methodology that can be used to improve extrapolations to other climate zones.

One principle observed in developing the adjustment methodology was to restrict the required information to two kinds of data. One kind is provided by PRISM itself, such as the PRISM-based reference temperature (T-ref). The second kind consists of data readily obtained for specific homes being analyzed with PRISM, such as weather data or the design UA.

BACKGROUND

The PRISM-based heating component consists of the product of the PRISM heating slope and the PRISM heating degree-days (HDD), which are based on outside daily average temperatures and the PRISM T-ref. The heating component can be represented through the following equation:

$$\text{PRISM-based heating component} = \text{PRISM slope} * HDD_p \quad (1)$$

where HDD_p is the PRISM estimate of HDD, based on PRISM *T-ref*. HDD_p is the summation of the difference between PRISM T-ref and the average daily outside temperature for those days when PRISM T-ref exceeds the average outside temperature. The PRISM reference temperature is estimated by PRISM and is intended to indicate the daily-average outside temperature at which heating begins.

Next, we assume that a true, but unobserved, linear relationship with a form similar to the form of PRISM's heating term exists for predicting heating energy consumption. This is essentially a degree-day formulation for estimating space-heating load. We write this relationship as

$$\text{Actual heating} = \text{actual slope} * HDD_a \quad (2)$$

where actual slope is the slope value that corresponds to the measured space-heating consumption and HDD_a is the heating degree-days based on the actual T-ref.

Next, we examine the difference between the PRISM-based heating component equation (1) and the actual heating load and define it as the heating error. This variable is the "heat error" reported in Table 1, multiplied by the actual heating consumption.

$$\begin{aligned}\text{Heating error} &= \text{PRISM-based heating component} - \text{actual heating} \\ &= (\text{PRISM slope} * HDD_p) - (\text{actual slope} * HDD_a) \quad (3)\end{aligned}$$

Next, we assume that the PRISM estimates of each term can be written as the actual value for that term plus what we might call an error term:

$$\text{PRISM slope} = \text{actual slope} + \text{slope error} \quad (4)$$

$$HDD_p = HDD_a + \text{HDD error} \quad (5)$$

The so-called "error terms" do not correspond to the usual statistical error terms that might result from a regression model (such as the PRISM model itself). The terms here capture the differences between the PRISM-based estimates of the slope and HDD values and the values that apply in a hypothesized model that correctly captures the dependence of heating energy on outside temperature. Specifically, the PRISM slope term includes the effects of loads that are correlated (both positively and negatively) with HDD, whereas the comparable term from the hypothetical model (actual slope) is defined to depend only on space-heating loads.

Next, we can substitute equations (4) and (5) in equation (3), as follows:

$$\begin{aligned}\text{Heating error} &= (\text{actual slope} + \text{slope error}) * (HDD_a + \text{HDD error}) - (\text{actual slope} * HDD_a) \\ &= (\text{slope error} * HDD_a) + (\text{HDD error} * \text{actual slope}) + (\text{slope error} * \text{HDD error}) \quad (6)\end{aligned}$$

Equation (6) gives a functional form that can be the basis for a model to estimate the difference between the PRISM-based heating component and the actual heating energy consumption.

MODEL SPECIFICATION

Given the form of equation (6), none of the variables is directly measurable. Our approach was to identify measurable variables that could serve as proxies for each term and use the available data to estimate the coefficients for each proxy. As noted earlier, we sought variables that were from the PRISM procedure, or were easily obtained weather data or housing characteristics, to serve as proxies for the parameters in equation (6).

The approach taken was a heuristic one with the goal of developing an explanatory estimation model which best fit the observed differences between the PRISM term and actual heating consumption [equation (3)]. Our approach was to estimate a relationship that fit the data adequately, and use that relationship as a source of insights into the theoretical, causal relationships and sources of error in PRISM, and provide a means to adjust the PRISM estimates.

The actual slope term in equation (6) should be closely associated with the building design total heat loss coefficient, UA, since this slope term by definition captures only the heating load relationship to HDD. Given the component insulation levels, window characteristics, and infiltration characteristics, the design UA can be estimated using standard procedures (6). We used design UA as a proxy for the actual slope in equation (6).

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

Second, we considered the actual heating degree-day term, HDD_a. The actual HDD corresponding to individual homes depends on the T-ref where heating appears to begin. Without detailed heating data, we could not estimate accurately the outside temperature at which heating began. We chose to use HDD calculated to a standard reference temperature. Both because it was readily available, and it provided the best fit of the T-refs tried in our analysis, we used HDD calculated to a T-ref of 65°F as a proxy for HDD_a.[2]

Third, the relative slope error is influenced by how large the heating load is relative to the total load. We would expect the PRISM slope to be larger than the actual slope since the PRISM slope would include the effect of temperature- and seasonally-dependent loads other than heating. As the heating load's share of the total load increases, the error introduced by including the other temperature- and seasonally-dependent loads would be expected to remain positive but have a decreasing relative effect on the slope. The observations made earlier about the observed errors for energy-efficient homes also suggested that the slope error was larger for efficient homes where heating constituted a relatively smaller share of total loads. To capture the expected behavior, we assumed that the slope error could be represented as follows:

$$\text{Slope error} \sim a_1 - a_2 * \frac{\text{PRISM-based heating component}}{\text{PRISM estimate of total load}} \quad (7)$$

where a_1 and a_2 are positive constants.

Finally, we considered the HDD error term in equation (6). We have very little information to allow us to determine how the HDD error behaves. A study by Hirst and Goeltz (4) estimated a T-ref based on the metered heating load and found that the average PRISM estimate was less than the T-ref based on the load data. Their load-based T-ref is similar to what we call here the actual T-ref and their observations suggested that the PRISM HDD was less than the actual HDD, or the HDD error was negative. Another recent study used daily, weekly, and monthly simulation model data to estimate T-ref with variations in climate and the building load coefficient, UA (7).[3] Those results indicated that the analysis using monthly data (comparable to applying PRISM) produced T-ref values less than those from the analysis using daily data (comparable to our assumed "true" model) and they agreed with those from Hirst and Goeltz. In addition, Palmiter and Toney (7) also showed that the difference between the T-ref estimates increased as T-ref decreased.

Based on this limited information, we developed a proxy for the HDD error. The behavior noted above suggested that the T-ref error could be estimated as a negative constant plus a term that was proportional to the PRISM T-ref. Though the relationship between T-ref and heating degree-days is complicated by the outside temperature profile, we would expect the HDD error to behave similarly to the T-ref error: the HDD error would be zero when the T-ref error was zero, it would be negative when the T-ref error was negative, and it would become more negative as the T-ref error decreased. Consequently, we assumed that the HDD error could be described as follows:

$$\text{HDD error} \sim -a_3 + a_4 * \text{PRISM T-ref} \quad (8)$$

where a_3 and a_4 are positive constants.

MODEL ESTIMATION

Given the proxies and model structure discussed, we next used linear regression techniques to estimate model parameters. Based on the proxies chosen for the variables, we developed the following model:

$$\begin{aligned}\text{Estimated heating error} &= (a_1 - a_2 * \text{PRISM heating ratio}) \\ &\quad * \text{HDD} \\ &\quad + (-a_3 + a_4 * \text{PRISM T-ref}) * \text{UA} \\ &\quad + (-a_3 + a_4 * \text{PRISM T-ref}) \\ &\quad * (a_1 - a_2 * \text{PRISM heating ratio})\end{aligned} \quad (9)$$

where $a_1,...,a_4$ are positive constants and the PRISM heating ratio is the ratio of the PRISM-based heating component to the PRISM estimate of total annual energy consumption.

We made two modifications before estimating the coefficients in this equation. First, we deleted the terms appearing on the last two lines of equation (9). These terms are the product of the estimated HDD error and slope error and would be expected to be second-order adjustments and dominated by the first two terms in the equation. (In addition, their inclusion implies complex constraints on the coefficient estimates because their coefficients are products of the coefficients appearing on the first two lines.) Eliminating them leads to a first-order estimate of the heating error. Second, we rewrote the relationship so that the dependent variable was the measured heating energy consumption and we moved the PRISM-based heating component term to the right side of the equation. We allowed this term to be a predictor and felt that its inclusion on the right side might partially account for the variations due to the term that we excluded from the right side. From the initial regression, we found that the PRISM heating ratio did not have a statistically significant coefficient (a_2) and dropped this term

[2] In subsequent analyses it would be beneficial to examine other values of T-ref that are likely to be more accurate for individual homes, such as the PRISM estimate of T-ref. This extension was beyond the scope of our analysis.

[3] Their analysis related changes in UA to differences in T-ref estimates. We assume that their simulation-based observations about differences in T-ref estimates apply to errors arising in empirical data as well, though factors other than UA changes may have an effect in actual homes.

from the regression. The resulting equation was the following:

$$\begin{aligned}\text{Adjusted heating estimate} &= a_0 * \text{PRISM-based heating component} \\ &+ (-a_1) * \text{HDD} \\ &+ (a_3 - a_4 * \text{PRISM T-ref}) * \text{UA} \qquad (10)\end{aligned}$$

We used the measured heating energy data for pre- and post-retrofit Hood River homes and the Tulalip homes in a regression analysis to estimate the coefficients in this equation. The results are presented in Table 3.

All the signs of the coefficients were as anticipated. All coefficients were significant at the 99% confidence level. The model fit the data well, with an R-squared value of 0.88.[4]

TABLE 3. Regression Results for PRISM Adjustment

Dependent Variable: Actual heat

Independent Variable	Estimated Coefficient	t-Statistic
PRISM-based space-heating component	0.982	8.66
HDD	-0.841	-4.46
UA	61.8	7.20
PRISM T-ref * UA	-0.850	-5.65
Number of Observations		45
R-squared		0.88
Corrected R-squared		0.87

DISCUSSION OF RESULTS AND CONCLUSIONS

The relationship says that the actual heating energy consumption equals 98% of the PRISM-based estimate plus three adjustments. The slope error is 0.841, in kWh/degree-day. As anticipated, the slope error is positive. The PRISM slope estimates for the HRCP homes had an average value of about 3 kWh/degree-day and our relationship suggested that the true value was about 28% less.

The HDD error is -61.8 + 0.850*PRISM T-ref. This term indicates that the HDD error is zero for a PRISM T-ref of 73°F, is negative for lower values of T-ref, and becomes more negative for smaller values of the PRISM T-ref. The temperature at which the error equals zero is quite close to the results from the study cited earlier by Palmiter and Toney (7). Since the energy consumption data used to estimate this equation were in units of kWh/yr and the UA values were in Btu/hr-°F, the HDD error term estimated is not in conventional units. After conversion, the HDD error term is (-8788 + 121*PRISM T-ref), in degree-days. For a representative PRISM T-ref of 50°F, for example, the HDD error would be 2738 degree-days.

We used the estimating relationship to calculate the adjusted PRISM-based heating consumption for the homes in our sample. Table 4 compares the measured space-heating consumption with the initial PRISM-based estimate and our adjusted estimate. The PRISM-based estimate overpredicts the heating consumption by an average of 16%. Our estimate overpredicts by only 5%. The adjusted estimates also reduce the standard deviation of the percentage error; the standard deviation of the PRISM-based estimates (not shown) is 36% while the standard deviation of the adjusted estimates is 21%.

Figure 1 compares the results graphically. The line in the figure displays equivalence between the measured and estimated space heating values. The adjusted PRISM estimates are closer to the line than the PRISM-based estimates in almost all cases. They are closer for both the higher and lower heating energy values.

The adjustment significantly reduces the error based on the PRISM-based estimate alone. The adjustment is based on homes representing a very wide range of thermal characteristics (UA ranges from about 170-700 Btu/hr-°F), therefore, it can be applied to manufactured homes representing a wide range of sizes and efficiency levels. Since it is based on data from basically one climate region, however, we do not believe it can be applied directly to significantly different climatic areas. There are several enhancements possible to the adjustment methodology. For example, an adjustment based strictly on PRISM outputs and weather data could be developed, thus eliminating the need for even UA information. With additional PRISM output data the basic relationship in equation (6) could have been redefined in terms of PRISM parameters (PRISM slope and HDD based on the PRISM T-ref) and reestimated, possibly eliminating the need for other data.

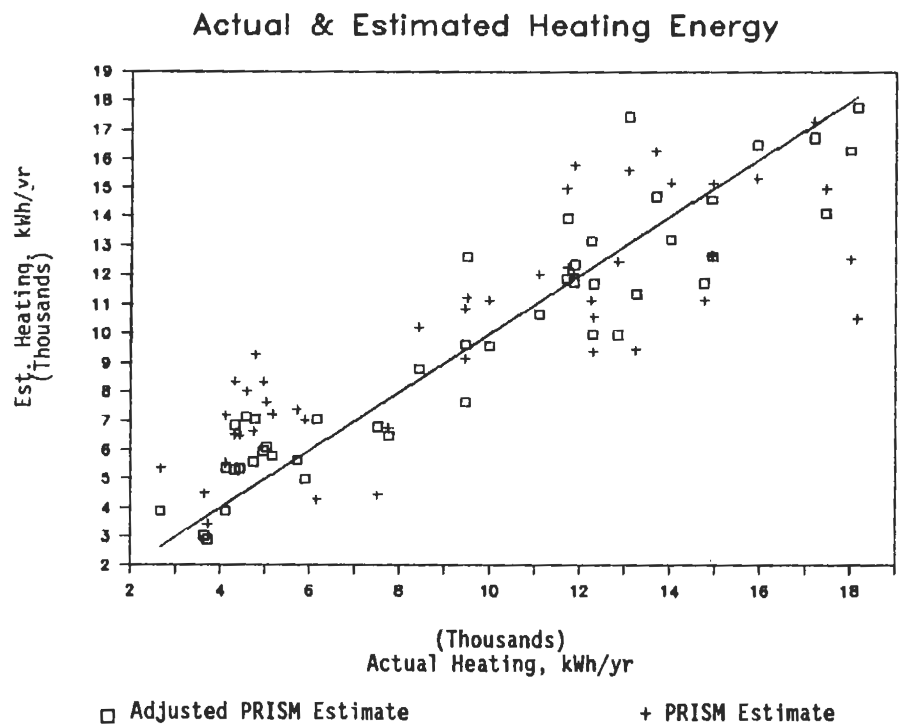
Enhancements to the adjustment that take into account additional climate factors should be examined. As noted, the relationship we estimated is only valid for climates similar to the one for which our data were available, specifically, moderate regions of the Northwest with moderate amounts of insolation. A method to extrapolate the adjusted heating energy consumption to other climates in the Northwest has been developed as a separate procedure and it takes into account the effects of differences in heating degree-days, insolation, and temperature swings (6). If both measured and simulation data were available, further analysis could explore the development of extrapolations to substantially different climate regions, such as the hot and humid parts of the country. Since our adjustment procedure relies on

[4]To validate this model we generated two random subsets of the cases used to derive these parameter estimates and re-estimated the model for each subset. We performed an F-test using the three sets of parameter estimates and found that the variance of the residuals was not statistically significantly different for the two estimating relations based on subsets (8). When we tested the hypothesis that the coefficients differed, the test indicated that the coefficients differed at about the 80% level, which was not considered a statistically significant difference.

TABLE 4. Comparison of Measured Heating, PRISM-Based Estimate, and Adjusted PRISM-Based Estimate (kWh/yr)[a]

	Measured	PRISM-Based Estimate	PRISM-Based -Measured	Adjusted Estimate	Adjusted - Measured
Average					
Value	9638	10086	447	9687	49
%	---	---	+16	---	+5
Minimum					
Value	2660	3429	-7607	2902	-4363
%	---	---	-42	---	-22
Maximum					
Value	18146	17300	4497	17786	3364
%	---	---	+102	---	+58

(a)Percents are the differences shown divided by measured heating.



Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

the assumption that heating energy can be estimated using a heating degree-day-based methodology, it suffers in part from the inherent weaknesses of that methodology in capturing the effects of solar gains and infiltration losses on energy consumption. Further investigation of climate effects on the adjustment would address these issues.

Though this adjustment procedure was developed for manufactured homes, there is no apparent reason it could not be applied to conventional site-built homes. Measured data for site-built homes covering a range of thermal characteristics could be used to examine extending the methodology.

Since PRISM requires only readily available billing and weather data, it is a very attractive technique for estimating the effects of conservation measures on space-heating energy consumption. Estimating these effects, however, requires the ability to estimate heating energy consumption accurately, and discrepancies between the PRISM-based estimates of space-heating energy consumption and measured data, especially in energy-efficient residences, have been observed in several previous applications of the model. As a result, it is desirable to increase the accuracy of the heating consumption estimates, but to retain the simple requirements of the PRISM approach.

The adjustment procedure described here represents a new approach for improving space-heating estimates developed from billing data. Adjusting PRISM-based space-heating estimates typically requires some information in addition to that required to run PRISM itself. For example, an estimate of seasonal variability in the non-heating load (9) or even the measured space-heating load (3) have been required in prior adjustment procedures. In the methodology proposed here, the building design load coefficient (UA) is required. In many cases, this information is either unavailable or unreliable. In applications (such as conservation demonstration programs) where good audit data or design data exist, however, UA estimates are usually available and this approach should be of use. The proposed technique also requires that measured space-heating data be available on a subset of homes. Given the fact that our sample of sub-metered homes was relatively small and located in a single climate region, the approach cannot be considered to be adequately tested and demonstrated for more general use. On the other hand, this technique shows promise as one way to reduce the errors in PRISM-based estimates for a population of homes when measured data are available on a sample of the homes.

ACKNOWLEDGMENTS

The research reported here was funded by the Bonneville Power Administration under an interagency agreement with the U.S. Department of Energy. The authors would like to thank Sheila Riewer and Kenneth Keating for their support throughout the project, and Rich Gillman and Fran Petersen. We also recognize the analytical support provided by William Monroe, Pacific Northwest Laboratory. Richard Goeltz, Oak Ridge National Laboratory, and Karen Schoch, Pacific Power, were very helpful in providing and interpreting the Hood River data. And we appreciate the assistance of Margaret Fels and the Princeton University Center for Energy and Environmental Studies in providing the PRISM model.

REFERENCES

1. Balistocky, S., A. A. Bohn, J. A. Heidell, P. L. Hendrickson, A. D. Lee, R. G. Pratt, and Z. T. Taylor, Impacts of Alternative Residential Energy Standards-Rural Housing Amendments Study, Phase I, PNL-5694-1, Pacific Northwest Laboratory, Richland, WA, 1985.

2. Fels, M. F., "PRISM: An Introduction," Energy and Buildings, Vol. 9, pp.5-18, Lausanne, Switzerland, 1986.

3. Bronfman, B. H., M. J. Horowitz, and D. I. Lerman, Energy Use in Homes Built to Model Conservation Standards: Outcomes Evaluation of the Tacoma Early Adopter Program, IEAL/PO-13, International Energy Associates Limited, Portland, OR, 1987.

4. Hirst, E. and R. Goeltz, Electricity Use for Residential Space Heating: Comparison of the Princeton Scorekeeping Method with End-Use Load Data, ORNL/CON-203, Oak Ridge National Laboratory, Oak Ridge, TN, 1986.

5. Westman, E. D. and W. H. Monroe, "Performance of the Princeton Scorekeeping Method for Estimating Annual End-Use Energy Shares as Measured with Metered End-Use Data," ACEEE Summer Study, Santa Cruz, California, 1986.

6. Lee, A. D., C. C. Conner, J. E. Englin, D. L. Hadley, R. G. Lucas, N. E. Miller, W. H. Monroe, Cost-Effectiveness of Conservation Upgrades in Manufactured Housing, PNL-6519, Pacific Northwest Laboratory, Richland, WA, 1988.

7. Palmiter, L. and M. Toney, "The Effect of Solar Gains on Degree-Day Regression Results," 12th National Passive Solar Conference, American Solar Energy Society, Ecotope, Inc., Seattle, WA, 1987.

8. Snedecor, G. W. and W. G. Cochran, Statistical Methods, Iowa State University Press, Ames, Iowa, 1987.

9. Fels, M. F., J. Rachlin, and R. H. Socolow, "Seasonality of Non-heating Consumption and Its Effect on PRISM Results," Energy and Buildings, V. 9, 1986.