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Electricity Use for Residential Space Heating: Comparison of the Princeton Scorekeeping Method with End-Use Load Data

Eric Hirst
Richard Goeltz

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ENERGY DIVISION

ELECTRICITY USE FOR RESIDENTIAL SPACE HEATING: COMPARISON OF THE PRINCETON SCOREKEEPING METHOD WITH END-USE LOAD DATA

Eric Hirst
Richard Goeltz

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SUMMARY

Because weather has a substantial effect on energy use, it is important to develop and apply methods that adjust for (normalize) variations in weather, both across space and time. The Princeton Scorekeeping Method (PRISM) is perhaps the best known and most widely used method to adjust residential energy use data for differences in winter severity. Nevertheless, questions remain about the accuracy of its results, especially about its ability to accurately decompose total residential energy use into its space heating and nonspace heating components.

The purpose of this report is to compare PRISM results with submetered data obtained from homes in Hood River, Oregon. The data used for this analysis are being collected as part of the Hood River Conservation Project (HRCP), a major residential retrofit demonstration project. HRCP data include whole-house and space-heating electricity uses, recorded at 15-minute intervals. Weather data are also recorded at 15-minute intervals, at the Hood River Experiment Station. The usual NOAA weather data were also available for this station; NOAA data on daily temperatures were used in this project. Finally, results of a detailed on-site home interview with these households are also available for analysis.

We compared PRISM estimates of total annual electricity use and of space heating electricity use with annual aggregates of the load data. These comparisons were conducted with two sets of the Hood River submetered homes. The first set consisted of 185 homes that used more than 2000 kWh for space heating during the 1984/85 year. The second set, a subset of the first, included 71 homes that used more than 4000 kWh/year for space heating, did not have portable electric heaters, and did not extensively use their air conditioners.

Our first comparisons were conducted using PRISM models estimated with monthly totals of the load data, rather than with monthly electricity bills. These comparisons were made for the 71-home subset and the larger set of 185 homes. Then we compared PRISM results obtained with actual monthly utility bills with load data. Finally, we estimated PRISM models using 12 weeks of data, rather than the usual 12 months, with starting dates in September 1984, November 1984, February 1985, and March 1985. Both the monthly and weekly models were estimated with 12 observations; the former set included 365 days while the latter included 84 days. The purpose of these latter comparisons was to see whether PRISM estimates obtained with only three months of data were accurate.

These analyses and comparisons suggest the following conclusions:

1. PRISM estimates of total electricity use (normalized annual consumption, NAC) are in almost perfect agreement with the annual totals of the whole-house load channel (Total).

2. PRISM estimates of space heating electricity use (Heat) are, on average, higher than the annual totals of the space-heating load channel (Space). For the 71-home subset, for which electricity is a major heating fuel, PRISM overestimated Space by an average of 600 kWh/year (6%). For the entire sample of 185 homes, the overestimate averaged 1,600 kWh (29%). Use of wood for space heating, PRISM estimates of reference temperature and the standard error of Heat, actual space heating electricity use, and use of air conditioning equipment are all statistically significant determinants of the discrepancies between Heat and Space. These discrepancies increase with wood use and reference temperature, and decrease with air-conditioner use, Space, and the standard error.

3. Two types of discrepancies between the monthly utility bills and monthly aggregates of the whole-house channel were uncovered. Single outliers are differences in these monthly totals of 10% or more of the load data; such outliers occurred with almost 10% of the monthly bills. Adjacent outliers are two single outliers of opposite sign, temporally adjacent, and roughly equal in magnitude. About 1% of the monthly bills were adjacent outliers.

4. Errors in the billing data (both single and adjacent outliers) affect the accuracy of PRISM estimates. Fortunately, there were only four household-years of billing data with substantial errors. Deletion of these four cases brings the PRISM estimates back into line with those obtained with load data (points 1 and 2 above).

5. The accuracy of PRISM results estimated with 12 weeks of data depends strongly on the time period chosen for estimation. Use of winter data (November 1984 through February 1985 in this case) led to poor results. On the other hand, use of Fall or Spring periods gave reasonably good estimates of NAC, when averaged over all households.

The comparisons and analyses conducted here suggest that, under certain circumstances, PRISM yields reliable estimates of weather-adjusted total and space heating electricity uses. Estimates of NAC are almost always quite accurate; estimates of space heating use are less so.

PRISM estimates of space heating use are more accurate for homes that rely primarily or excusively on electricity for space heating and that do not use much electricity in summer for air conditioning. On the other hand, PRISM estimates of space heating electricity use are relatively inaccurate for homes that rely primarily on wood for space heating and that show large seasonal variations in baseload uses. Regression models estimated here can be used to adjust PRISM results to yield improved estimates of actual space heating electricity use.

Because monthly utility bills are the raw material for PRISM estimates, errors in the billing data can lead to errors in PRISM estimates. Therefore, it is important to examine billing data before estimating PRISM models. Fortunately, it is usually possible to identify and either correct or delete these outliers.

LIST OF ACRONYMS

Base	Baseload (nonspace heating) electricity use, Total - Space
BPA	Bonneville Power Administration
D( )	difference, e.g., DSpace = Heat - Space
HDD	heating degree days
Heat	PRISM estimate of annual space-heat electricity use
HRCP	Hood River Conervation Project
k	thousand
M	million
NAC	normalized annual consumption
NOAA	National Oceanic and Atmospheric Administration
PNWRES	Pacific Northwest Residential Energy Survey
PP&L	Pacific Power & Light Company
PRISM	Princeton Scorekeeping Method
R( )	Ratio, e.g., RSpace = Heat/Space
Space	annual total of space-heat load channel
Total	annual total of whole-house load channel
Tout	outdoor temperature
Tref	reference temperature

1. INTRODUCTION

The amount of energy used in a home for space heating, water heating, lighting, operation of appliances, and miscellaneous purposes is a complicated function of many factors. These factors can be separated into two groups: the dwelling unit and its energy-using equipment (capital stock), and the ways in which these energy-using systems are operated. Both sets of factors are themselves functions of other variables such as present and past fuel prices, household income, number and ages of household members, climate and weather, age and type of dwelling unit, design efficiency of appliances and heating equipment, and so on.

Understanding the influence of these various determinants of residential energy use is important for several purposes. In particular, the design and implementation of successful residential energy conservation programs depend on adequate understanding of how and why households use energy. In addition, analysis of changes in energy use (e.g., due to a particular conservation program) requires identification and quantification of the various factors that account for changes in energy use over time. At a more aggregate level (e.g., utility service areas), weather-adjustment is needed to properly compare electricity sales trends from year to year (Cambridge Systematics, Inc. 1983).

Weather (especially outdoor temperature) is the major short-term determinant of residential energy use (Fels 1986). Depending on the climate, weather affects space heating, air conditioning, or both. For example, electrically heated homes in Oregon typically use four times as much electricity per week in mid-winter than they do in summer (Fig. 1). Adequately adjusting residential energy use data for temporal changes in

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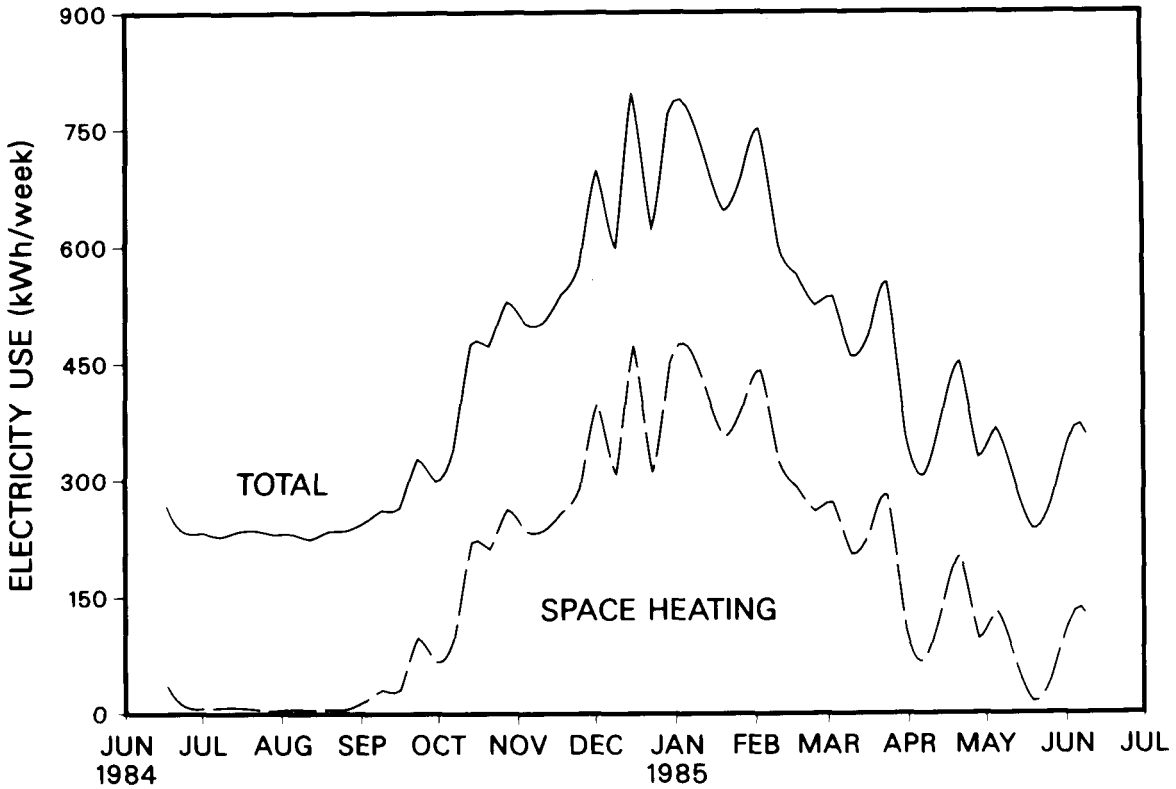

Fig. 1. Mean whole-house and space-heating electricity uses (kWh/week) from July 1984 through June 1985 for 185 homes in Hood River, Oregon. These homes all used more than 2000 kWh/year for space heating.

weather (e.g., from month to month or from year to year) is a critical initial step in identification of the importance of other determinants of energy use.

The Princeton Scorekeeping Method (PRISM) is perhaps the best known and most widely used method to adjust residential energy use data for differences in winter severity (Fels 1986; Wayne 1985).* Although PRISM has been used by many organizations, questions remain about the accuracy of its results, especially about its ability to accurately decompose

*A forthcoming issue of the journal Energy and Buildings (Volume 9, Numbers 1 and 2) will be devoted exclusively to PRISM.

total residential energy use into its space heating and nonspace heating components (Fels et al. 1983 and 1985; Fels, Rachlin, and Socolow 1986; Burnett and Lesser 1985).

The purpose of this report is to compare PRISM results with submetered data obtained from 185 homes in Hood River, Oregon. The data used for this analysis are being collected as part of the Hood River Conservation Project (HRCP), a major residential retrofit demonstration project. HRCP's collection of comprehensive data from these homes provides a rare opportunity to examine the detailed performance of PRISM and to identify reasons for differences between PRISM estimates and submetered electric load data. BPA is interested in the performance of PRISM because PRISM is frequently employed in evaluations of BPA residential conservation programs.

Discrepancies between PRISM estimates and load data can occur for various reasons (Table 1). The load data themselves may be measuring the wrong loads or may include missing values and errors. For example, the space heating and water heating loads were combined in at least one Hood River monitored home. In another, the range and clothes dryer loads were included in the space heat channel.

The monthly electricity billing data may also include errors that complicate comparisons between PRISM results and load data. Errors can occur in the field during meter reading or in the central-office processing of these data.

Finally, the PRISM model is based on assumptions about how households use their space heating fuel and the constancy of baseload uses (Chapter 2). For example, PRISM assumes that electricity use for space

heating varies linearly with outdoor temperature (Tout); however, heat pump performance varies with Tout leading to a nonlinear relationship between electricity use and Tout.

Table 1. Factors leading to discrepancies between PRISM estimates and actual electricity use

LOAD DATA
Electrical space heat loads not recorded properly
Portable electric space heaters
Incorrect loads on space heat channel
Use of electric stoves for space heating
Errors
Missing values
Errors in sensing, recording, or coding equipment
MONTHLY ELECTRICITY BILLING DATA
Incorrect readings of meter (kWh value) or date
Coding, keypunching, and processing errors
Vacant dwelling
PRISM
Misinterpretation of baseload use
Air conditioning, irrigation pump, etc.
Seasonality of nonspace heating electricity uses, both temperature dependent and season dependent
Nonlinear relationship between electricity use and outdoor temperature
Wood use, thermal capacitance of house, insolation, changes in indoor temperatures, heat pump
Microclimatic effects due to differences in outdoor temperature between dwelling unit and weather station

Because of potential problems with the load data and billing data themselves, the comparisons discussed here proceed from the "pure" to the actual. Our initial comparison is limited to homes that used more than 4000 kWh for space heating during the 1984/85 heating season, that have no portable electric heaters, and that use little or no electricity for air conditioning. In addition, the PRISM model is estimated using monthly totals of the load data rather than the monthly electricity bills. The second comparison expands the sample to include all homes that use more than a minimal amount of electricity for heating (2000 kWh). Our toughest comparison uses actual monthly electricity bills to estimate the PRISM model.

The next chapter discusses the theoretical determinants of residential energy use. Chapter 3 describes the HRCP data used in this project. Chapters 4 and 5 compare PRISM results with load data, under increasingly severe conditions. Chapter 6 uses 12 weeks (rather than 12 months) of load data to estimate PRISM models and compares these results with annual totals of load data. These comparisons are made using different time periods (Fall, Winter, Spring) to see whether data from a short period can yield accurate estimates of annual use. If three months of data are sufficient to accurately estimate annual electricity use, then future evaluations of conservation programs will take less time to complete.

2. THEORY OF HOUSEHOLD ENERGY USE

Of the many factors that affect household energy use, outdoor temperature surely has the greatest short-term influence (Fig. 1). That is, changes in temperature from day to day affect energy use for space heating and/or air conditioning. Changes in fuel prices, household income, the number and ages of household members, and other such factors affect energy use only in the longer term (over several months or years).

Because of the strong temporal influence of outdoor temperature on electricity use, our analyses of residential electricity use are typically conducted in two stages (Hirst and Goeltz 1985; Hirst et al. 1985). The first stage of our approach adjusts electricity use for changes in outdoor temperature during a heating season, using the Princeton Scorekeeping Method (PRISM) developed by Fels (1986). The second stage (not discussed in this report) uses PRISM results as the dependent variable in cross-section regression models. The explanatory variables in these models are demographic and dwelling unit characteristics, used to explain variations in annual electricity use across households.

Household energy use is the sum of energy use for the various end-uses (e.g., space heating, water heating, air conditioning):

$$E_i = \sum_{j=1}^{J} D_{ij} U_{ij} , \qquad (1)$$

where E is electricity use for household i, j is an index of electricity uses (e.g., space heating, dishwasher, clothes washer, color TV), D is a set of binary (0/1) variables that indicate presence of each (j) type of

electricity-using equipment, and U is electricity consumption for end-use j by household i (Bohi and Zimmerman 1984). Thus, the vector D captures the capital stock available to a particular household and the vector U reflects the ways in which this stock is operated by the household.

Our focus in this project is on houses that use electricity for some or all of their space heating. Because space heating is generally the major energy end-user (accounting for almost 50% of total electricity use for the households in this analysis) and because space heating energy use is strongly temperature-dependent, we write a simpler model of electricity use:

$$E_{it} = a_i + b_i HDD_{it}(Tref_i) \ , \qquad (2)$$

where the unit of analysis is one year of billing data for one household, called a household-year. In this model, j is implicitly set equal to 2: j = 1 refers to space heating and j = 2 includes all other electricity uses. D_1 and D_2 are both equal to 1.

In eqn. 2, E is energy use for household i during monthly billing cycle t.* The coefficient a_i reflects household use of energy for nonspace heating purposes and the coefficient b_i reflects use of energy for space heating (more accurately nonweather- and weather-sensitive consumption, respectively).

---

*Electricity billing and HDD data are normalized by the number of days in each billing cycle to correct for differences across households in the number of days per cycle.

HDD is the number of heating degree days to reference temperature Tref, for the same time period as the utility bill, for a weather station near that household. Daily HDD is defined as maximum (0, Tref - average daily temperature); daily HDD values are summed to obtain monthly or annual values. Daily temperature data are generally from the National Oceanic and Atmospheric Administration (e.g., NOAA 1984).

The reference temperature (Tref) is defined as that temperature which yields the highest explanatory power (R^2) in the above model; we restricted Tref to integers in the range 10 - 90°F. Physically, Tref is the outdoor temperature below which the heating system must operate to maintain the desired indoor air temperature; i.e., no heating is required at temperatures higher than Tref.

The physical basis for eqn. 2 assumes that the electricity required for space heating is linearly proportional to the difference between Tref and Tout. The expected relationship between daily space heating electricity use and Tout is shown in Fig. 2. The HRCP load data can be used to estimate the following model:

$$\text{Space}_{it}\ (\text{kWh/day}) = c_i + d_i * \text{Tout}_t\ , \qquad (3)$$

where Space is daily electricity use recorded by the space heat channel,* and c and d are coefficients estimated with the model. The reference temperature (intercept in Fig. 2) is computed as $-c_i/d_i$ for each household i. If the R^2 for this model is low (e.g., below 0.4), then the

---

*We excluded days with less than 5 kWh for space heat use in estimation of eqn. 3, consistent with prior work in the Pacific Northwest (Dickinson et al. 1982). Equation 3 is <u>not</u> part of PRISM. PRISM uses whole-house data while eqn. 3 uses space-heating end-use data.

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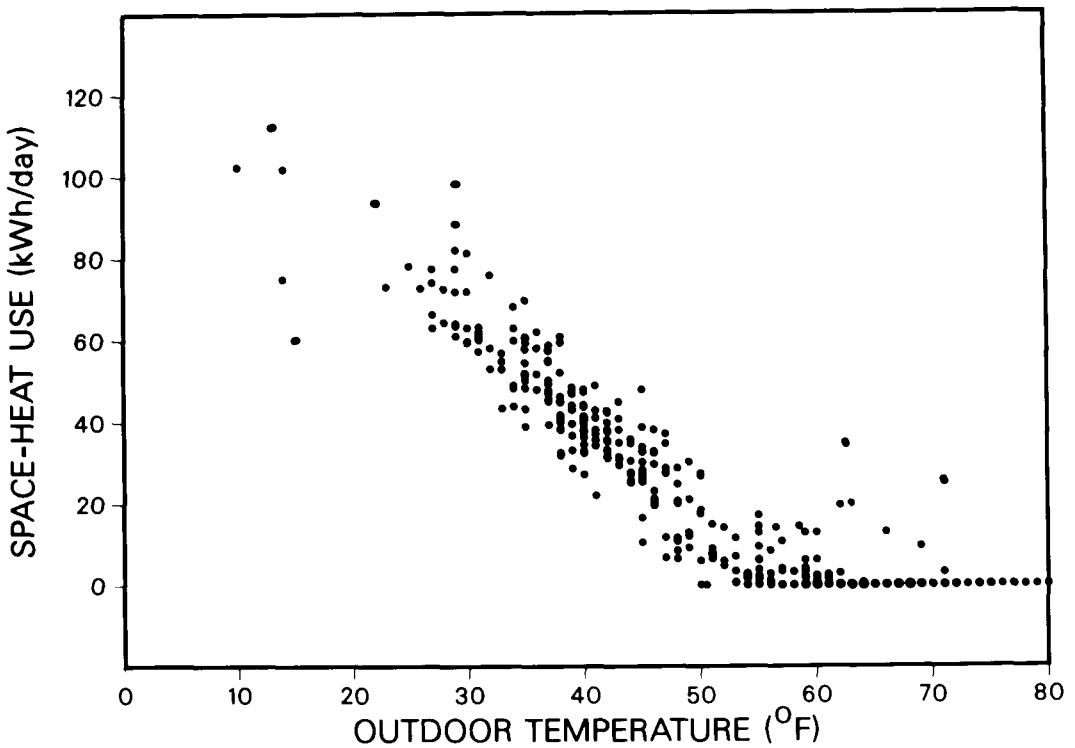

Fig. 2. Daily space heating electricity use as a function of outdoor temperature for a home in Hood River. Tref, computed from eqn. 3, is 58°F and the model R^2 is 0.84.

underlying PRISM assumption of linearity between space heating electricity use and outdoor temperature (Fig. 2) is probably incorrect.

The parameters from eqn. 2 (a_i, b_i, $Tref_i$) are estimated for each household using a year of electricity billing data (Fig. 3). The parameters are used to define Normalized Annual Consumption (NAC) for household i and year j:

$$NAC_{ij} = 365*a_{ij} + b_{ij}\overline{HDD}(Tref_{ij}) \ , \qquad (4)$$

where $\overline{HDD}$ is the long-run* normal HDD at base Tref for household i. A

*NOAA defines long-run as the 30-year average (e.g., NOAA 1982).

year is defined in this project as the 12 months from July 1984 through June 1985; the long-run HDD used here is set equal to the actual HDD for the 1984/85 period to permit comparisons between PRISM estimates and actual load data.* The NAC formula "corrects" household energy use for year-to-year changes in winter severity and for temporal misalignment across households in fuel bills (e.g., some records begin on July 1 and others on July 23; some histories are for 320 days and others for 375 days days).

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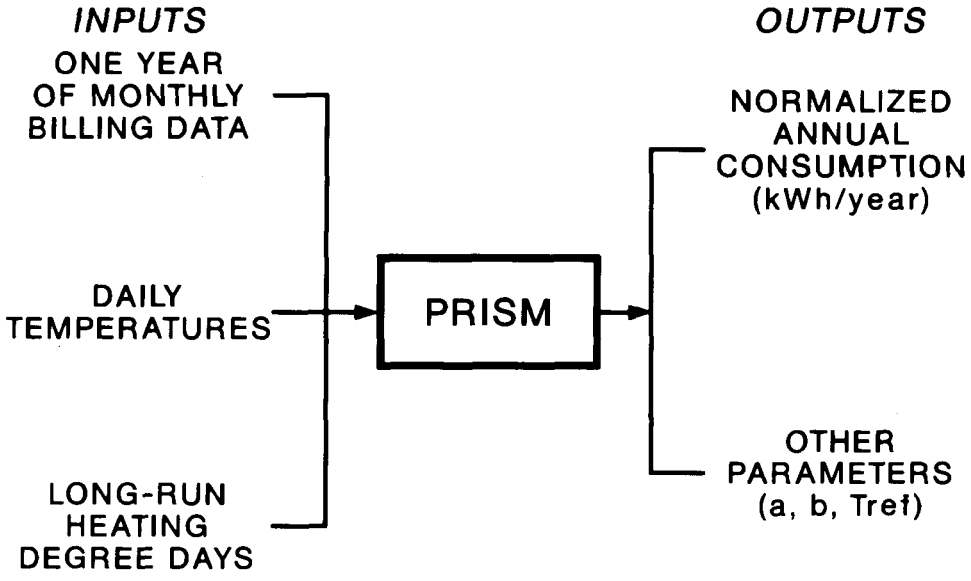

Fig. 3. Schematic diagram showing inputs to, and outputs from, PRISM.

*Total HDD (65°F base) for 1984/85 was 5900 based on daily temperatures at the Hood River Experiment Station. Long-run HDD is 5570.

The method described above does not deal with electric air conditioning because suitable analytical techniques to normalize air-conditioning electricity use have not yet been fully developed,* air conditioning loads are quite small in Oregon, and only about one-fifth of the homes in Hood River have air conditioners.

The second term in eqn. 4 is generally referred to as space heating electricity use. However, this term includes all electricity uses that depend on outside temperature (Fels et al. 1985) and/or that vary seasonally (Burnett and Lesser 1985). For example, water heating electricity use is generally higher in the winter than in the summer, both because households use more hot water in the winter and because ground water temperatures are lower in the winter (Fig. 4). Thus, water heating electricity use depends both on outside temperatures and on the season.

Lighting, on the other hand, depends on the season but not on outdoor temperatures. That is, household use of electricity for lighting is surely a strong function of the number of hours of daylight, which leads to more lighting use in winter than in summer (regardless of outdoor temperatures).

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*Electricity use for air conditioning depends on both dry and wet bulb temperatures (i.e., humidity is an important determinant of air conditioner use). Also, household operation of air conditioners is much more variable than is operation of space heating equipment. Both factors make it more difficult to analyze and normalize air conditioning energy use than space heating energy use.

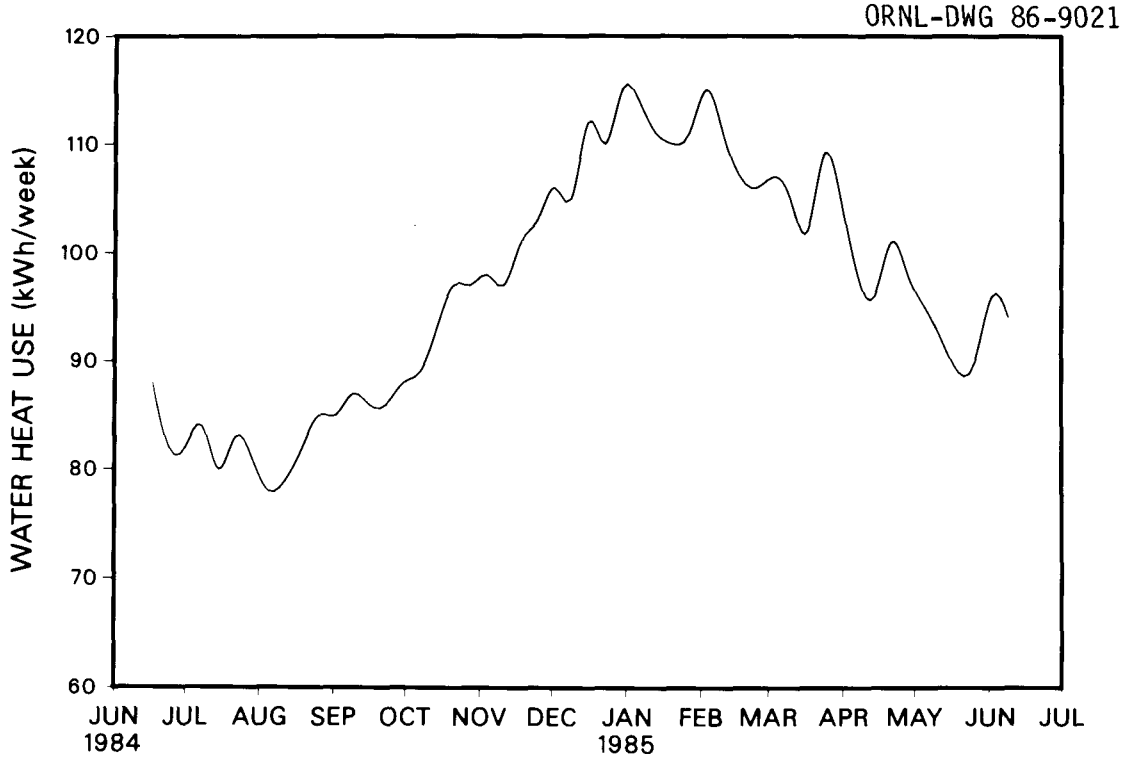

Fig. 4. Mean water heating electricity use (kWh/week) for 144 homes in Hood River, Oregon.

Electricity use for refrigerators is related to kitchen temperatures. Even in homes with air conditioning, kitchen temperatures are generally warmer in summer than in winter. Thus, refrigerator electricity use is higher in summer, displaying a seasonal pattern opposite that of water heaters.

This discussion illustrates two potential problems with PRISM. First, its estimates of space heating electricity use (Heat = b*HDD) may include some portion of baseload uses. Fels et al. (1985) show that, on average, b*HDD overestimates space heating energy use. Second, to the extent that some of the baseload use captured in this term is not dependent on outdoor temperatures, adjustment for changes in winter severity

from year to year will overcorrect NAC values (Burnett and Lesser 1985). The extent to which PRISM over- or under-estimates space heating electricity use is examined in Chapters 4 through 6.

We assume, in our two-stage analysis approach, that the first-stage NAC estimation removes the effects of changing weather (and more generally of all short-run time dependence) from household annual electricity use. Variations in NAC are assumed to be a function solely of cross-sectional (i.e., individual household) factors. In essence, PRISM converts the raw electricity billing data into a form suitable for further analysis.

In stage two of our approach, we analyze NAC as a function of these cross-sectional factors:

$$NAC_{ij} = e_o + \sum_k e_k Z_{ik} , \qquad (5)$$

where Z_{ik} is a vector of k demographic and dwelling unit characteristics (e.g., income, number of household members, floor area of home, age of dwelling unit, participation in a conservation program). The e_k coefficients show how weather-adjusted annual electricity use depends on these cross-section factors (i.e., varies from household to household).

The focus of this report is on the first stage of our approach, use of PRISM to adjust monthly billing data for temporal variations in outdoor temperature. See Hirst and Goeltz (1985), Hirst et al. (1985), and Goeltz, Hirst and Trumble (1986) for discussions of the second stage.

3. DATA FROM THE HOOD RIVER CONSERVATION PROJECT

HRCP is a $21 million, three-year residential retrofit demonstration project. The Project is intended to define the maximum limits of a utility-operated residential retrofit program, one in which cost to participating households is not a barrier and in which the level of retrofit measures installed is beyond that conventionally installed (PP&L 1983).

DATA RESOURCES

Because HRCP is an expensive and complicated project, the data associated with the project are correspondingly extensive and detailed. Perhaps more important, the project's focus on research - on the use of this demonstration to identify and quantify several important issues - requires collection of extensive data (Table 2).

Detailed electricity end-use data are being obtained from 319 homes in Hood River. Information on total, space heating, and water heating electricity use as well as indoor temperatures is collected at 15-minute intervals in these homes. Wood heat sensors are used in place of the water heating electricity use monitors in 100 of these homes (Oliver et al., 1984). These data are being collected for a period of at least two years, beginning in Spring 1984. Because these 319 homes were all retrofit in mid-1985 (May through July), a full year of preretrofit data and at least one year of postretrofit data will be available for analysis. The present project uses daily totals of the first year of data (July 1984 through June 1985) to compare PRISM results with actual load data.

Table 2. Data used in evaluation of HRCP

Data	Source	For whom
Pretest (1983) mail survey	Oregon State University	Random samples of households in Hood River, Grants Pass, Pendleton, and PNW region
Household monthly electricity bills and rate schedules	PP&L and Hood River Elec. Coop.	Households in Hood River, Grants Pass, and Pendleton
Detailed and daily weather data	NOAA, Univ. of Oregon	NOAA weather stations in 3 communities, 3 detailed weather stations in Hood River
End-use load data	PP&L	319 homes in Hood River; 15-minute data on total, space, and water heat electricity use, and indoor temperatures; wood heat sensors replace water heater load in 100 homes
On-site home interview	Bardsley & Haslacher	319 load-metered homes, conducted in July 1984
Load monitors on one feeder line	PP&L	
Project data	PP&L	Households that participate in HRCP Marketing questionnaire Demographics and appliance data Energy audit Barriers to retrofit measures Cost-effectiveness results Postinstallation inspection
Nonparticipant survey	Bardsley & Haslacher	Telephone survey in late-1985
Wood heat survey		Survey in Spring 1986 to determine ownership of wood burning equipment and amount of wood used for space heating
Posttest (1986) mail survey	Oregon State University	Random samples of households in Hood River, Grants Pass, Pendleton, and PNW region

Data at a comparable level of temporal detail (15-minute intervals) are collected at three weather stations in Hood River. The primary weather station is at the same location as the NOAA Hood River Experiment Station. We used daily temperature data from NOAA (e.g., NOAA 1984) in the present project.

The Project collects information on household demographics and appliance holdings at the time of the initial energy audit. The audit yields estimates of the applicable retrofit measures, their likely energy savings and expected costs. Information on appliance holdings (especially portable electric heaters) are used in the present analyses.

A detailed on-site home interview was conducted in July 1984 among the load-metered homes. This interview, which used the same questionnaire used in the 1983 Pacific Northwest Residential Energy Survey (BPA 1984), included detailed questions on the demographic characteristics of these households, the characteristics of their dwelling units and appliances, primary and supplemental heating fuels, and other energy-related attributes. Much of this data is used here to explain differences between PRISM estimates and actual load data.

DATA QUALITY

Although 319 homes were nominally load metered, data on only 268 were available for this project (Table 3). Seven households lacked the on-site home interview, monthly electricity bills were unavailable for two households, eight households had problems with one or more load channels (e.g., incorrect loads recorded on channels), 41 households had more than 35 days of missing electricity use for the whole-house or space heat channels, six households had more than five days of zero

electricity consumption on their total channel, and two households shared electric meters with another household (master-metered).

Table 3. Disposition of HRCP load-metered data

	No. of homes
Total	319
Available for present analysis with usable data: surveys, bills, nonmissing/nonzero load data, no master-meter duplications	268
With space heating electricity use > 2000 kWh/year	185
With total electricity use > 8000 kWh/year, space heat use > 4000 kWh/year, Space/Total > 0.25, no portable electric heaters, zero or modest use of air conditioning, R^2 for Tref from eqn. 3 > 0.4	71

The following procedure was used to impute values for whole-house (Total) or space heating (Space) load when either was missing. If data were missing for more than 35 days, the household was dropped. Otherwise, the daily total for the appropriate channel from a week earlier was used to impute the missing value. If the prior-week value was also missing, then the prior day was used. Finally, if neither procedure yielded a nonmissing value, then the daily value averaged over all nonmissing days was used to impute a value. Imputed values were not allowed to propagate themselves; i.e., imputed values were never used to provide data for other missing days.

A total of nine households had one or more days of zero total electricity use. Of these, three had fewer than six days missing and

were retained for further analysis. The remaining six cases had zero consumption for an uninterrupted period of more than five days; they were dropped under the assumption that the zero days reflected a change in occupancy with a vacancy some time during the one-year period.

Although all 268 homes had permanently installed electric space heating equipment (the primary requirement for participation in HRCP), many households used little or no electricity for heating. About 15% of these homes used less than 1000 kWh/year for heating (10% used less than than 300 kWh). By comparison, space heating electricity use averaged 10,000 kWh among the 74 homes that reported electricity as their sole heating fuel in the 1984 survey. Because PRISM is designed to weather-adjust energy use for the primary space heating fuel, we dropped households that used less than 2000 kWh/year for space heating; the remaining 185 households form the basis for our analyses.

Many of these remaining 185 households used wood as either their primary or supplemental heating fuel. We therefore defined a subset of these households, those for which electricity is probably the primary heating fuel. This subset of 71 households met the criteria shown in the bottom portion of Table 3.

The first three criteria ensure that the household uses a substantial amount of electricity for space heating and for other purposes, and that space heating electricity use accounts for at least 25% of total use. The restriction concerning portable heaters is imposed because such units are not included in the space heating load channel and would therefore yield misleading comparisons between PRISM results and the load data. Considerable use of air conditioning equipment affects

summer (baseload) electricity use. PRISM's estimates of baseload use (the coefficient a) would be too high in these cases, leading to underestimates of space heating electricity use. The R^2 restriction applies to models we estimated using daily space heating electricity load data, eqn. 3. If the R^2 for this model is low (e.g., below 0.4), then the underlying PRISM assumption of linearity between space heating electricity use and outdoor temperature (Fig. 2) is probably incorrect.*

Thus, the subset of 71 households defined above represents those homes whose use of electricity for space heating closely conforms to the assumptions embodied in the PRISM model. In other words, the agreement between data and PRISM should be particularly close for these homes.

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*One-third of the 185 households had Tref models estimated with daily space-heat end-use data with R^2 less than 0.4.

4. PRISM RESULTS OBTAINED WITH LOAD DATA

HOMES THAT USE ELECTRICITY AS A MAJOR HEATING FUEL

We begin comparison of PRISM results with actual electricity load data using the subset of 71 homes (Table 3); monthly billing data are not included in these comparisons. Because these homes use a substantial amount of electricity for space heating (at least 4000 kWh/year), PRISM is likely to perform well with these data.

PRISM's estimate of normalized annual consumption (NAC) and actual total annual electricity use (Total) are in almost perfect agreement for these homes (Table 4), as expected (Hurvich 1986). The maximum discrepancy between NAC and Total is less than 1% of Total.

On average, PRISM's estimate of space heating electricity use is 6% higher than the annual total obtained from the space heat channel; PRISM underestimates baseload use by an average of 3% (Table 4 and Fig. 5). As discussed in Chapter 2, we expect PRISM estimates of space heating electricity use to be higher than actual use because some baseload electricity uses are either temperature- or season-dependent. For these homes, the discrepancy is small and, on average, in the expected direction.

The agreement between the two estimates of reference temperature is not nearly so good as are the agreements for total and space heating electricity uses. On average, PRISM's estimate of reference temperature is 5°F lower than the estimate derived from a regression model of daily space heat electricity use vs Tout (eqn. 3). While the correlation coefficients between the load data and PRISM for total electricity use and space heating use are quite high ($r = 1.00$ and 0.89, respectively), the correlation coefficient for reference temperature is only 0.68.

Table 4. Comparison of PRISM estimates with load data for 71 homes that use more than 4000 kWh/year for space heating

	Median	Mean	Standard deviation
Total electricity use (kWh/yr)			
Load data	22,500	23,300	6900
PRISM	22,500	23,300	6900
Ratio (PRISM/Load)	1.00	1.00	0.00
Space heating use (kWh/yr)			
Load data	11,600	12,000	5100
PRISM	10,900	12,500	5600
Difference (PRISM-Load)	600	500	2500
Ratio (PRISM/Load)	1.05	1.06	0.22
Base use			
Ratio (PRISM/Load)	0.94	0.97	0.25
Reference temperature (°F)			
Load data	62.1	61.9	4.0
PRISM	56.0	57.0	6.1
Difference (PRISM-Load)	-4.4	-5.0	4.5
Model performance (R^2)			
Load data (eqn. 3)	0.75	0.74	0.09
PRISM (eqn. 2)	0.97	0.96	0.04

These results show that PRISM estimates of total annual electricity use are extremely accurate and that PRISM estimates of space heat use are slightly high. These HRCP data were next used to estimate regression models that can be used to adjust PRISM estimates of space heating electricity use.

Two models were estimated (Table 5). One used the difference between space heating estimates as the dependent variable (PRISM - Load) and the second used the ratio of these two values (PRISM/Load). The four explanatory variables used in these models include: dummy variable

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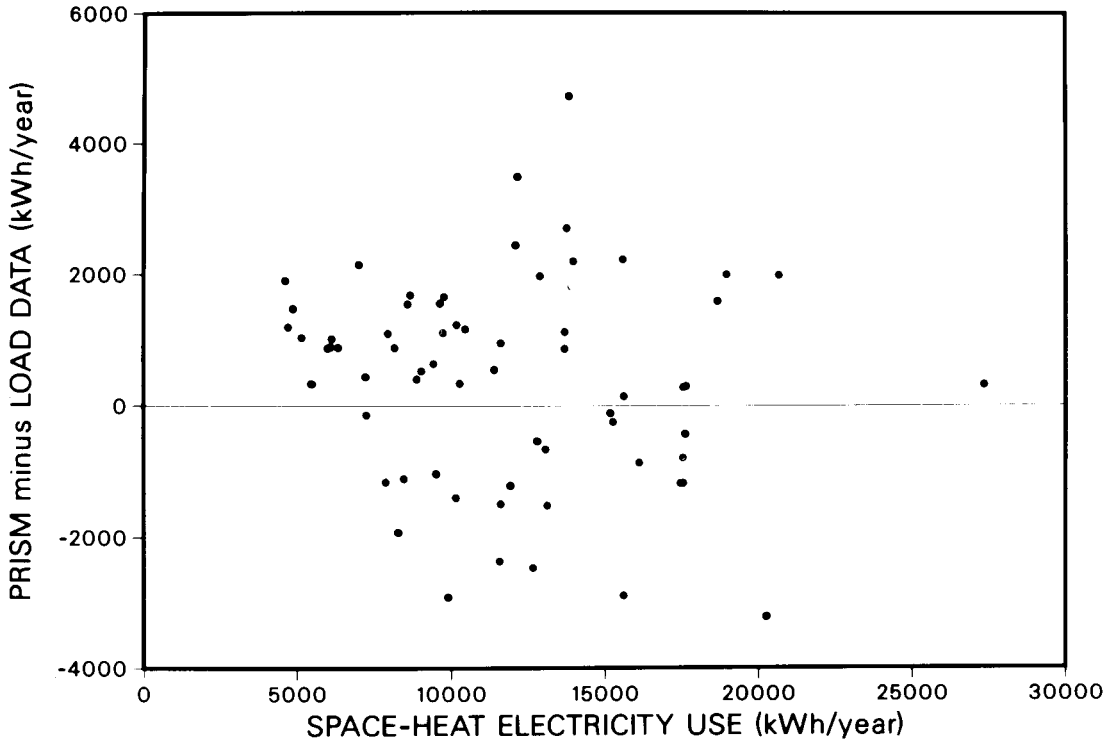

Fig. 5. Difference between PRISM estimate of space heating electricity use and load data vs load data for 71 homes in Hood River, OR. These homes all used more than 4000 kWh/year for space heating. Four of these households had DSpace values outside the range of the graph.

Table 5. Regression models of PRISM space heat estimates vs load data for 71 homes that use more than 4000 kWh/year for heating

	Dependent variable	
	PRISM-Load	PRISM/Load
Intercept	-10,110[c]	0.360[a]
Wood used for heating	941[b]	0.112[c]
Actual space heat use (MWh/yr)	-144[c]	-0.0185[c]
PRISM estimate of:		
Std error of heating (MWh/yr)	131[c]	0.0096[c]
Ref. temperature (°F)	205[c]	0.0150[c]
Model R^2	0.53	0.41

[a]Significant at the 10% level.

[b]Significant at the 5% level.

[c]Significant at the 1% level.

for use of wood for space heating (household reports of wood as the primary or supplemental heating fuel), the annual total of the space heat load channel, the standard error of the PRISM space heat estimate, and the PRISM estimate of reference temperature. The first variable is from the on-site home interview, the second is from the load data, and the last two are PRISM outputs.*

Use of wood for space heating will emphasize the importance of the seasonal component of baseload and increase the difference between PRISM and load data.** On the other hand, the importance of seasonal baseload decreases as actual space heating electricity use increases. The larger the standard error, the larger the expected difference between the two values. Higher PRISM estimates of Tref imply higher values of Heat, increasing the difference between Heat and Space.

The overall performance of these models is quite good, with about half the variation in the dependent variables explained by only four explanatory factors.† All the coefficients have the expected signs. For example, PRISM's overestimate of actual space heating electricity

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*We also tested other explanatory variables. In particular, we tested a pair of dummy variables for use of wood as the primary or supplemental heating fuel, rather than the single dummy variable. The single dummy variable performed better in all models.

**More than half the homes in this subset were all-electric (i.e., used no wood for heating). The remainder reported electricity as their primary heating fuel and wood as their supplemental heating fuel.

†Examination of the residuals from these models showed no heteroskedasticity problems. Also, the correlations (r) among explanatory variables were sufficiently small to suggest no problems with multicolinearity; the highest r among these variables was that between Tref and standard error, equal to 0.49.

use is increased by 940 kWh if wood is a heating fuel. A 1000 kWh/year increase in actual space heating electricity use reduces the discrepancy between PRISM and actual use by 140 kWh. An increase in the standard error of 1000 kWh increases the discrepancy by 130 kWh. Each 1°F increase in Tref increases the discrepancy by almost 210 kWh. All variables in both models were statistically significant, generally at the 1% level.

ALL HOMES

We continue our comparison of PRISM results with actual electricity load data with all the 185 homes that used more than 2000 kWh/year for space heating. This larger set of homes provides a tougher test of PRISM's performance because about 20% of these homes do not use electricity as their primary heating fuel.

PRISM's estimate of normalized annual consumption (NAC) and actual total annual electricity use (Total) are again in almost perfect agreement for these homes (Table 6).

On average, PRISM's estimate of space heating electricity use is 29% higher than the figure obtained from the space heat channel (Table 6 and Fig. 6), much higher than the 6% average overprediction for the 71 homes discussed above. The PRISM overprediction averages 1600kWh/year, compared with an average overprediction of only 600 kWh for the subset of 71 homes.

The relationship between the PRISM estimate and actual space heating electricity use depends strongly on whether electricity is used as the primary heating fuel (Table 6). The PRISM estimate exceeds actual space

heating electricity use by an average of 14% for all-electric homes,* by 35% for homes that use wood as a supplemental heating fuel, and by 46% for homes that use wood as the primary heating fuel.

Comparison between PRISM and load data estimates of reference temperature is meaningful only for the all-electric homes. The performance

Table 6. Comparison (means) of PRISM estimates with load data for 185 homes that use more than 2000 kWh/year for space heating

		By heating fuel(s)		
	All	All electric	Elec primary, wood supp	Wood prim elec supp
Total electricity use (kWh/yr)				
Load data	22,400	21,600	24,400	20,600
PRISM	22,500	21,600	24,400	20,600
Ratio (PRISM/Load)	1.00	1.00	1.00	1.00
Space heating use (kWh/yr)				
Load data	9,100	10,300	10,000	5,800
PRISM	10,800	11,300	11,900	8,000
Difference (PRISM-Load)	1,600	1,000	1,900	2,200
Ratio (PRISM/Load)	1.29	1.14	1.35	1.46
Base use				
Ratio (PRISM/Load)	0.91	0.93	0.89	0.89
Model performance (R^2)				
Load data (eqn. 3)	0.53	0.71	0.52	0.25
PRISM (eqn. 2)	0.87	0.94	0.87	0.72
No. of households[a]	185	68	76	40

[a]One household reported use of no electricity for space heating; its space heat channel recorded 2900 kWh during 1984/85.

*Analysis of all-electric homes in Colorado showed an average PRISM overestimate of 11%, very similar to the 14% observed in Hood River (Fels, Rachlin and Socolow 1986).

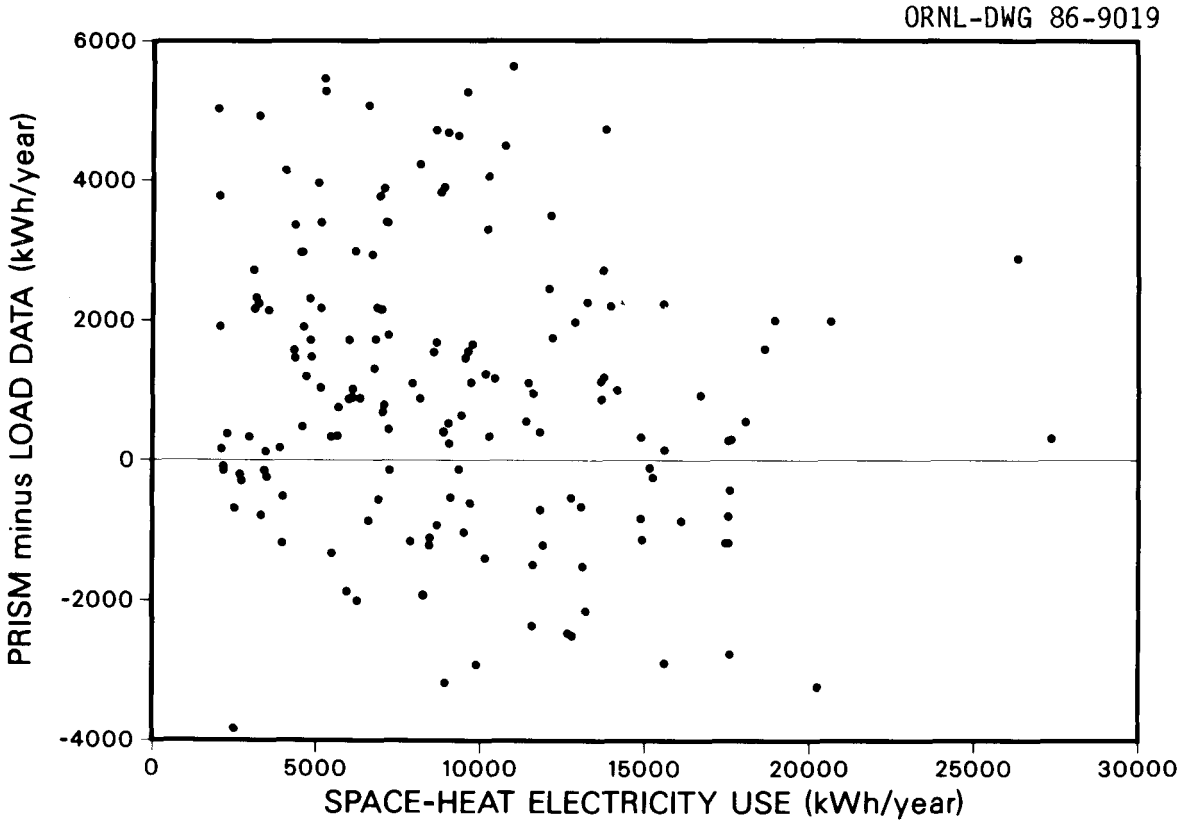

Fig. 6. Difference between PRISM estimate of space heating electricity use and load data vs load data for 185 homes in Hood River, OR. These homes all used more than 2000 kWh/year for space heating. Nineteen of these households had DSpace values outside the range of the graph.

of the regression model (eqn. 3) used to derive reference temperature with the load data is generally poor for homes that use wood for some heating; i.e., R^2 averages only 0.42 for these homes, compared with 0.72 for the all-electric homes. For the all-electric homes, PRISM's estimate of reference temperature is 5°F lower than the estimate derived from a regression model of daily space heat electricity use vs outdoor temperature. The average discrepancy between these two estimates of reference temperature is the same as for the subset of 71 homes.

The correlation coefficient between the load data and PRISM for total electricity use is again very high (r = 1.00). However, the correlation coefficient for space heating (0.80) is lower than the 0.89 for the subset of 71 homes. The correlation coefficient for reference temperature is only 0.54 for those cases where R^2 is greater than 0.4 for eqn. 3.

Finally, the overall predictive power of the PRISM model is quite good for these households. As wood use increases, the PRISM model R^2 decreases, from an average of 0.93 for all-electric homes to 0.72 for homes that use wood as the primary heating fuel and electricity as a supplemental fuel.

As with our analysis of the 71-home subset, these results show that PRISM estimates of Total are extremely accurate and that PRISM estimates of Space are generally too high.

These HRCP data were next used to estimate regression models that adjust PRISM estimates of space heating electricity use. In addition to the explanatory variables used in the earlier models (Table 5), we include dummy variables for homes that have portable electric heaters or that use their air conditioners a "moderate amount" or "all of the cooling season" (Table 7). Use of portable electric heaters should increase the PRISM estimate of space heating use relative to that recorded on the space heat channel. Use of electricity for air conditioning will increase PRISM's estimate of baseload and correspondingly reduce the PRISM estimate of space heating use.

Table 7. Regression models of PRISM space heat estimates vs load data for 185 homes that use more than 2000 kWh/year for heating

	Dependent variable	
	PRISM-Load	PRISM/Load
Intercept	-4901[b]	0.1443
Wood used for heating	99	0.0924
Actual space heat use (MWh/yr)	-146[b]	-0.0397[b]
PRISM estimate of:		
Std error of heating (MWh/yr)	128[b]	0.0079[a]
Ref. temperature (°F)	124[b]	0.0247[b]
Portable electric heater	394	-0.0556
Air conditioner used a lot	-1706[b]	-0.2387[a]
Model R^2	0.45	0.35

[a]Significant at the 10% level.

[b]Significant at the 1% level.

The overall performance of these models is almost as good as that of the models estimated with the 71-home subset (compare Tables 5 and 7).* Although the R^2 values are almost as high with the full data set, some of the explanatory variables are not statistically significant. Surprisingly, the dummy variables for wood use and for use of a portable electric heater are not significant in either model. Perhaps portable electric heaters are used only rarely. The effects of wood use might be picked up by other variables in the model, although the correlations among the explanatory variables are quite low.

*Once again, neither heteroskedasticity nor multicolinearity were problems with these models.

These models can be used to adjust PRISM estimates of space heating electricity use in cases where submetered data are not available. These adjustments will not be helpful for individual homes, but should improve the accuracy of estimates for groups of homes. We used these models to infer values of Space, using the coefficients in Table 7 for the all-electric and supplemental wood heat groups of the 71-home subset and for various groups of the 185-home total. The difference model is much easier to use than the ratio model* and yields more accurate estimates of Space. The difference model (Table 7) can be transformed so that Space appears only as the dependent variable:

$$\text{Heat} - \text{Space} = -5476 + \ldots -0.150*\text{Space} + \ldots$$

$$(1 - 0.15)*\text{Space} = \text{Heat} + 5476 + \ldots$$

$$\text{Space} = 1.176*[\text{Heat} + 5476 + \ldots]$$

Difference-model estimates of Space were generally within a few hundred kWh of the actual values.

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*Use of the ratio model to estimate Space requires solution of a quadratic equation.

5. PRISM RESULTS OBTAINED WITH MONTHLY BILLING DATA

The analyses presented in the preceding chapter involved estimation of PRISM models using monthly totals of the 15-minute load data. In typical applications of PRISM, the models are estimated using monthly utility bills. This chapter compares PRISM estimates based on monthly billing data with the load data (both whole-house and space heat channels).

We first compared monthly electricity bills with monthly aggregates of the whole-house channel. The 15-minute load data were summed to provide daily (24-hour) totals. These daily values were then summed to yield whole-house electricity use for each household's billing cycle. For example, if a household's bill was for the period July 27 through August 30, then the total load channel was summed for this period.

Discrepancies between the billing and load data were then identified. Single outliers were defined as differences in monthly totals with a relative error of 10% or more of the load data. These limits were chosen so that errors in the meter-read dates of one or two days would not lead to identification of an outlier. Almost 10% of the monthly observations were classified as single outliers.

Adjacent outliers were defined as two single outliers of opposite sign that were temporally adjacent and similar in magnitude. If a meter is read incorrectly one month and correctly the following month, there will be two errors of opposite and roughly equal magnitude. Adjacent outliers occurred much less frequently than did single outliers; about 1% of the monthly observations were classified as adjacent outliers.

Overall, only one-third of the household-years of electricity billing data had no outliers (Table 8). Almost 20% of the files had one or two pairs of adjacent outliers and 60% had one or more single outliers.

Table 8. Discrepancies between monthly electricity bills and whole-house load data for 185 Hood River homes

	Percentage of homes with:	
No. of single outliers	No. of adjacent outliers	
	0	1 or 2
0	33	7
1	38	9
2	6	2
3+	5	0

To examine the relationship between NAC and Total, we defined variables that indicate the presence and magnitude of single and adjacent outliers:

$Sin = load_t - bill_t$

$Sinp = Sin$ if $Sin > 0$ and not Adj otherwise 0,

$Sinn = Sin$ if $Sin < 0$ and not Adj otherwise 0,

$Adj = |Sin_t| + |Sin_{t-1}|$ if both Sin_t and Sin_{t-1} > 10% of whole-house channel monthly total

and $-1.2 < (Sin_t/Sin_{t-1}) < -0.8$ otherwise 0.

Values of Sinp, Sinn, and Adj are summed across the twelve months of billing data for each household-year. Thus, these variables indicate

the extent of errors in the billing data for an entire year. Our definition of Sinp and Sinn permit us to analyze the effects of positive and negative outliers separately.

We used these measures of the discrepancies between monthly bills and whole-house load data as explanatory variables in models of DTotal and RTotal, analogous to the models of space heating electricity use developed in Chapter 4. These models, estimated with the 71-home subset, had very high explanatory power, with R^2 values of about 0.8. PRISM estimates of NAC differed by more than 5,000 kWh from Total for four of these 71 households.

PRISM estimates of NAC are too low when there are positive single outliers (Sinp); i.e., when the monthly bill is lower than the actual whole-house load, NAC is lower than Total. The reverse occurs with negative single outliers (Sinn). Adjacent outliers increase NAC relative to Total. The remarkably high model R^2 shows, once again, that PRISM estimates of NAC are very accurate unless the billing data contain errors.

Because of the enormous influence of errors in the billing histories for a few homes, we deleted the four anomalous cases before continuing our comparison of PRISM and load data.* For the remaining 67 homes, PRISM's estimate of NAC and total are in almost perfect agreement, on the average (Table 9). The maximum disagreement is 10% of Total. Our

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*Two of these four cases had single outliers for each of the twelve months, which suggests an error in the meter multiplier used to convert meter readings into kWh values. The other two cases had adjacent outliers, probably because of errors in coding or keypunching meter reading dates.

earlier comparison of NAC and Total, based on PRISM models estimated with the load data, showed a 1% maximum discrepancy. Thus, errors in the billing data lead to some errors in NAC estimates.

To quantify the effects of errors in the billing data, we estimated regression models of DTotal and RTotal (Table 10), similar to those mentioned earlier in this section. Model performance is quite good, with R^2 values of almost 0.9. Thus, even after the largest outliers are removed, three variables related to errors in the billing data explain almost all of the discrepancy between NAC and Total. Again, both single and adjacent outliers contribute to discrepancies between NAC and Total.

Table 9. Comparison of PRISM estimates with load data for 67 homes that use more than 4000 kWh/year for space heating, using monthly billing data to estimate PRISM models

	Median	Mean	Standard deviation
Total electricity use (kWh/yr)			
Load data	22,500	23,200	6900
PRISM	23,200	23,100	6800
Ratio (PRISM/Load)	0.99	1.00	0.02
Space heating use (kWh/yr)			
Load data	11,600	12,000	5100
PRISM	11,400	12,500	5200
Difference (PRISM-Load)	800	500	2000
Ratio (PRISM/Load)	1.06	1.07	0.22
Base use			
Ratio (PRISM/Load)	0.91	0.96	0.22
Reference temperature (°F)			
Load data	62.1	61.8	3.9
PRISM	55.9	55.8	7.0
Difference (PRISM-Load)	-4.8	-6.0	6.5
Model performance (R^2)			
Load data (eqn. 3)	0.75	0.74	0.09
PRISM (eqn. 2)	0.98	0.96	0.04

Table 10. Regression models of PRISM total electricity use estimates vs whole-house load data for 67 homes that use more than 4000 kWh/year for space heating

	Dependent variable	
	PRISM-Load	PRISM/Load
Intercept	-62[b]	0.9965[c]
Single error		
positive[a]	-975[c]	-0.0374[c]
negative[a]	-866[c]	-0.0420[c]
Adjacent error[a]	271[c]	0.0109[c]
Model R^2	0.88	0.87

[a]The coefficients are multiplied by 1000 to improve readability.

[b]Significant at the 10% level.

[c]Significant at the 1% level.

On average, the PRISM estimate of space heating electricity use is 7% higher than the annual total from the space heat channel for these 67 homes. The agreement between PRISM and load data is as good as it was for PRISM models estimated with load data (compare Tables 4 and 9). In general, the two sets of PRISM results - those obtained with monthly billing data and those obtained with monthly totals of the whole-house channel - are in very close agreement.

As before, we estimated models to explain variations in DSpace and RSpace. In addition to the variables tested earlier (Table 5), we included variables related to discrepancies between the billing data and whole-house load channel (Table 11). The variables related to errors in the billing data are less important than the other variables in explaining space heat discrepancies. In particular, use of wood for

space heating, reference temperature, and the actual amount of electricity used for space heating are all important determinants of the difference between the PRISM estimate and actual space heating electricity use. The coefficients in Tables 5 and 11 all have the same sign and are generally similar in magnitude.

Table 11. Regression models of PRISM space heat estimates vs load data[a] for 67 homes that use more than 4000 kWh/year for heating

	Dependent variable	
	PRISM-Load	PRISM/Load
Intercept	-11683[c]	-0.0641
Wood used for heating	1336[c]	0.1726[c]
Actual space heat use (MWh/yr)	-146[c]	-0.0207[c]
PRISM estimate of:		
Std error of heating (MWh/yr)	-172	-0.0419
Ref. temperature (°F)	233[c]	0.0232[c]
Single error		
positive[a]	59	0.0023
negative[a]	-1827[c]	-0.2095[c]
Adjacent error[a]	700[b]	0.0849[b]
Model R^2	0.48	0.42

[a]These coefficients are multiplied by 1000 to improve readability.

[b]Significant at the 5% level.

[c]Significant at the 1% level.

The models of DSpace and RSpace developed here (Table 11) are not suitable for adjustment of PRISM estimates of Heat because load data are generally not available. The purpose of developing the present models is to examine the influence of errors in the billing data on PRISM estimates.

The models discussed earlier (Table 7) can be used to adjust PRISM results to obtain better estimates of actual space heating electricity use.

The comparisons performed in this chapter show that discrepancies between monthly billing data and load data can have substantial effects on PRISM estimates. Fortunately, large errors in the billing data occur for only a small fraction of the households considered; i.e., about 5% of the household-years of billing data were dropped from further analysis. Also, such errors are generally easy to identify (Hirst, Goeltz, and White 1984). However, even minor differences between billing data and load data lead to small errors in PRISM estimates of both NAC and Heat.

In general, however, comparison of PRISM estimates of Heat with Space yields results very similar to those obtained with PRISM models estimated with load data (Chapter 4). The factors that lead to differences in space heating electricity use estimates are unchanged. Because the effects of billing data on results - after deletion of large outliers - are small, there is little to be gained in analyzing the full set of 185 households using monthly billing data.

6. PRISM RESULTS OBTAINED WITH WEEKLY LOAD DATA

A persistent problem in evaluation of energy conservation programs is the long time required to obtain results. Careful analysis of actual energy savings due to a program generally involves collection of a full year of preparticipation energy billing data plus a full year of post-participation data. Thus, evaluation results are often not available until 1½ to 2 years after the time of evaluation attention because of the need for postretrofit data and the time needed for data management and analysis.

Some have suggested use of energy consumption data for shorter periods. For example, Nadel and Sherman (1985) used run-time meters on gas and oil furnaces to record space heating (furnace) fuel consumption. These meters were read weekly for four weeks prior to retrofit and for four weeks after retrofit. Fuel consumption per heating degree day was computed separately for each time period. The change in this ratio was used as a measure of program effectiveness.* Unfortunately, there is little evidence that collection and analysis of energy consumption data over a four-week period is sufficient to determine normalized annual fuel use.

Weekly measurements of energy use can be obtained by asking households to record meter readings. This is inexpensive but subject to both

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*A similar project is underway at ORNL, using natural gas data obtained from low-income homes in Wisconsin. Both the Nadel and Sherman and ORNL projects involve measurement of space heat fuel use, not just whole-house data.

errors and incomplete reports. An alternative is to have a project staff member read meters on a weekly basis, which is much more costly.

The HRCP load data permit estimation of PRISM models using electricity consumption data for less than the usual monthly billing cycle. In the experiment reported here, we used weekly summaries of the whole-house channel as the input data to PRISM. Specifically, we estimated PRISM models for each of the 71 households in our subset using 12 weeks of data,* beginning on September 1, 1984, November 1, 1984, February 1, 1985, or March 1, 1985. Thus, we have PRISM estimates obtained with billing data for the Fall, Winter, and Spring months. The Winter period chosen has no nonheating periods, while the Fall and Spring periods include weeks with modest or zero space heating electricity use (Table 12). We estimated PRISM models with two Spring periods to examine sensitivity of results to small shifts in time periods.

Table 12. Heating degree days (60°F base) for the Hood River Experiment Station, 1984 to 1985

	Monthly HDD by start date			
	9/1/84	11/1/84	2/1/85	3/1/85
Month 1	107	582	694	550
Month 2	375	830	550	252
Month 3	582	885	252	149
Total	1064	2297	1496	951

*We used 12 weeks of data so that the same number of observations would be used in these models as was used in the models estimated with monthly data.

Comparison of PRISM results obtained with 12 weeks of data with actual load data (Table 13) shows that agreement between analysis and data depends strongly on the time period chosen. PRISM models estimated with winter data perform very poorly. Lack of time periods with modest or zero space-heating electricity use prevents estimation of reasonable coefficients (Fig. 2). Thus, the time periods chosen for estimation of PRISM models should include some shoulder and baseload periods (Dunsworth and Hewett 1985).

The three sets of models estimated with Fall or Spring data provide reasonably good agreement with load data. For example, the mean difference between NAC and Total for the models estimated with September - November 1984 data is only 400 kWh/year, the mean ratio of NAC to Total

Table 13. Comparison of PRISM estimates obtained with weekly data with load data for 71 homes that use more than 4000 kWh/year for space heating[a]

	PRISM estimation period beginning on:			
	9/1/84	11/1/84	2/1/85	3/1/85[b]
Total electricity use (kWh/yr)				
Difference (PRISM-Load)	440	8000	760	1210
Ratio (PRISM/Load)	1.02	1.34	1.03	1.05
Space heating use (kWh/yr)				
Difference (PRISM-Load)	150	-7520	-1820	1180
Ratio (PRISM/Load)	1.05	0.41	0.89	1.13
PRISM model R^2	0.86	0.60	0.92	0.81

[a]Total and space heating electricity use for these homes averaged 23,300 and 12,000 kWh/year, respectively, based on the load data (Table 4).

[b]Deletion of one outlier (see text) changes these values to 730 kWh, 1.02, 700 kWh, 1.08, and 0.81.

is 1.02, and the standard deviation of NAC-Total is about 2700 kWh. On average, these models estimated with 12 weeks of data perform almost as well as models estimated with 12 months of data in terms of predicting total electricity use.

Not surprisingly, the agreement between estimates of space heating electricity use are not as good as the agreement between estimates of total electricity use. Considering the models estimated with weekly data beginning in September 1984 again, the mean difference between PRISM estimates and load data is 150 kWh, the standard deviation is 3200 kWh, and the mean ratio of Heat/Space is 1.05. This agreement is only slightly worse than that obtained with 12-month PRISM models (compare Tables 4 and 13). Note, however, that the models estimated with data beginning in February or March 1985 did not perform as well as the September models (Table 13).

The February and March results show disturbing differences. These differences, however, are due entirely to one household. For that household, the PRISM estimates of NAC and Heat are too high by about 36,000 kWh. Dropping this single observation brings the mean values of DTotal and RTotal for February and March into almost perfect agreement; the differences in DSpace and RSpace are substantially reduced but not eliminated.

As a final test of the accuracy of PRISM models estimated with weekly data, we computed the differences in NAC and HEAT between the "Fall" and "Spring" models. In principle, these differences should equal zero. The purpose of this test is to simulate the accuracy of such PRISM models in estimation of energy savings due to installation of conservation measures during the intervening time period.

The mean difference in NAC (320 kWh) between the November and February models was not statistically significant. However, the mean difference in Heat (1970 kWh) was significant at the 1% level. The mean differences in NAC and Heat between the November and March models were both statistically insignificant. The lack of statistical significance is reassuring; it suggests that PRISM models estimated with 12 weeks of data might yield results precise enough to measure annual energy savings.

Unfortunately, the standard deviation of the difference in NAC was quite large, 3800 kWh for the November - February comparison. Roughly 20% of the cases had a difference in NAC of 4000 kWh or more. These large changes in NAC, obtained with different time periods, suggests that individual-household PRISM results are sensitive to the time period chosen for estimation.

7. DISCUSSION

Residential energy use is very sensitive to weather conditions (primarily for space heating and air conditioning). Therefore, correction for temporal and locational differences in weather is crucial in analysis of household energy use.

Such corrections can be accomplished with end-use (submetered) data collection projects, which record space heating (and/or air conditioning) energy use of individual households. However, such detailed monitoring is quite expensive. An inexpensive alternative is to use whole-house monthly energy billing data and an appropriate analytical technique to identify the weather-sensitve component(s) of energy use.

The Princeton Scorekeeping Method (PRISM) is probably the most widely used method to disaggregate household energy use into its weather- and nonweather-sensitve components; PRISM also adjusts energy use to account for differences between current winter severity and the long-run average. Essentially, PRISM performs three functions. First, it adjusts household energy billing data for differences in winter severity (using heating degree days). Second, it provides information on the space heating and nonspace heating components of energy use. Finally, it temporally aligns household billing data so that results can be compared for a predetermined time period (generally one year).

The seasonality and temperature dependence of some baseload energy uses complicates interpretation of PRISM results. Because the Bonneville Power Administration relies heavily on PRISM in their analyses of residential electricity use and in their evaluations of the BPA

residential conservation programs, it is important to compare PRISM estimates with actual end-use data from homes in the Pacific Northwest. Fortunately, the Hood River Conservation Project provides that opportunity. Of the Hood River homes being end-use monitored, 185 used more than 2000 kWh for space heating during the 1984/85 year; these homes form the data set used here to compare PRISM estimates of total and space heating electricity use with annual aggregates of the end-use load channels.

Results show that PRISM estimates of whole-house electricity use are extremely accurate. Errors occur only when the monthly billing data contain errors. On average, PRISM estimates of space-heating electricity use are higher than the space-heat channel outputs. PRISM's overprediction averaged 14% for all-electric homes and 35% for homes that use electricity as the primary heating fuel and wood as a supplemental heating fuel. The extent of PRISM's overprediction is a function of whether wood is used for heating, actual space heating electricity use, PRISM estimates of reference temperature and the standard error of heating use, and extensive use of air conditioners.

We also examined the accuracy of PRISM parameters for PRISM models estimated with less than 12 months of data. Prior research suggests that a full year of data is optimal and that a minimum of nine months is necessary. We tested models estimated with 12 weeks of data (thus maintaining the same number of observations, while cutting the time period by 75%). Results obtained with 12 weeks of data beginning in October, February, or March were reasonably accurate. Results obtained with midwinter data were very poor. These comparisons suggest that it may be

possible to estimate annual whole-house and space-heat electricity uses with less than a full year of data; however, additional work is needed to confirm this.

Errors in the billing data affect PRISM estimates. Therefore, methods are needed to identify such errors. In addition, a "robust" regression method could be used to estimate the PRISM parameters; such a method (using something other than ordinary least squares, OLS) would be much less sensitive to one or two outliers than is OLS.

Additional work is needed (and is underway at Princeton) to develop a method for adjusting household electricity use for summer air conditioning use. This is generally not a problem in the Pacific Northwest, but is quite important in other parts of the country.

Finally, we plan to update this analysis later this year, when postretrofit data (1985/86) are available for the households examined here. This update will examine the accuracy of PRISM estimates of electricity savings, by comparing year-to-year changes in the PRISM parameters with comparable changes in the end-use load data.

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