ABSTRACT

COMPARISON OF PRINCETON SCOREKEEPING METHOD RESULTS WITH SUBMETERED CONSUMPTION DATA: EMPIRICAL AND THEORETICAL OBSERVATIONS

Michael S. Burnett
Jonathan A. Lesser
Pacific Northwest Utilities Conference Committee
520 S.W. Sixth Avenue, Suite 505
Portland, OR 97204
(503) 223-9343

The Princeton Scorekeeping Method (PRISM) is a model which weather normalizes utility bills. The performance of PRISM is investigated empirically using submetered data from 40 homes in Oregon. Comparisons are made between submetered data and PRISM results for "baseload," "space heat," temperature sensitivity coefficient, and reference temperature.

The submetered data makes possible testing theoretical aspects of PRISM. PRISM is found to have a bias that is relatively minor in magnitude and easily correctable: it overstates the sensitivity of energy use to weather. The theoretical basis for this problem is the inclusion of non-temperature sensitive seasonal baseload consumption in its determination of the temperature normalizing (beta) coefficient. This component of baseload, best exemplified by lighting, exhibits a seasonality which is coincident with, but independent of, temperature. The result is that PRISM estimates of conservation savings are not entirely independent of weather. Savings are overstated if the second year is colder than the base year, and vice versa. Fortunately, the magnitude is small, approaching 10 percent of savings only under extreme circumstances. The theoretical basis for the phenomenon is presented, and an approach for correcting the bias is proposed.

COMPARISON OF PRINCETON SCOREKEEPING METHOD RESULTS WITH SUBMETERED DATA: EMPIRICAL AND THEORETICAL OBSERVATIONS

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The Princeton Scorekeeping Method (PRISM) is a model which weather normalizes utility bills. It is a state of the art model, and is perhaps the most popular approach for analyzing billing data when performing conservation impact evaluations.[1] In this paper, we compare PRISM results with submetered data in order to gain a better understanding of the model's performance. We summarize the results of our empirical comparison of PRISM estimates of current year total load, "space heat," reference temperature, and temperature sensitivity coefficient. The submetered data also allows testing certain theoretical aspects of PRISM. Specifically, we evaluate the effects PRISM's inclusion of non-temperature sensitive seasonal baseload consumption in its weather adjustment coefficient.

I. COMPARISON OF PRISM TO SUBMETERED DATA

We obtained a 60 home load research data base from Pacific Power and Light Company. This data included submetered total load, space heat, and water heat consumption, as well as household survey data. We removed from the sample those homes lacking a complete year of data, as well as homes with heat pumps. The data from the remaining 40 homes was used to develop monthly space heat, water heat, and total load data for each site. The total load data was then analyzed using the PRISM approach using a spreadsheet program developed by Michael Burnett. PRISM results were then compared with the original submetered data. Our analyses of the 40 home sample led to the following conclusions.

1. The PRISM methodology estimated current year total household consumption quite accurately. The difference between the mean PRISM estimate and the mean submetered value was less than -0.3 percent. Hirst and Goeltz found similar results using data from the Hood River Conservation Project.[2] See the table below for data set averages. Standard deviations are shown parenthetically.

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[1]A special issue of Energy and Buildings (Vol. 9, #1 and 2, spring 1986) is dedicated entirely to the Princeton Scorekeeping Method. See especially M. Fels' "Introduction to Scorekeeping" in that issue.

[2]Hirst, E. and R. Goeltz. 1986. "Analysis of Electricity Use for Residential Space Heating: Validation of the Princeton Scorekeeping Method of Weather Adjustment." Oak Ridge National Laboratory, ORNL/CON-203, Oak Ridge, TN.

Annual Current Year Total Consumption (kWh/Year)

	PRISM Estimate	Submetered Data	Percent Difference
Data Set Average	20,443 (5,511)	20,497 (5,550)	-0.3

2. PRISM space heat estimates were about 10 percent greater than submetered actuals. While PRISM was able to predict current year total consumption very accurately, it was less adept at making its allocation between "baseload" and "space heat" portions match actuals. Again, this is similar to the Hirst and Goeltz findings.2/ See the table below for data set averages. Standard deviations are shown parenthetically.

	Baseload	Space Heat
Submetered	10,860 (4,432)	9,637 (4,576)
PRISM	9,913 (4,224)	10,529 (4,369)
Difference Between Means	-947	+892
Percent Difference	-8.7%	+9.3%

Since PRISM in fact shifts seasonal baseload (hidden non-heating consumption) into its "space heat" category, these average differences are in the right direction and of reasonable magnitude.3/

3. For the sample taken as a whole, PRISM derived a reference temperature equivalent to that derived from submetered space heat data. However, on an individual site basis, there was considerable dispersion from the reference temperature derived from submetered data. We estimated an "actual" reference temperature for each site in a regression of submetered monthly space heat use and mean monthly temperature. Both sample means were 57°F, while the standard deviation of the difference between reference temperature calculated by both approaches was 4.5°F.

4. PRISM slope terms were about 15 percent greater than those calculated from submetered space heat data. The average PRISM slope was 3.35 kWh/HDD, while that for the submetered space heat is 2.91 kWh/HDD. The latter was calculated with heating degree days to the "actual" reference temperature base described in Section 3 above. This comparison is somewhat biased because it does not include the water heat slope for the submetered data. The average water heat slope was 0.08 kWh/HDD for this sample. Adding this to the space heat slope gives a result of 2.99 kWh/HDD. The PRISM estimate is 11 percent greater than this value.

5. In nearly one-third of the sites, the PRISM "space heat" component was less than submetered space heat, contrary to expectations. One expects the PRISM slope term to include all space heat plus the seasonal baseload. Therefore, consumption calculated from the slope term should be larger than submetered space heat readings. However, in 12 of 40 cases, the PRISM "space heat" component was less than the

3/Fels, M., J. Rachlin and R. Socolow. 1984. "Seasonality of Non-Heating Consumption Data: A Study Based on Submetered Data." Volume B, ACEEE Summer Study on Energy Efficiency in Buildings.

submetered reading. For these cases, an average of about 2,200 kWh of submetered space heat was included with the baseload (nonseasonal) component. These may in part be due to wood heat. Of the 12 sites, seven had wood heat (58 percent), while for the remaining 28 sites not showing this phenomenon, nine had wood heat (32 percent). In addition, all 12 such sites have PRISM reference temperatures below that estimated by submetered space heat and temperature regressions. Of the 10 sites in our sample that had PRISM reference temperatures 2° or more below the "actual" reference temperature, eight are in this anomalous group. The anomalous PRISM results at these sites acts to decrease the effect of the correction factor we suggest later in this paper.

6. Households indicating the use of supplemental wood heat had similar R^2 to households indicating no supplemental wood heat. This is contrary to analyses that have removed wood heaters to "clean" the data.[4] The table below summarizes the results for households with and without wood heat. The wood heat homes had noticeably greater slope terms (39 percent using submetered data and 31 percent using PRISM). However, they were also larger. But even when analyzed on a per square foot basis, they still consumed almost 20 percent more.

	n	Ft^2	Adjusted R^2	Submetered kWh/ HDD	PRISM kWh/ HDD	PRISM kWh/ HDD/ Ft^2
Wood Heated	16	1,500	0.91	3.50	3.91	2.68
Non-Wood Heated	24	1,383	0.90	2.52	2.99	2.25

II. PRISM OVERSTATES TEMPERATURE SENSITIVITY OF LOADS

Source of the Problem. PRISM uses regression analysis to derive an estimate of weather sensitivity of household energy consumption. The slope of the best linear fit between average monthly electricity consumption and average monthly heating degree days is used to normalize consumption to average conditions. This slope term is often approximately termed the "space heat slope." Since the only explanatory variable that varies seasonally is heating degree days, any seasonally varying load will tend to be attributed to weather. Thus the slope term also includes the seasonal portion of baseload consumption. Seasonal baseload consumption is divisible into temperature sensitive and non-temperature sensitive components. (See Figure A-1 of the Appendix). The latter, best exemplified by lighting, exhibits a seasonality which is coincident with, but independent of, temperature. That is, it should be unchanged as one moves from a warmer to colder winter. The problem: inclusion of the non-temperature sensitive seasonal baseload inflates the space heat slope term used for normalization.

[4] Stram, D., R. Socolow and M. Fels. 1984. "The Effect of Burning Wood on Saving Electricity: An Exploratory Analysis." Volume K, ACEEE Summer Study on Energy Efficiency in Buildings.

Effect of the Problem. The PRISM weather normalized energy consumption formula may be rewritten as:

NAC = kWh + β(HDDLT - HDDACT),

where

NAC = Normalized annual consumption

kWh = Actual total kWh consumption
(i.e., unadjusted total consumption from utility bills)

β = PRISM slope coefficient

(See equation 4 in Appendix). Thus, PRISM normalizes utility bills by adding the results of multiplying the slope coefficient by the difference between long term and actual heating degree days. Since the slope coefficient includes a portion which is not temperature sensitive, it follows that the PRISM formula overstates the sensitivity of energy consumption to weather.

The effects of this phenomenon on energy savings is similar. Calculated savings will differ depending on whether they are measured during a warmer to colder versus a colder to warmer trend. The model will show savings in a house with absolutely no change in physical or behavioral attributes. The general trends of this effect are:

- o Savings are overstated if the second year is colder than the base year.
- o Savings are understated if the second year is warmer that the base year.

(See Section 3 of the Appendix.) An ideally performing normalization technique will avoid such biased indications.

Magnitude of the Problem. Estimating the magnitude of the error requires knowledge of: (1) The portion of the slope coefficient attributable to seasonal baseload, rather than space heat, consumption; and (2) The share of the seasonal baseload which is not temperature sensitive, but merely coincident with it. The former can be obtained by comparing submetered data with PRISM results. The latter can be estimated by judging each end use individually as to temperature sensitivity of its seasonality.

A bias of up to $\pm$240 kWh appears when normalizing data for a given year. Thus this bias is small, on the order of 1 percent of total consumption. It is noticeably less than the 3 percent standard error typically associated with PRISM estimates.

Judging the magnitude of the problem as it applies to energy savings is easiest if simplifying assumptions are made. Assume a house with no physical or behavior change between years. One expects normalized savings to be zero. However, using what may be typical numbers for the Pacific Northwest, savings of 480 kWh appear using the PRISM model if the current year is extremely cold and the base year is extremely warm. When weather conditions are reversed, a consumption increase of 480 kWh appears from the normalization model. (See Section 5 of the Appendix.) A perfectly operating normalization model would show no such variation with weather conditions.

Suppose that typical gross savings are 4,800 kWh. Extrapolating from the 480 kWh from the previous argument, the savings estimates have a possible error of up to ± 10 percent, depending on weather conditions. This is in addition to the inherent variability of the savings estimates that are derived from the PRISM model. Typical standard errors for PRISM savings estimates are on the order of 750 kWh. Thus this effect is of a magnitude lower than the statistical uncertainty of savings estimates.

Nonetheless, the effect is systematic and related to weather, and may be removed by applying a correction factor. Under more typical circumstances when weather conditions do not range from one extreme to the other between the two years of interest, the bias will be less. The 10 percent error is intended only to approximate the upper bound of the problem. It will be lower under more likely conditions.

Suggested Correction the PRISM Model. In order to correct for this problem, the slope term derived by the PRISM model should be multiplied by a correction factor derived from the following formula prior to performing the normalization calculation. This formula (see Section 2 of the Appendix) removes the non-temperature sensitive seasonal baseload from the PRISM slope term.

$$\left(1 - \frac{\beta_{bl} \cdot \gamma}{\beta_{nac}}\right)$$

where β_{nac} = slope term derived by PRISM model

β_{bl} = slope term for seasonal baseload

γ = proportion of seasonal baseload that is not temperature sensitive

For our data set, the seasonal baseload slope (β_{bl}) averaged 0.34 kWh/HDD. (See Figure A-2 in the Appendix.) For the data set average, 71 percent of this slope was not temperature sensitive (γ = 0.71). Thus, the NAC slope was overstated by 0.24 kWh/HDD. Since the NAC slope was 3.33 kWh/HDD, 7 percent of the slope should be removed. The correction factor is 0.93.

An alternative means (see Section 3 of the Appendix) of including the correction is

$$NAC_{corr} = NAC - \beta_{bl} \cdot \gamma \cdot (HDDLT - HDDACT)$$

where NAC_{corr} = corrected NAC estimate

NAC = NAC estimate

HDDLT = long-term heating degree days

HDDACT = actual heating degree days

For our data set, the correction to the NAC was

$$-0.24 \text{ kWh/HDD} \cdot (HDDLT - HDDACT).$$

Our suggested correction effectively subdivides "hidden non-heating" consumption[5/] into two components, and removes the non-temperature sensitive component from the slope term used in normalization.

Suggestions for Application. PRISM has a theoretical bias that causes it to overestimate the sensitivity of energy consumption to weather. The source of the problem is the inclusion of non-temperature sensitive seasonal baseload energy use, such as lighting, in its "space heat" slope. The magnitude of the effect is small, on the order of 1 percent of normalized annual consumption estimates and 10 percent of savings estimates. In kilowatt hour terms, it is less than the standard error of either consumption or savings estimates. Thus, PRISM users ignoring the bias will not introduce a large error into their results.

However, the error is additive to the standard statistical error associated with PRISM. And it is systematic and related to weather. Therefore, it can be corrected if adequate data is available. Those concerned with savings estimates that may be high or low by up to 500 kWh have several options. The bias becomes greatest as the pre-and post-weatherization winters deviate in opposite directions from normal weather. The first step is to compare heating degree days from each winter. If they are not substantially different, then one need not be concerned about the effect.

If the heating degree days are noticeably different, the best approach is to apply a correction factor to the data set average savings estimates. As mentioned above, if sufficient data is not available to make the correction, any bias in the results will be relatively small. At this stage, applying the correction factor to individual homes is probably not the recommended approach. There is a wide variability in the correction factors when this is done. This is in part due to the anomalous sites in which PRISM "space heat" consumption was less than submetered space heat, contrary to expectations.

If one has submeter data available, then it is useful to investigate and correct for this effect. However, submetering just to account for this effect is not warranted, due to its small magnitude.

If no submeter data is available, then applying the correction factor derived in this paper is permissable. It represents an attempt at removing electric end uses other than space heat and water heat from the PRISM normalization coefficient. It is probably reasonable to apply this number to data sets from the Pacific Northwest. Notably, this region has very little air conditioning. We are uncertain of the extent that the seasonality of this type of electrical consumption is uniform from region to region. Many of the end uses in this category seem as if usage would vary little geographically, but we have not seen data to support such a conclusion. One has to weigh the uncertainty in the correction factor against the size of the heating degree day difference. If the pre- and post-weatherization winters are quite different, one would be more willing to tolerate uncertainty in the correction factor. Until better data becomes available, the correction factor derived in this paper seems to be a reasonable first approximation.

[5/] Ibid 4/.

Suggestions for Further Research. Further research and evaluation of this effect should focus on verifying its consistency and magnitude. Submetering data is becoming more common, and studies such as these can be conducted to gain more insight into the seasonal portion of baseload consumption. We made a simplifying assumption that may not necessarily be true: we assumed that the seasonal portion of water heat consumption to be entirely temperature sensitive and that the rest of seasonal baseload consumption was not sensitive to temperature.

The methodology we used to determine the slope of seasonality for water heat and basic service is a simplification. We used the difference between December and August consumption to quantify this slope. A more rigorous approach might prove fruitful.

Finally, the anomalous sites in which PRISM "space heat" was less than submetered space heat are of concern. Twelve of the 40 sites we studied fell in this category. In these sites, data does not support the rule of thumb that seasonal baseload is loaded onto the PRISM "space heat" coefficient. These sites do not conform to the theory underlying the proposed correction factor. Their correction factors are therefore in the opposite direction. This set of homes is of concern not only to those investigating the bias described in this paper, but also to PRISM researchers in general. In these homes, PRISM space heat estimates are less than actuals.

SUMMARY

Comparison of PRISM results to submetered data led to the following conclusions:

- PRISM matched submetered current year total consumption quite accurately.
- PRISM "space heat" estimates were about 10 percent greater than submetered actuals, due to its inclusion of seasonal baseload in the "space heat" portion of load.
- PRISM estimate of the reference temperature for the sample mean was equivalent to that derived from submetered space heat data, but was less accurate at predicting reference temperature for any one site.
- PRISM slope terms were about 15 percent greater than those calculated from submetered space heat data.
- PRISM overstates the sensitivity of load to weather, due to its inclusion of non-temperature sensitive seasonal baseload in its "space heat" slope term. In the Pacific Northwest, errors in estimating conservation savings as large as 500 kWh may occur, depending on the severity of winter. Under more typical circumstances, errors will be lower. In all cases they will be smaller than the standard error of PRISM savings estimates. For a highly energy efficient new home, the temperature sensitivity may be overstated by as much as one third.

APPENDIX

THEORETICAL DERIVATION OF SLOPE TERM CORRECTION FACTOR FOR PRISM MODEL

1. Establishing the relationship between current year total consumption, current year heating degree days, and PRISM model coefficients.

As a foundation for deriving a corrected Normalized Annual Consumption (NAC) model, it is necessary to establish the relationship between current year total consumption, current year heating degree days, and the PRISM model coefficients.

The PRISM model can be used to predict current year total consumption. This is done by multiplying the slope term by the current year heating degree day count, and adding in the baseload component. The model performs this prediction very accurately. The mean error for our data set was less than 1 percent (actually -0.3 percent). Given this excellent fit, it is possible to assert that

$$\text{kWh} = 365 \cdot \alpha + \beta \cdot \text{HDDACT}, \tag{1}$$

where kWh = Actual total kWh consumption (i.e., unadjusted total consumption from utility bills)

α = PRISM baseload coefficient

β = PRISM slope coefficient

HDDACT = Actual (current year) heating degree days.

Equation (1) is the basis for further equations leading to a corrected NAC formula. These derivations are presented in Section 3.

2. Establishing a correction factor to remove the non-temperature sensitive seasonal baseload from the slope term.

The PRISM model slope term includes both space heat and seasonal baseload components. The seasonal baseload component can be further subdivided into temperature sensitive and non-temperature sensitive components. The latter, best exemplified by lighting, exhibits a seasonality which is coincident with, but independent of, temperature. That is, it should remain unchanged as one moves from a warmer to colder winter, or vice versa. Since it is independent of temperature, it should be removed from the slope term prior to normalization.

Figure 1 presents a schematic showing each of the components of the PRISM slope. It assumes that non-temperature sensitive seasonal baseload is coincidentally linear with, yet independent of, temperature. The goal is to reduce the term β_{NAC} to β_{TS}. Then it will include the entire temperature sensitive slope component, and no more.

One wants to use β_{TS} in the normalization calculation. Our goal is to define β_{TS} in terms available either from the PRISM model or from submetered data. By definition,

$$\beta_{TS} = \beta_{NAC} - \beta_{NTSSBL} \qquad \text{(Terms defined in Figure A-1)}$$

$$= \beta_{NAC}\left(1 - \frac{\beta_{NTSSBL}}{\beta_{NAC}}\right)$$

Define γ to be the proportion of seasonal baseload that is not temperature sensitive.

Then

$$\beta NTSSBL = \beta_{BL} \cdot \gamma$$

Substituting,

$$\beta_{TS} = \beta_{NAC}\left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_{NAC}}\right)$$

This is an equation in the desired form. β_{NAC} is the PRISM model β, and β_{BL} can be derived by comparing PRISM results with submetered data. γ can be estimated by judging each end use individually as to the temperature sensitivity of its seasonality. This estimation is performed in Section 5.

The correction factor

$$\left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_{NAC}}\right) \tag{2}$$

will be applied to the NAC and DNAC formulas in the next section.

3. Deriving corrected NAC and DNAC models.

a. Deriving corrected NAC model

Equation (1) states

$$kWh = 365 \cdot \alpha + \beta \cdot HDDACT.$$

Rearranging

$$365 \cdot \alpha = kWh - \beta \cdot HDDACT. \tag{3}$$

The NAC formula is

$$NAC = 365 \cdot \alpha + \beta \cdot HDDLT,$$

where HDDLT = long-term heating degree days.

Substituting (3) for $365 \cdot \alpha$

$$NAC = kWh - \beta \cdot HDDACT + \beta \cdot HDDLT$$

$$= kWh + \beta\,(HDDLT - HDDACT) \qquad (4)$$

Applying the correction factor (2)

$$NAC_{corr} = kWh + \beta_{NAC}\left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_{NAC}}\right)(HDDLT - HDDACT), \qquad (5)$$

where NAC_{corr} = corrected NAC value.

Substituting in (4)

$$NAC_{corr} = NAC - \beta_{BL} \cdot \gamma \cdot (HDDLT - HDDACT)$$

or

$$NAC = NAC_{corr} + \beta_{BL} \cdot \gamma \cdot (HDDLT - HDDACT)$$

The correction factor is applied in the temperature normalization calculation. It follows that the normalization performed by the uncorrected NAC model is not independent of temperature. Only if HDDACT = HDDLT, does the uncorrected PRISM model normalize properly. Under more typical circumstances, an error will be propagated in the results depending on the extent that HDDACT deviates from HDDLT.

b. Deriving corrected DNAC model.

The NAC difference (DNAC) model involves subtracting consumption in year 2 from year 1. Using equation (4) for each year:

$$NAC_1 = kWh_1 + \beta_1\,(HDDLT_1 - HDDACT_1)$$

$$NAC_2 = kWh_2 + \beta_2\,(HDDLT_2 - HDDACT_2)$$

$$DNAC = NAC_1 - NAC_2$$

$$= DkWh + \beta_1\,(HDDLT_1 - HDDACT_1)$$

$$- \beta_2\,(HDDLT_2 - HDDACT_2),$$

where $DkWh = kWh_1 - kWh_2$

This formula is complicated by the possibility of different reference temperatures in each year. The heating degree day bases would, therefore, be different. In order to gain an understanding of the effects of the DNAC correction factor, one can proceed by making some simplifying assumptions. Assume that no physical or behavioral changes take place in the house between years 1 and 2. Then any changes in consumption will be due entirely to weather variations. The reference temperatures are the same, and $HDDLT_1 = HDDLT_2$. Similarly $\beta_1 = \beta_2 = \beta$.

Then

$$DNAC = DkWh - \beta\,(HDDACT_1 - HDDACT_2)$$

$$= DkWh - \beta \cdot DHDDACT \qquad (6)$$

where $DHDDACT = HDDACT_1 - HDDACT_2$

Equation (6) states that the difference in first and second year utility bills is normalized by subtracting the β slope multiplied by the difference between the first and second year heating degree days.

However, similar to equation (4), this is in error, since it contains the non-temperature sensitive seasonal baseload in its slope term. It requires the correction term to properly normalize.

Therefore

$$DNAC_{corr} = DkWh - \beta_{NAC}\left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_{NAC}}\right)(DHDDACT), \qquad (7)$$

where $DNAC_{corr}$ = corrected DNAC value

Substituting in (6)

$$DNAC_{corr} = DNAC + \beta BL \cdot \gamma \cdot DHDDACT \qquad (8)$$

or

$$DNAC = DNAC_{corr} - \beta BL \cdot \gamma \cdot DHDDACT \qquad (9)$$

By evaluating equation (9) one can deduce the following:

- When DHDDACT is positive, DNAC is less than $DNAC_{corr}$. That is, when the second winter is warmer than the first, DNAC (uncorrected) will understate savings.

- When DHDDACT is negative, DNAC exceeds $DNAC_{corr}$. That is, when the second winter is colder than the first, DNAC (uncorrected) will oversate savings.

The formula presented in equation (7) applies only to the special case, but the phenomenon continues to operate for more complicated situations.

The more general formula for corrected DNAC is

$$DNAC_{corr} = DkWh + \beta_1 \left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_1} \right) (HDDLT_1 - HDDACT_1)$$

$$- \beta_2 \left(1 - \frac{\beta_{BL} \cdot \gamma}{\beta_2} \right) (HDDLT_2 - HDDACT_2) \qquad (10)$$

4. Converting the correction factor into terms available from the NAC model and from submetered data.

In order to quantify the correction factor, it is desirable to convert into terms available from the NAC model and from submetered data.

The correction factor is

$$CF = \left(1 - \frac{\beta BL \cdot \gamma}{\beta NAC} \right)$$

Now

$$\beta_{BL} = kWhSBL/HDD$$

and

$$\beta_{NAC} = kWhSH_{NAC}/HDD,$$

where kWhSBL = Current year seasonal baseload consumption in kWh

$kWhSH_{NAC}$ = Current year space heat consumption in kWh from applying the PRISM model coefficients to current year heating degree days.

Substituting yields

$$CF = 1 - \frac{\left(\frac{kWhSBL}{HDD} \right) \cdot \gamma}{\left(\frac{kWhSH_{NAC}}{HDD} \right)}$$

$$= 1 - \frac{kWhSBL \cdot \gamma}{kWhSH_{NAC}}$$

Now the seasonal baseload consumption kWhSBL is equivalent to the difference between the submetered baseload value and the baseload derived by the NAC model, assuming the estimate of α is correct. The former includes seasonal baseload and the latter does not: the NAC model includes the seasonal baseload in its slope term. The difference is seasonal baseload. Therefore

$$CF = 1 - \frac{(kWhBL_{SUB} - kWhBL_{NAC}) \cdot \gamma}{kWhSH_{NAC}}$$

Where $kWhBL_{SUB}$ = Submetered baseload consumption in kWh

$kWhBL_{NAC}$ = Estimate of annual baseload consumption derived from PRISM alpha coefficient (i.e., $365 \cdot \alpha$)

This equation for the correction factor is in the desired form. Aside from γ, each of its components is available from either the NAC model or submetered data:

- $kWhBL_{SUB}$ is the submetered baseload reading
- $kWhBL_{NAC}$ is the PRISM alpha coefficient times 365
- $kWhSH_{NAC}$ is the PRISM beta coefficient times current year heating degree days.

The estimation of γ is the subject of the following section.

5. <u>Estimating γ, the proportion of seasonal baseload that is not temperature sensitive.</u>

This estimation can be performed by making some simplifying assumptions: These are:

- Both the water heat and basic service components of baseload exhibit seasonality that is apparently linear with temperature (heating degree days)
- The seasonality of water heat is entirely dependent on temperature (heating degree days)
- The seasonality of basic service (i.e., lighting, cooking, clothes washers, clothes dryers, dishwashers, television, and miscellaneous appliances) is independent of temperature (heating degree days), but dependent on seasonal behavior effects which coincide with temperature changes. Basic service seasonality is unchanged as one moves from a warm to cool winter, and vice versa.

From the submetered data, it is possible to identify both the water heat and basic service components. In our data base they exhibit August minima and December maxima, as does space heat. Subtracting the minima from the maxima yields a measure of the seasonal consumption of the baseload components. This simplification is permissable since we are assuming a linear (but independent in the case of basic service) relationship with temperature. The table below gives the mean monthly usage in kWh for each component for each of these two months.

Component	August	December	Difference
Water heat	284	401	117
Basic Service	494	669	175
Baseload	777	1,070	292

Water heat exhibits a seasonal difference of 117 kWh/month, while for basic service the seasonal difference is 175 kWh/month. Baseload seasonal difference is 292 kWh/month. Given the assumptions that water heat seasonality is temperature sensitive and basic service is non-temperature sensitive, then 60 percent (175/292) of the seasonal baseload is non-temperature sensitive. That is, $\gamma = 0.60$ using the average values of our data set. If the above calculation is performed for each site, and the individual γ figures are averaged, the resulting $\gamma = 0.71$.

Given this value for γ, it is possible to estimate the potential upper limit of this error for typical regional conditions. Since the error is related to the intensity of winter, we will assume extreme weather conditions and typical regional values for other parameters. Equation (8) defines the correction to the DNAC model as

$$+ \beta BL \cdot \gamma \cdot DHDDACT.$$

Typical values of βBL are on the order of 0.3 kWh/HDD. Our study shows 0.34 kWh/HDD. A Portland General Electric study showed 0.33 kWh/HDD[1/]. Long term heating degree days might be 5,000, while an extremely cold winter might have 6,000 HDD, and an extremely warm winter might have 4,000 HDD. Thus DHDDACT = $\pm$ 2,000, and the correction is

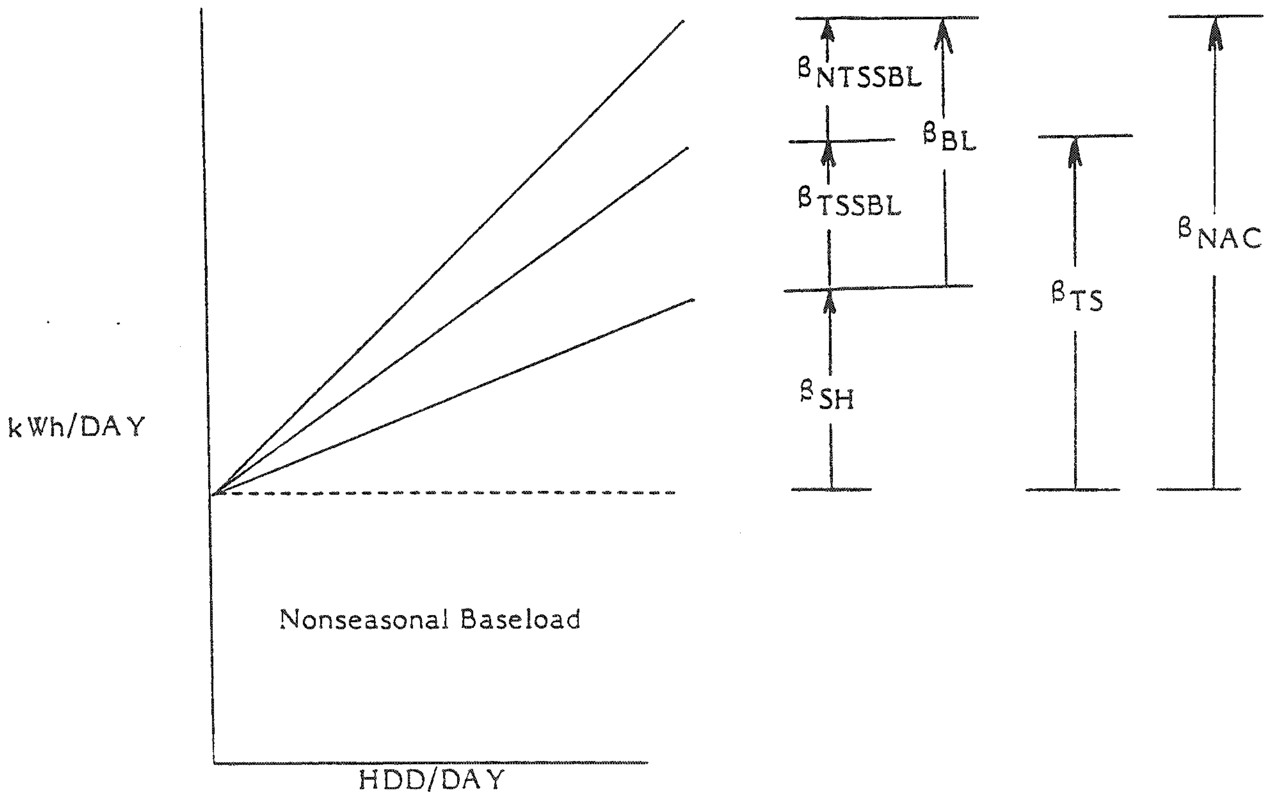
$$(0.34)\ (0.71)\ (\pm\ 2{,}000)$$

$$= \pm\ 480 \text{ kWh.}$$

Thus, a home in which we expect no savings can show savings ranging over nearly 1,000 kWh, from +480 kWh to -480 kWh, depending on the extremity of weather conditions.

1/Burnett, T.; Weatherization Within Single Family Residences, Report III. Portland General Electric. 1982. p. 12.

FIGURE A-1
COMPONENTS OF THE NAC SLOPE TERM
(Not drawn to scale)



β_{NAC} = NAC model slope

β_{SH} = Space heat (only) slope

β_{BL} = Seasonal baseload slope

β_{TSSBL} = Temperature sensitive seasonal baseload slope

β_{NTSSBL} = Non-temperature sensitive seasonal baseload slope

β_{TS} = Temperature sensitive slope

γ = $\beta_{NTSSBL}/\beta_{BL}$

FIGURE A-2

AVERAGE USAGE PER MONTH

APRIL 83 TO MARCH 84