Using Simulations to Explore the Physical Meaning of PRISM's Parameters

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Users of PRISM are cautioned that its Normalized Annual Consumption (NAC) estimates are the most robust, but there remains a strong temptation to see changes in other PRISM regression parameters as clues to the physical causes of NAC changes. This paper explores the degree to which PRISM's regression parameters match those calculated directly from DOE-2 energy and temperature data.

Heating energy data generated by DOE-2 for four different houses modeled in Minneapolis and San Francisco are analyzed using PRISM. In addition, the DOE-2 data are converted directly into counterparts to the PRISM regression parameters. These "DOE-2 parameters" are then compared with those of PRISM, first for the individual houses and then for the houses examined in pairs, as if the first house in each pair had been converted into the second via a conservation retrofit.

The results show PRISM's estimates of regression parameters and their changes in Minneapolis very closely match analogs calculated directly from the DOE-2 data. High standard errors for base level consumption, however, would make the tracking of such retrofits as water heater improvements problematic. While the regression R^2s remained high in San Francisco, PRISM's interpretation of the substantial amount of warm-season heat as base level consumption resulted in a significant downward bias in reference temperature estimates. PRISM slope estimates for San Francisco houses, on the other hand, tended to be overestimates of effective building UA. Even with the contrasting effects of temperature and slope biases, PRISM heat part estimates generally fail to closely track percentage changes in actual DOE-2 heating. The data suggest that, in the absence of methods for removing biases, analysts in climates with significant amounts of summer heating confine themselves to using NAC and base consumption estimates.

Introduction

PRISM is a software package widely used to assess the effectiveness of space heating energy conservation retrofits in buildings. PRISM's estimates of changes in Normalized Annual Consumption generally are considered a reliable indicator of the effectiveness of conservation measures. However, the meaning and usefulness of the component PRISM regression parameters (slope or "lossiness", intercept or "base level consumption", and reference temperature for heating degree day calculations) are still subject to differing interpretations. Many people intuitively associate PRISM's heat part with actual heating, base level consumption with non-heating energy use, regression slope with building UA, and PRISM's reference temperature with the building's balance temperature.

According to Fels, PRISM's weather normalization procedure has a "physical foundation, which allows a physically meaningful interpretation of [its component as well as total] results" (Fels 1986). Further, the standard errors attached to each of PRISM's parameter estimates allow appropriate confidence in these estimates. Users of PRISM are cautioned, however, that the parameters other than NAC provide "useful indicators of the components of NAC" but require "sensitive interpretation with careful consideration of their errors," and that "their changes over time are often difficult to interpret due to the interference of physical and statistical effects." (Fels, Rachlin, and Socolow 1986)

One obvious cause of such interference involves including in the PRISM data a period in which a house undergoes a change in base consumption, lossiness, or reference temperature. This kind of change violates PRISM's assumption of constant parameters during the period of study. This problem is said to occur "often" in real data, being "particularly acute" when the periods of estimation include major changes to the house. (Fels 1986) While these warnings are no doubt useful, they do raise some questions. If one is confident, for instance, that the estimation periods excluded major changes to the house, are the changes in parameter estimates necessarily accurate, when allowance is made for their standard errors? Do mismatches between PRISM parameter estimates and actual physical parameters correlate with certain types of buildings or climates? To answer such questions, one needs the values for both PRISM's regression parameters and the building's physical parameters.

There have been numerous field studies of PRISM's performance using both submetered data and engineering calculations. For example, DeCicco et al. (1986) use estimates for heating system efficiency, intrinsic gains, infiltration rates, effective UA for the building envelope, and average indoor temperature to set bounds for NAC estimates, which are then compared with actual PRISM results. The authors conclude that, for a given building, a combination of field measurements, engineering calculations, and PRISM analysis are "merely suggestive of what the building's physical characteristics really are," largely because of the wide margins of error involved.

Field verification, while essential, is unable to address all aspects of PRISM's reliability because many factors cannot be accurately controlled or measured in a real house. It is impossible, for example, to precisely calculate a building's overall heat loss coefficient. Similarly, varying thermostat settings, window management strategies, occupancy patterns or appliance usage will influence heating requirements.

For these and other reasons, use of synthetic data--generated by building energy use simulation software--has certain advantages (Meier et al. 1988). One can produce data for many different localities, building descriptions, and levels of internal gains (Palmiter and Toney 1986). The parameters of interest can be precisely specified.

In this study, we generated synthetic energy consumption data with DOE-2. We then created synthetic utility bills for PRISM analysis. Finally, we compared PRISM's regression values to those calculated directly from DOE-2 data.

Methodology

The DOE-2 Model

San Francisco and Minneapolis were chosen for this study because they represent relative extremes on the spectrum of clearly heating-dominated climates. The four houses modeled in the two cities by DOE-2 had certain common features. They were 1540 square foot single-story residences, with equal-sized walls containing equal-sized windows oriented to all four cardinal directions. All system heating was provided by electric baseboard heaters. All had uninsulated basements, separated from the conditioned space above by a layer of R30 insulation. The differences between the houses are summarized in Table 1. For convenience, the abbreviated names--R19, R60, R60+Set, R60+Inf--will be used throughout this paper.

Table 1. Distinguishing Features of the Buildings

House Code	Ceiling/Wall Insulation	Infiltration Level	Other Measures
R19	R19/R11	Low	
R60	R60/R34	Low	
R60+Inf	R60/R34	Medium	
R60+Set	R60/R34	Low	Setback

Notes:
Low: 0.0003 relative leakage area.
Medium: 0.0005 relative leakage area.
Setback: Nights, weekdays from 70°F to 64°F

The reliability of DOE-2 is known to vary with the nature of the house being modeled (Colborne et al. 1984; Sorrel et al. 1985). The prototypes in the present study were selected to avoid most of the weaker points of DOE-2. Thermal mass was low; foundations were relatively isolated by R30 insulation from the conditioned space and modeled using the USCUG integrated finite difference method. (Huang et al. 1987) Infiltration was kept to low and medium levels and modeled using the Sherman-Grimsrud (relative-leakage-area) method. (DOE-2 Supplement 1990) Electric resistance heating was used to ensure a consistent 100% efficiency in the heating system.

In this study, particularly in San Francisco, some practical features have been sacrificed to obtain greater reliability of DOE-2 results. Most houses in San Francisco have gas rather than electric heat; few have basements, let alone R30 insulation topping them. Fewer, if any, are super-insulated. Further, in real houses, people have guests, take vacations, forget to close windows, and have thermostats whose accuracy wavers. In short, the simulations assume more consistent behavior than is likely in real people and their heating systems, and therefore are best seen as a starting point or best-case scenario.

The DOE-2 parameter calculations. A house's heat loss coefficient or UA is, on the surface, a simple calculation involving summing the values for heat losses over all paths given a specified temperature gradient. In fact, the rates of such heat losses through the three main routes--ceiling and walls, foundation, and infiltration--vary with some degree of independence. To arrive at an annual value for UA or balance temperature, one could choose to use simple annual totals or weighted sums of shorter-term values, based on either hourly, daily, or larger aggregates of temperature and energy data.

We used methods of analyzing the DOE-2 data which were likely to correspond well with the approach taken by PRISM users. Since PRISM typically accepts average daily outdoor temperatures and monthly energy data, we chose to start with the same.

The first step in our estimation of DOE-2 counterparts to the PRISM parameters was to calculate total heating degree days (HDD_Total) for the year. This was done by dividing the sum of each day's hourly temperatures by 24 to get average daily outside temperature T_Out, and then subtracting T_Out from the thermostat setpoint T_Set whenever T_Out was below T_Set. For houses without thermostat setbacks, this setpoint was 70°F. Houses with setbacks from 70°F to 64°F during working and sleeping hours had an average weekly setpoint of 66.8°F, which was used as the basis for heating degree day calculations for these houses.

$$HDD\_Total = \sum Max(0, T\_Set - T\_Out)) \qquad (1)$$

Each building was modeled with and without the usual internal and solar gains, known collectively as intrinsic gains (IG). In the latter case, the building was equivalent to being unoccupied, with window shading coefficients of zero. The difference in annual total energy use (Q) between the building with and without intrinsic gains was assumed equal to actual contributions of intrinsic gains to offsetting system heating.

$$IG = (Q\_without\_IG) - (Q\_with\_IG) \qquad (2)$$

The annual UA estimates (with units of kWh/heating degree day) were the quotient of the sum of system heat and intrinsic gains (Q_Total) divided by the year's total heating degree days.

$$UA = (Heat + IG) / HDD\_Total \qquad (3)$$

The system heating degree days (HDD_System or henceforth just HDD) for the year were calculated by subtracting from total heating degree days the share covered by "free heat" (intrinsic gains divided by UA).

$$\begin{aligned} HDD &= HDD\_Total - (IG/UA) \\ &= ((Heat + IG)/UA) - (IG/UA) \qquad (4) \\ &= (Heat)/UA \end{aligned}$$

These HDD values were then compared to a table of heating degree days to a range of integer values for reference temperatures for the year, to determine by interpolation the effective balance temperature (T_Bal). An alternative method, using heat-weighted sums of the respective UA and T_Bal monthly values, was found to give almost identical UA and T_Bal estimates for all houses in both cities.

PRISM Model

PRISM is a statistical procedure for calculating changes in energy use in a building over time. By performing a linear regression of energy used per day versus heating degree days per day during each billing period, PRISM determines the degree to which these variables are correlated. The temperature on which the heating degree days are based, known as reference temperature or τ, is then varied systematically until the highest correlation between daily energy use and heating degree days is achieved. The resulting regression slope β and intercept α, when applied to the number of heating degree days for a typical year H_0 to base τ, yield an estimate of Normalized Annual Consumption, or NAC, for the building or buildings.

$$NAC = 365\alpha + \beta H_0(\tau) \qquad (5)$$

The first term in the NAC equation is known as "base level consumption", with α sometimes described as a measure of daily appliance energy usage in the house. (Fels 1986) The second term, the product of lossiness β and normalized heating degree days $H_0(\tau)$, is the "heating part" of NAC. By making NAC estimates for periods preceding and following an energy conservation retrofit, PRISM can be used to gauge the retrofit's effectiveness. Figure 1 shows a typical graph of energy per day versus heating degree days per day and average monthly temperatures, indicating both PRISM's regression line and daily non-heating energy use. The intercept of PRISM's regression line with the x-axis indicates daily base level consumption.

Our synthetic data differed from that in the typical field PRISM study in two respects. First, a constant value was used for daily non-heating energy consumption. In most field data, average daily residential non-heating energy use drops by about 10% in the summer and rises by about

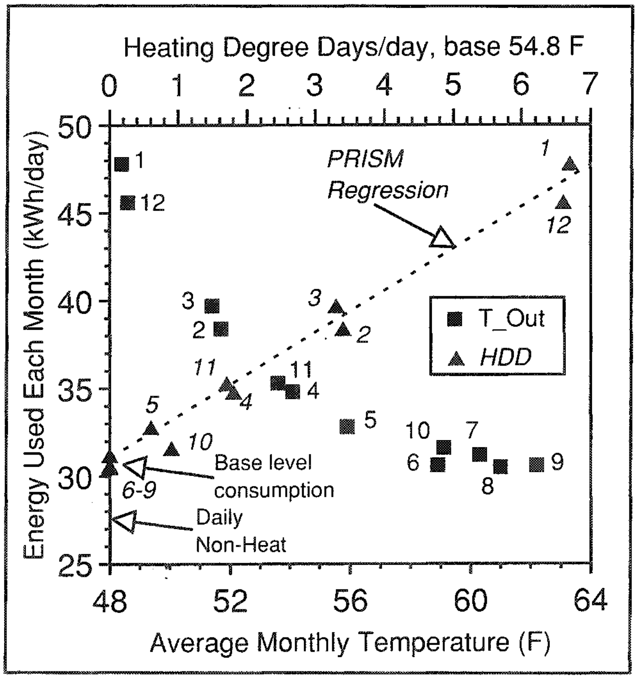

Figure 1. Energy Per Day vs Outside Temperature and PRISM Heating Degree Days Per Day, Each Month, House 60+Inf, San Francisco

10% in the winter relative to the annual average. (Fels, Rachlin, and Socolow 1986) PRISM ascribes this relatively higher winter non-heating value to additional heating and reduces base level consumption to match the unusually low summer non-heating level. Our model, while less realistic, allows for simpler interpretation of PRISM's partitioning between heat part and base level consumption.

Another difference between our PRISM analyses and those using typical field data is that we used identical outdoor temperature data for PRISM's "current" year and for the long-term average or "typical" year. The reason was that having PRISM's slope and intercept estimates match those calculated directly from DOE-2 data required PRISM's "current" year temperature data to match those used by DOE-2; in addition, having DOE-2 values for heating and total energy use which were comparable to PRISM's heat part and NAC estimates required PRISM's "long-term" temperature data to be the same as the "current" year data used by DOE-2.

The result, however, is that the sum of the monthly energy data used by PRISM for its slope and intercept parameter calculations (i.e., the annual total energy use from DOE-2) is more likely to be extremely similar to the total energy use (NAC) predicted by these PRISM parameters based on the "long term" (but here identical to "current") heating degree day data. In short, comparisons of NAC and its changes to those reported for total energy use by DOE-2 are not as meaningful as when PRISM's current and long-term temperature data differ.

For such meaningful analyses of NAC and its changes, our synthetic database would have to be doubled, using another set of climate data for both DOE-2 and PRISM. One set of DOE-2 results could be used by PRISM for its intercept and slope calculations, while the temperature data for the other DOE-2 simulation could be used by PRISM to produce the NAC estimates to compare with this second DOE-2 simulation's total energy value. Since the choice of which climate data to use as "current" and "long term" is arbitrary, one could examine the data using either set as the starting point. This will be investigated in a future project.

Results

Statistical significance and standard errors of PRISM regressions

PRISM's weather normalization procedure provides not just an estimate of annual energy usage, but also a number of measures of the statistical significance of the regression.

Coefficients of Determination. The coefficients of determination (R^2) of all the PRISM regressions, which show the proportion of variation in monthly energy used per day associated with variation in monthly heating degree days per day, were quite high. (See Table 2) R^2 in Minneapolis averaged 0.996, while that in San Francisco averaged 0.979. In both locations, R^2 was positively correlated with building lossiness. Both the magnitude and stability of these R^2 values is impressive, especially given the substantial differences in the houses modeled. One wonders, in fact, what conditions would be required to get R^2 values below 0.9 from synthetic monthly data.

These results render almost pointless any effort, based on synthetic data, to pinpoint causes of departures of monthly energy use from linear dependence on changes in outside temperature. After all, the residuals are only a percent or two of the total energy used. Weekly or daily data, which show lower R^2 values, would be more fertile ground for such efforts.

The sizeable variations in the building descriptions yielded large variations in the relative effects of infiltration and internal gains on total heating needs (not detailed here). In the R19 house in San Francisco, for instance, intrinsic gains met 58% of total heating needs, but 78% of such needs for the R60 house with setbacks. The share of

Table 2. PRISM Parameter Estimates and Analogs Calculated Directly from DOE-2 Data

Minneapolis:	PRISM						DOE-2				
		Base	Ht Part	Slope	T_Ref	NAC	Summer	Heat	UA	T_Bal	E_Total
House	RxR	kWh/Day	kWh/Yr	kWh/HDD	°F	kWh	kWh/day	kWh/Yr	kWh/HDD	°F	kWh/Yr
R19	.997	29.33	17458	2.678	59.2	28169	29.34	18358	2.743	59.8	28396
R60	.995	28.31	11027	1.926	55.8	21368	28.13	11494	2.015	55.6	21532
R60+Inf	.997	28.36	14376	2.329	57.7	24734	28.38	14893	2.392	57.9	24930
R60+Set	.995	28.15	9770	1.846	53.9	20053	27.83	10171	2.012	52.7	20209

San Francisco:	PRISM						DOE-2				
		Base	Ht Part	Slope	T_Ref	NAC	Summer	Heat	UA	T_Bal	E_Total
House	RxR	kWh/Day	kWh/Yr	kWh/HDD	°F	kWh	kWh/day	kWh/Yr	kWh/HDD	°F	kWh/Yr
R192	.986	33.96	2671	3.157	55.5	15073	33.66	5100	2.667	60.1	15137
R60	.976	30.46	883	2.426	52.2	12008	29.96	2014	2.003	56.3	12052
R60+Inf	.982	30.98	1684	2.421	54.6	12999	30.78	3014	2.327	57.7	13051
R60+Set	.971	29.56	654	2.084	51.7	11450	29.09	1451	2.096	54.5	11489

heating load due to infiltration was 13% for the R19 house, but 24% for the R60 house with higher infiltration. Given the relatively minor effect on R^2 of these substantial variations, the data also suggest that the major source of significant reductions in coefficients of determination is likely to be how the building is operated, rather than such climatic factors as wind and sunlight.

Standard Errors and Coefficients of Variance. As expected, the standard errors (SEs) for NAC were relatively smaller than for the other PRISM parameters (Table 3). Expressed as coefficients of variance (CV), the ratio of the SE to the value of the parameter itself, the Minneapolis houses had NAC CVs of about 1 percent, while San Francisco's had about 0.5 percent. (Using a Student's t test with 9 degrees of freedom, the CVs would have to exceed 44% for their corresponding parameter estimates with three significant digits to be insignificantly different from zero.) We will discuss the standard errors of the other PRISM parameters in conjunction with the parameters themselves.

Static Analysis of the Four Houses

We begin our comparison of PRISM's and DOE-2's parameter estimates by looking at the four houses considered individually in each city. These data give a picture of how PRISM arrives at its overall partitioning between base level consumption and heat part, and at the implications for estimates of the lossiness and reference temperature parameters.

NAC and Total DOE-2 Eergy Use Comparisons. Table 2 shows that PRISM's NAC estimates for all houses in both cities are extremely close to the actual total energy value produced by DOE-2, typically biased downward by only about 0.8 percent in Minneapolis and 0.4 percent in San Francisco. In all cases, NAC was within one SE of the DOE-2 value.

Base Level/Summer Consumption Comparisons. PRISM's NAC is the sum of temperature-dependent ("heat part") and temperature-independent ("base level consumption") components. It is tempting to consider base level consumption as simply the daily non-heating energy usage, particularly when the other term in PRISM's NAC equation is referred to as the "heat part". In fact, field studies have shown that base level consumption is more closely associated with average daily summer *total* energy use (Fels, Rachlin, and Socolow 1986).

The present study supports that finding. Figure 2 shows the relation between actual average daily summer consumption and base level consumption. In San Francisco, with summer comprising July-September, PRISM's α exceeds average daily summer consumption by only about 0.3 kWh/day. In the R60 house with and without setbacks, this upward bias exceeds the standard error of the base level parameter estimate. In Minneapolis, with summer comprising June-August, there is an extremely close match between summer and base for the "lossier" houses R19 and R60+Inf, while PRISM's base consumption again slightly exceeds DOE-2's summer consumption for houses R60 and R60+Set. Here, all

Table 3. Standard Errors of PRISM Parameters

Minneapolis

House	Base SE	Base CV	Heat SE	Heat CV	Slope SE	Slope CV	T_Ref SE	NAC SE	NAC CV
R19	1.67	0.057	531	0.030	0.083	0.031	1.3	298	0.011
R60	1.30	0.046	400	0.036	0.080	0.042	1.6	254	0.012
R60+Set	1.22	0.043	374	0.038	0.085	0.046	1.7	245	0.012
R60+Inf	1.39	0.049	434	0.030	0.078	0.033	1.4	260	0.011

San Francisco

House	Base SE	Base CV	Heat SE	Heat CV	Slope SE	Slope CV	T_Ref SE	NAC SE	NAC CV
R19	0.53	0.016	152	0.057	0.236	0.075	0.5	120	0.008
R60	0.28	0.009	71	0.080	0.229	0.094	0.4	72	0.006
R60+Set	0.23	0.008	55	0.084	0.244	0.117	0.6	62	0.005
R60+Inf	0.39	0.013	109	0.065	0.237	0.098	0.6	93	0.007

houses' base level consumption estimates are well within one SE of the DOE-2 summer energy value. The high values for SE suggest, however, that appliance usage in Minneapolis would have to change by almost 10% for such a change to be identified with any confidence.

PRISM Heat Part vs DOE-2 Heating. Base level consumption includes bth average daily summer heating in addition to average daily non-heating energy consumption. The effect of PRISM's attributing of summer heating to base level consumption is shown in Figure 3. Note that the Minneapolis data show PRISM heat part to be about 95% of actual DOE-2 heat, while the San Francisco values range from only 44-56%. Put another way, about 5% of Minneapolis heat actually shows up in base level consumption, while 50% of San Francisco's does. The absolute amounts of heat misapportioned in relatively balmy San Francisco are, of course, smaller than the percent figures might suggest. But clearly, in climates with mild winters and cool summers, PRISM's apportioning of summer heating away from "heat part" can have significant effects on estimates of its component parameters β and $H_0(\tau)$.

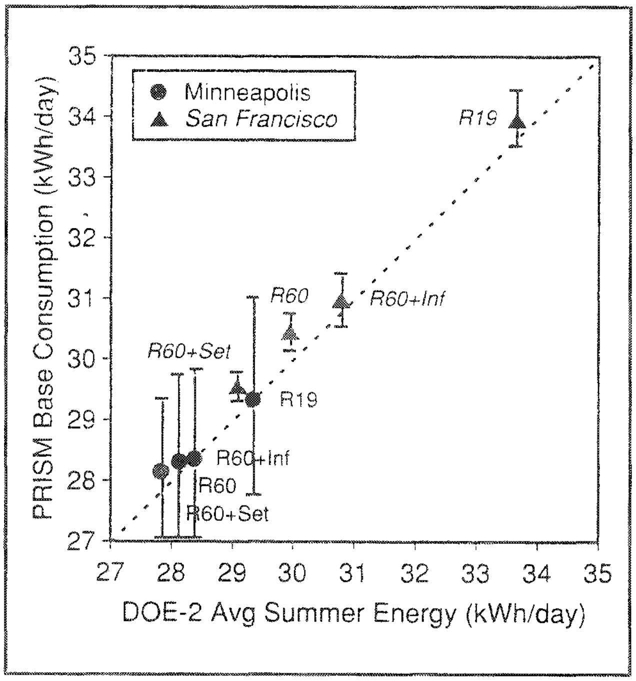

Figure 2. PRISM Base Level Consumption and DOE-2 Average Daily Summer Consumption

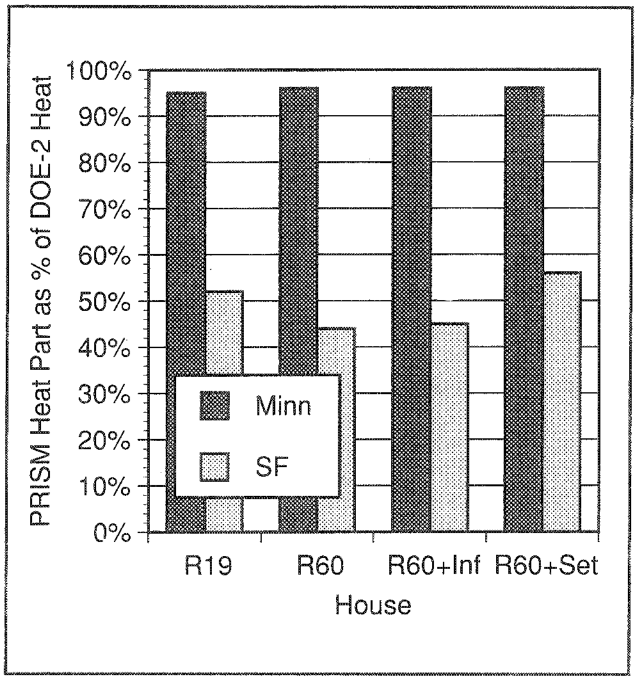

Figure 3. PRISM Heat Part as Percent of DOE-2 Heat

Lossiness Comparisons. Figure 4 shows the comparisons of DOE-2 and PRISM "lossiness" estimates for the four houses in each city. The Minneapolis data show a far closer match between PRISM and DOE-2 parameter estimates, with the greater gaps visible for the R60 houses and houses with setbacks. Only in the latter is the slope more than one SE different than the UA. In San Francisco, for most houses in this sample, the PRISM slope β is greater than the DOE-2 UA. Even with SEs far higher than in Minneapolis, half the San Francisco βs are more than 1.5 SEs higher than UA.

Reference Temperature Comparisons. Figure 5 shows the remarkably close match between PRISM T_Ref and DOE-2 T_Bal in Minneapolis. Even the largest gap, only about 1°F for the R60+Set house, is less than 1 SE. In San Francisco, the match between DOE-2 and PRISM is considerably poorer, with T_Bal exceeding T_Ref by about 3-4°F, or about 2-4 SEs. The tendency for T_Ref to exceed T_Bal as UA drops is less pronounced in San Francisco than in Minneapolis.

This shortfall of T_Ref relative to T_Bal in San Francisco is a direct consequence of PRISM's assigning of summer heating to base level consumption. For "heat part" to be significantly lowered relative to actual heating, either one or both of its components--β and $H_0(\tau)$--must be lowered relative to the value calculated from DOE-2. Earlier we noted that, in San Francisco, PRISM's β actually tends to overstate the building's UA. This means that the heating degree days portion $H_0(\tau)$ of $\beta H_0(\tau)$ is compensating for overestimates of both slope and intercept. This reduction in heating degree days manifests itself as a significant shortfall in PRISM's reference temperature relative to the calculated balance temperature.

Comparisons of Changes in DOE-2 and PRISM Parameter Estimates

PRISM is typically used for estimating changes in energy consumption resulting from conservation retrofits. We therefore compared PRISM's estimates of parameter changes to those calculated directly from the DOE-2 data. In this study, the four buildings were chosen so that most could be seen as resulting from the application of retrofits to one of the other buildings. Imagining that the weather remained exactly the same from one year to the next, we can see the differences in PRISM and DOE-2 parameters as reflecting how they would each characterize a single building undergoing that specific retrofit.

PRISM NAC and DOE-2 Total Consumption Change Comparisons. Given the extremely (and tautologically) close match between the PRISM and DOE-2 values for total energy consumption for the houses considered individually, it is hardly surprising that changes in NAC follow those in DOE-2 with remarkable accuracy. When changes are considered as percentages of original values, the PRISM values in Table 2 differ from DOE-2's by no more than 0.1 percent. More meaningful comparisons of changes in NAC with changes in DOE-2 total energy use await the production of synthetic data from a second set of temperatures in each city.

Base/summer Consumption Change Comparisons. In both cities, Figure 6 shows that the percentage changes in PRISM base level consumption are within 1 percent of the DOE-2 summer consumption changes. We can conclude that PRISM's α is a reliable indicator of both average daily total energy consumption and its changes during the three warmest months. We note, however, that the large SEs in Minneapolis make confident identification of base level consumption changes problematic.

Changes in PRISM Heat Part vs DOE-2 Heating. Figures 7 and 8 show the changes in PRISM's heat part vs changes in DOE-2 heating. In general, PRISM underestimates actual heating changes. The Minneapolis estimates are quite close, particularly when seen as percentage rather than absolute changes. The San Francisco estimates show a poorer match, with most of the PRISM absolute change estimates more than one SE

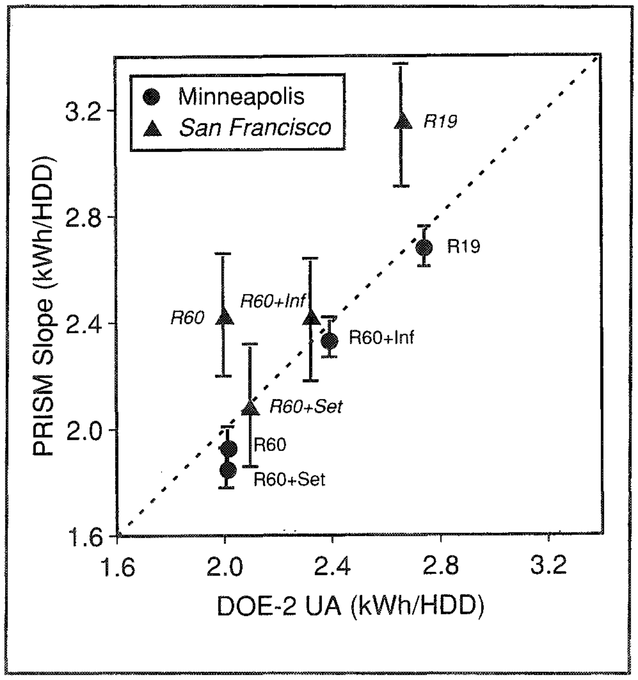

Figure 4. PRISM Slope and DOE-2 UA

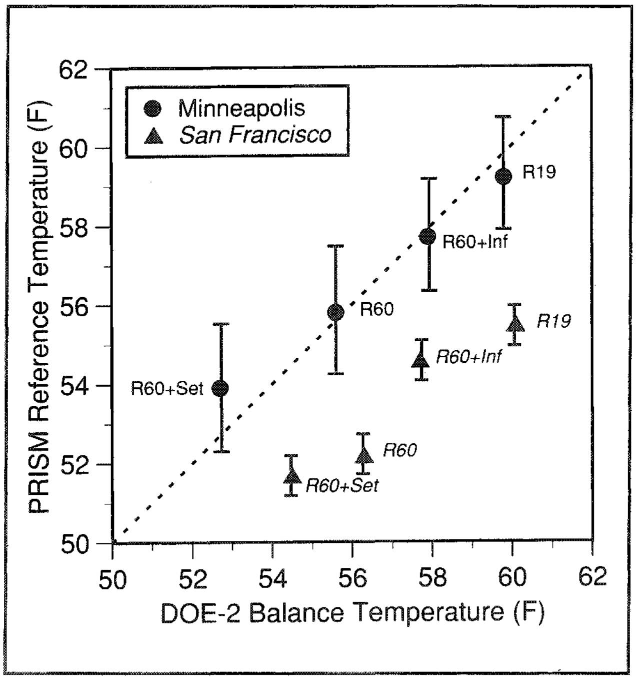

Figure 5. PRISM Reference Temperature and DOE-2 Balance Temperature

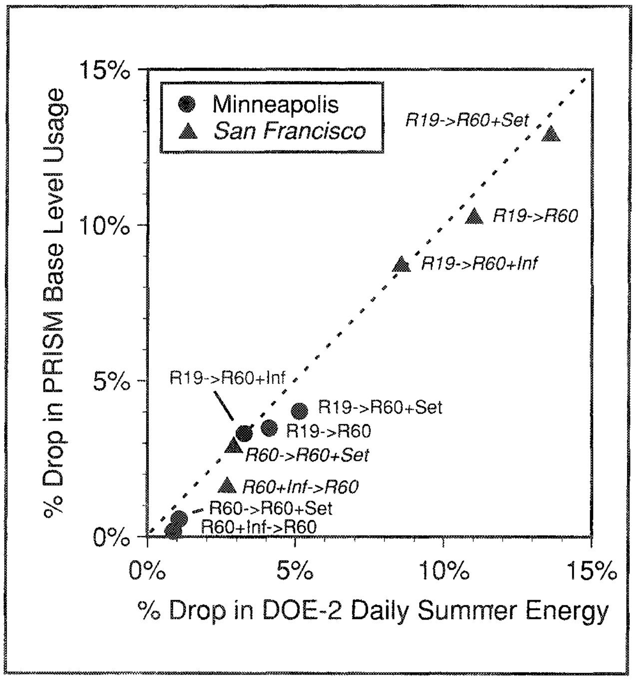

Figure 6. Percent Changes in PRISM Base Level Consumption and in DOE-2 Average Daily Summer Consumption

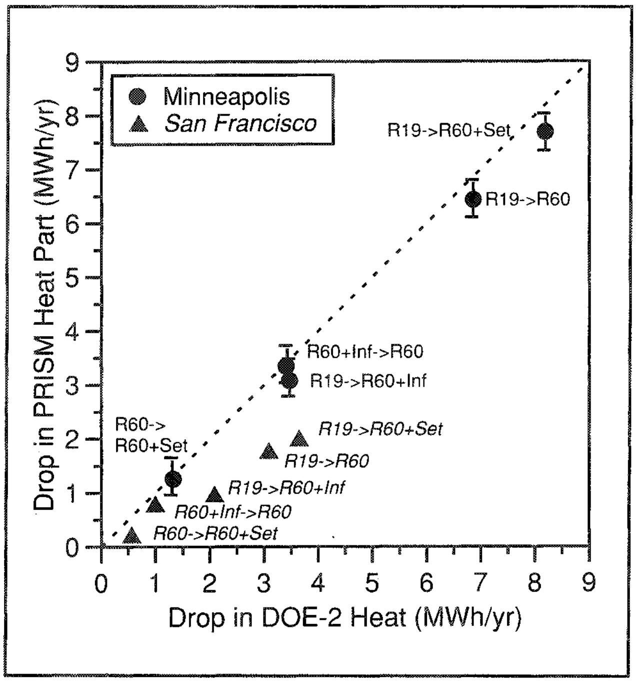

Figure 7. Changes in PRISM Heat Part and in DOE-2 Heat

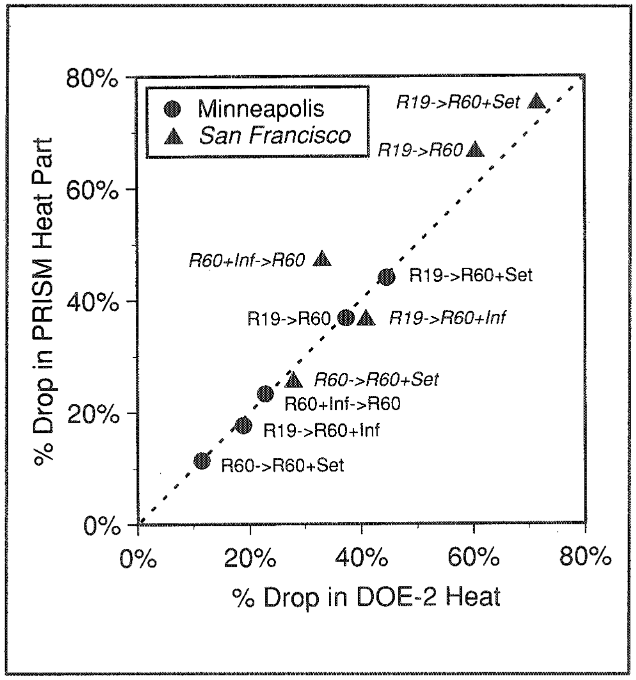

Figure 8. Percent Changes in PRISM Heat Part and in DOE-2 Heat

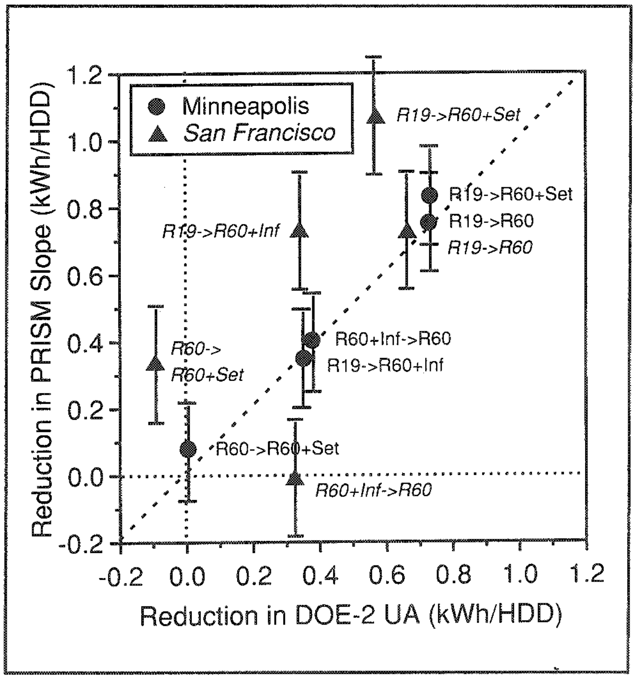

Figure 9. Changes in PRISM Slope and in DOE-2 UA

below the actual DOE-2 heating changes. (Note that the SE of the change is calculated as the square root of the sum of the squares of the original and final SEs.) To further complicate matters, PRISM overestimated the corresponding percentage changes in DOE-2 heating in three cases, while underestimating in the remaining two.

Lossiness Changes. Figure 9 shows the reductions in PRISM slope and DOE-2 UA as houses are changed. (A chart of percent reductions looks almost identical.) In both cities, the adoption of thermostat setbacks in R60 houses yields the largest gap between changes in β and UA. While this gap in Minneapolis is less than 5 percent, that in San Francisco is close to 20 percent or about 0.4 kWh/HDD. Half the San Francisco houses show PRISM's lossiness changes overstating changes in UA by about 5 percent or more. The only house for which PRISM's changes in slope significantly understate the changes in UA is the San Francisco R60 house which has infiltration reduced.

In San Francisco, PRISM seems blind to effects on lossiness of an infiltration change: note that the UA changes almost 15% between houses R60 and R60+Inf, while the PRISM slope is virtually unchanged. In fact, PRISM substitutes an unusually large decrease in T_Ref for the expected decrease in slope, as Figure 10 shows.

Further, adding setbacks to the R60 house in San Francisco results in PRISM and DOE-2 actually showing the lossiness changing in opposite directions. While one would expect virtually no change in UA as a result of setbacks, DOE-2 shows a small increase (about 5%). This is explainable in terms of our method of computing annual UA. The reduction in total heat occasioned by the introduction of thermostat setbacks occurs slightly disproportionately in winter months, which have lower UAs (heat + intrinsic gain/HDD) than do the summer months. As a result, summers with their lower heat but higher UA take on a larger share in total heat. The net result is a slight rise in effective annual UA. PRISM, on the other hand, shows a drop in slope of about 15 percent.

In summary, for this set of simulated houses, PRISM's changes in β in Minneapolis seem to be far more reliable indices of the changes in UA than are the β changes in San Francisco, where both thermostat setbacks and infiltration reduction resulted in significant discrepancies. Even when SEs are taken into account, the San Francisco slope changes are poor indices of building UA changes.

Reference and Balance Temperature Change Comparisons. Figure 10 shows that PRISM's changes in reference temperature typically understate the changes in the balance temperature. In both cities, houses with setbacks showed the greatest underestimates: up to 2°F. Minneapolis houses without setbacks showed very close matches; changes in PRISM reference temperature were typically within 0.5°F of the changes in DOE-2 balance temperature. In San Francisco, only the R19 house changed to R60 produced a very close match. All others were off by 1-2°F.

Even given SEs of about 2°F for the estimates of changes in Minneapolis T_Ref and about 0.7°F for those in San Francisco, the gaps between T_Ref and T_Bal in San Francisco are frequently sufficient to undermine the use of PRISM's parameters as clues to physical changes in the houses.

PRISM's treatment of the adding of setbacks to the R60 house has already been mentioned. On theoretical grounds, one would expect a drop in reference temperature of about 3°F and little change in slope. The Minneapolis data are fairly close to expectation, as shown by Figures 9 and 10. In San Francisco, the reference temperature dropped by only 0.5°F, with the SEs suggesting a likely range of 0-1°F. The slope dropped by almost 0.4 kWh/HDD or about 14 percent; the SEs suggest perhaps 0.2-0.5 kWh/HDD. If one assumed a close correlation between the PRISM parameters and physical changes in the house, but paid close attention to SEs, one still could conclude wrongly that the building shell had been tightened.

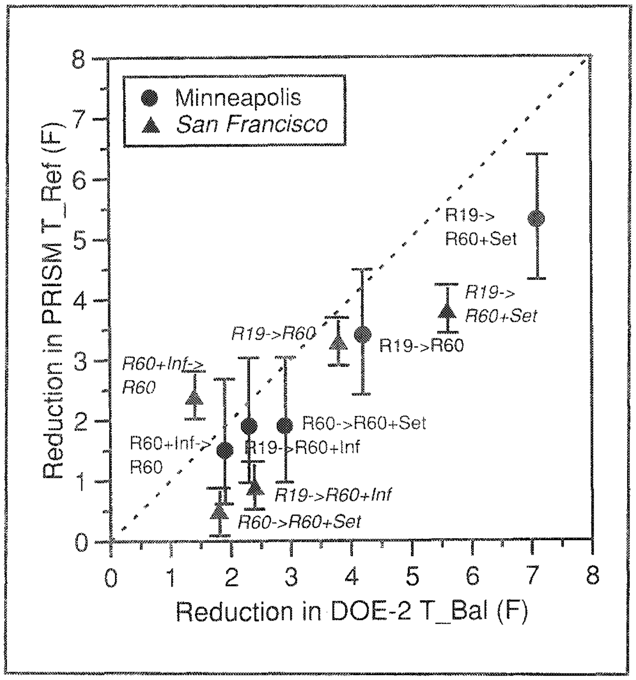

Figure 10. Changes in PRISM Reference Temperature and in DOE-2 Balance Temperature

Conversely, PRISM's treatment of reducing infiltration in the R60 house--with slope staying constant as reference temperature dropped almost 3°F--produces the results expected with the introduction of thermostat setbacks.

Conclusions

For all houses in both cities, PRISM's regression coefficient of determination (R^2) is extremely high, and Normalized Annual Consumption (NAC) has extremely low standard errors. PRISM's base level consumption is a close match to DOE-2's average daily summer total energy consumption.

In Minneapolis, the PRISM parameter estimates for slope β, intercept α, reference temperature τ, and heat part $\beta H_0(\tau)$ are all extremely close to those calculated directly from DOE-2 data. High standard errors for α imply that changes in appliance energy usage would have to be substantial for confident identification. In San Francisco, the large share of total heating which occurs during the warmer months is apportioned by PRISM away from heat part and into base level consumption. Perhaps because relative changes in the remaining energy use per heating degree day in winter are larger, regression slope β tends to overstate UA. The changes in slope suggested by PRISM are so sizeable that, even given high SEs for these estimates, the changes appear statistically significant. Taken together, the result is that PRISM heating degree days and therefore reference temperature in San Francisco are significantly underestimated relative to the DOE-2 balance temperatures.

Further, for the retrofits considered in San Francisco, PRISM exaggerates the reductions in lossiness while understating changes in reference temperature and heating degree days. These discrepancies, which exceed the standard errors in the PRISM estimates, combine to somewhat dampen the changes in their product ("heating part"), though not enough to bring the PRISM heat part changes within 1 SE of the changes in DOE-2 heat.

Under these ideal conditions, a user of PRISM could safely assume that the Minneapolis parameter estimates accurately reflect the physical causes behind observed changes in NAC for the simulated houses. The San Francisco data, however, with the exception of base level consumption and sometimes the percent changes in heat part, tend to be less reliable than their standard errors would indicate. Both infiltration reduction and thermostat setbacks resulted in unexpected changes in slope and reference temperature, such that one conservation measure could actually have been confused for the other.

The present study offers no ready prescription for identifying the circumstances and for predicting the sizes of discrepancies between PRISM's parameters and their physical counterparts. It does show that these discrepancies are most prominent when summer heating is a large fraction of total heating, and that in such climates even the standard errors of parameter estimates may be insufficient to permit confidence that PRISM parameter changes reasonably reflect simple physical changes in the building under analysis.

Further research, modeling different combinations of conservation measures and more subtle changes in more lightly-insulated slab- and basement-foundation buildings in a range of climates with significant summer heating shares, could provide a broader and more realistic set of data with which to work. Theoretical models could be created to account for PRISM's anomalous treatment of slope and reference temperature. At the very least, the research should give a clearer picture of which parameters for which retrofits in which climates are likely to be reliably characterized by PRISM.

Acknowledgments

The authors wish to acknowledge the contributions of the following, all from Lawrence Berkeley Laboratories: Joe Huang, from whom the DOE-2 building descriptions were borrowed and slightly modified; Jim Hanford, who assisted in the pre- and postprocessing of the DOE-2 data; Bruce Nordman, who helped with the preparation of the DOE-2 data for PRISM's analysis; and to Bruce Nordman and Ellen Franconi, for helpful comments during the research and writing of a larger study from which this paper is drawn. Thanks are also due to Meg Fels and three anonymous referees for their comments on the preliminary draft. The computer services were supplied by LBL.

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