DETERMINANTS OF ACTUAL ELECTRICITY SAVINGS AFTER RETROFIT: ELECTRICALLY HEATED HOMES IN THE PACIFIC NORTHWEST

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ABSTRACT

A Pacific Northwest utility operated an interim Residential Weatherization Program during 1982 and 1983. The program offered free home energy audits and cash rebates to help pay for installation of recommended retrofit measures in electrically heated homes. The program retrofit almost 104 thousand homes at a cost of almost $160 million.

This study analyzes actual electricity savings for homes retrofit by the program. We examine the electricity savings achieved by these homes and the relationships between actual and predicted savings. This involves calculation of summary statistics, comparisons among groups of homes, development of regression models that explain variations across households in actual electricity savings, and examination of individual homes with anomalously large or negative savings. Data are available for nearly 1000 participants.

INTRODUCTION

Electric and gas utilities throughout the U.S. offer on-site home energy audits, often as part of the federal Residential Conservation Service (U.S. Department of Energy 1982). During the first three years of its operation, about three million RCS energy audits were conducted (Centaur 1985).

Many utilities supplement their audit programs with cash rebates or low-interest loans to encourage households to install measures recommended during the energy audit. For example, a Tennessee utility gave low-interest retrofit loans to almost 500 thousand households between 1977 and 1984 (TVA 1985). Another, in the Pacific Northwest gave cash rebates to 104 thousand households during 1982 and 1983 (Eissler 1984).

The underlying assumption of these conservation programs is that installation of retrofit measures will lead to substantial reductions in residential energy use, reductions that justify the utility and household costs of implementation. However, the limited data available on the actual energy savings experienced in homes after retrofit show two important problems. First, the average energy saving experienced in these retrofit homes falls short of the saving estimated during the energy audit (Wagner 1984; Hewett et al. 1985; Hirst and Goeltz 1984; Hirst et al. 1983). Second, there is enormous variation across households in their actual savings (Goldman 1984); a nontrivial minority of households actually show an increase in energy use after retrofit.

The purpose of this study is to analyze actual electricity savings for homes that participated in the interim Residential Weatherization Program (RWP). The focus is on analytical methods that can be used to understand the determinants of actual energy savings after retrofit and the relationships between actual and predicted savings. Detailed results obtained with these methods are given in the original report by Hirst et al. (1985b). The interim RWP was offered to electric utilities in the Pacific Northwest in January 1982 (BPA 1982). During its two-year lifetime, the program retrofit 104 thousand homes at a total cost of $157 million.

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The data for the present project came from an evaluation of the interim program (Hirst et al. 1985a). The major purpose of this evaluation was to estimate the electricity savings that could be directly attributed to the program. Several types of data were collected:

- electric utility bills for samples of participants from mid-1981 through mid-1984;
- daily temperature data for each relevant weather station, to match with utility bills to adjust consumption for changes in weather;
- information on recommended and installed retrofit measures, from energy audits and weatherization completion forms;
- information on demographic, economic, and structure characteristics, on recent conservation measures installed and practices adopted, and on conservation attitudes, from mail and telephone interviews conducted in 1983 and 1984.

The ten utilities included in this evaluation accounted for slightly more than half the total weatherizations completed during the two-year life of the interim program.

The evaluation was restricted to households that had lived in their present residence for at least a year prior to participation (to ensure that a full year of preretrofit billing data would be available). Almost all (97%) of these households lived in single-family homes; 96% owned their homes. We further defined participants as households that had received an energy audit and financing to retrofit their homes in either mid-1982 or mid-1983 (between heating seasons).

SUMMARY STATISTICS

The simplest way to begin analysis of actual electricity savings is with examination of summary statistics for the retrofit homes. The utility energy audit data and weatherization completion forms, plus the electricity billing data, provide the raw material for this initial review of retrofit electricity savings. (For simplicity, we present results in this paper for only the 1983 participants; results for both the 1982 and 1983 participants are included in Hirst et al. 1985b).

Program operation data from the participating utilities show that ceiling and floor insulation were the most widely adopted retrofit measures (Table 1). Wall insulation, duct insulation, and storm doors, on the other hand, were installed in only 10 to 20% of the homes.

The audit estimate of electricity saving for the measures installed by the program averaged 5800 kWh per home and the average cost of the installed retrofit measures was $1700 (Table 2). The actual one-year reduction in electricity use was 2700 kWh (Table 2 and Figure 1),* a 10% reduction in electricity use relative to preprogram consumption.

Comparing the mean values of actual and predicted electricity savings suggests that 47% of the predicted saving was actually realized. This is close to the median values of the ratios. Thus, the actual saving was far below the audit estimate.

Many factors might account for the differences between actual and predicted electricity savings: errors in audit methodology, errors in auditor data collection and interpretation, installation of inappropriate measures, use of poor quality retrofit materials, sloppy installation of measures, changes in occupant energy-related behavior after retrofit, errors in electricity billing data, and errors in methods used to analyze electricity-use data. Although the data and analyses presented in this paper shed some light on these issues, little empirical data are available on the importance of each of these factors.

There is substantial variation among homes in the relationship between actual and predicted electricity savings (Figure 2). Electricity savings were negative in 19% of these homes and exceeded 10,000 kWh in 5%. The actual saving was within ±50% of the predicted saving in 35% of the homes.

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*We used the Princeton Scorekeeping Model (PRISM) to calculate weather-adjusted electricity use for each household, pre- and post-retrofit (Fels 1984; Hirst et al. 1985a). The primary output of PRISM is normalized annual consumption (NAC) in kWh/year. The difference between pre- and post-retrofit NACs is denoted by DNAC.

STATISTICAL MODELS OF ACTUAL ELECTRICITY SAVINGS

To further explore the relationship between actual and predicted savings - and more generally - to understand better the factors that affect actual savings after retrofit, we developed statistical models of actual savings (DNAC). These models build upon, and use, the data discussed in the preceding section.

We began with simple models that relate DNAC solely to the measures installed in each house. We estimated a model of DNAC as a function of the audit estimate of saving due to the measures installed by the program. This model explained less than 10% of the variation across households in actual electricity savings. Model results suggest that a 1 kWh increase in estimated saving yields only a 0.3 kWh increase in actual saving.

In general, we hypothesize that the variation in actual electricity savings is a function of the structure itself, the measures installed, the conservation practices adopted, and the characteristics of the occupants. We tested several variables from the household surveys in models of DNAC. This model (Table 3) explained one-third of the variation across the 1983 households. That is, adding several variables (preprogram electricity use, heated floor area, household income, change in electricity price, and long-run heating degree-days) and dummy variables (for houses that switched primary heating fuel from electricity, for homes with air-conditioning equipment, and for homes that added floorspace) to the simple model that included only the audit prediction as an explanatory variable increased the R^2 from 0.1 to 0.3. This dramatic improvement in model performance demonstrates the importance of several factors in explaining household electricity savings; clearly, the retrofits were only one determinant of actual savings.

The most important determinant of DNAC is preprogram electricity use. A 1 kWh/yr increase in NAC_1 leads, all else being equal, to a 0.2 kWh/yr increase in actual savings. The audit estimate of electricity saving for the measures installed by the program is also an important determinant of actual savings. On average, a 1 kWh increase in audit estimate leads to a 0.1 kWh increase in actual saving, less than half the estimate obtained with the simple model discussed above.

Actual savings are negatively correlated with house size, presumably because larger homes using the same amount of electricity preretrofit are more efficient to begin with. Households that switched their primary heating fuel from electricity to another fuel (usually wood) had much larger electricity savings (3400 kWh) than those who did not switch heating fuels. Increases in electricity prices led to significant increases in actual savings. Presence of air conditioners or increases in house size led to reductions in actual savings.

COMPARISONS AMONG LARGE, MEDIUM, AND SMALL SAVERS

An approach that is complementary to the use of statistical models involves disaggregation of the households into a small number of groups, based on actual electricity savings. Comparison among these groups is based on the assumption that differences within groups are much smaller than differences across groups (i.e., the groups are homogeneous with respect to important energy-related characteristics).

Here we compare the characteristics of three groups of households - those whose actual electricity savings fall into the top 10% of the distribution of households for that year, those that fall into the bottom 10%, and the middle 50%, ranging from 25 to 75% of the distribution (Figure 1). We call these three groups "large," "small," and "medium" savers, respectively. Note that the three groups do not include all the households: those in the 10 to 25% and the 75 to 90% ranges were excluded to provide sharper distinctions among groups.

Comparison of the mean values across these three groups (Table 4) shows several interesting differences. Large savers used 50% or more electricity preretrofit than did small savers.

Perhaps because of these large differences in preretrofit electricity use, large savers installed more retrofit measures, with larger estimated savings and higher costs than did the small savers. Large savers were more likely to switch primary heating fuel from electricity and less likely to switch from another fuel to electricity. Consistent with these fuel switching results, large savers were more likely to increase use of wood for heating after retrofit. Finally, large savers were less likely to have added floorspace to their home after retrofit. These differences between the two outlier groups are consistent with prior expectations.

Small savers faced higher electricity prices, which may have induced them to adopt conservation measures and practices before participation in the program. In addition, electricity price increases were higher for the large savers than the small savers in both years. Economic theory suggests that higher electricity prices should lead to larger electricity savings, which is what the data show. Thus, both preparticipation differences and subsequent increases in electricity prices help explain differences in electricity savings between large and negative savers.

Differences among groups in terms of house age and size, winter severity, household education, years in present home, household income, change in number of household members, and electricity price are small and lack consistency.

EXAMINATION OF INDIVIDUAL OUTLIER HOUSEHOLDS

The logical extension of the approach discussed above (disaggregation of households into a few groups) involves examination of data for individual households. Here we examine the electric utility bills and the 1983 telephone and 1984 mail survey responses for a few of the 1983 participant households whose electricity savings are either anomalously large or small. We hope that this detailed, house-by-house examination will identify specific factors that account for the observed anomalies in actual electricity savings.

We first examined detailed data for the homes with the smallest electricity savings. We examined survey responses that support very small or negative savings and responses that are counterintuitive. More than half (54%) of these 48 households reported a decrease in supplemental fuel use and/or an increase in electricity use as the primary or supplemental heating fuel. By comparison, only 20% of these households gave survey reponses suggesting an increase in supplemental fuel use and/or a decrease in electricity use.

Seven households reported an increase in the size of their house, which would reduce electricity savings. Four households increased the number of electric appliances, while only one decreased the number of appliances. One household increased the number of household members, but four decreased the number of occupants.

In general, the majority of these survey responses concerning use of electricity and wood for heating, floorspace additions, and changes in the number of appliances are consistent with the negative savings for these participants. However, some of the responses, especially those on change in number of occupants, are not consistent with the actual changes in electricity use.

Similar patterns occur for the very large savers. More than one-third of these households reported an increase in nonelectric fuel use and/or a decrease in electricity use for space heating. On the other hand, almost 20% reported opposite changes in heating fuel use. Four households had a decrease in number of occupants, but six reported a counterintuitive increase. The one report of an increase in floorspace and the two reports of more electric appliances are also counterintuitive.

Here again, most of the responses concerning primary and supplemental heating fuels are consistent with the very large electricity savings. Also, most of the reported changes in number of household occupants are counterintuitive, as occurred with the negative outlier households.

We also examined plots of monthly (or bimonthly) electricity use as a function of HDD [in terms of kWh/day vs HDD(60F base)/day] to identify individual outlier bills that might explain these anomalous electricity savings. Because of the editing done by our energy analysis software (see Hirst et al. 1984), there are only a few cases where one bill is sufficiently out-of-line to explain the anomalous change in overall electricity saving (Figures 3 and 4). There are also a few cases in which the month-to-month pattern of electricity use relative to winter severity is unusual (Figure 5).

DISCUSSION

We used a variety of simple analytical techniques to examine and understand the factors affecting actual electricity savings after retrofit. The data used in this project were for electrically heated single-family homes that participated in the interim Residential Weatherization Program. Because the data (electricity bills, energy audit and weatherization completion forms, and household surveys) were collected as part of an evaluation of the program, the cost of conducting this project was quite small.

We began analysis of electricity savings with examination of simple statistics (means and standard deviations) and histograms showing variation across participants in actual savings and in the ratio of actual to estimated savings.

We next developed simple regression models to statistically explain variation across households as functions of the retrofit measures installed by the program and characteristics of the house and household. We also compared the mean characteristics of the top and bottom 10% of the energy savers. Finally, we examined data from individual outlier households to see if their survey and electricity billing data could explain their anomalous electricity savings.

Our examination of summary statistics showed that less than half the expected saving, on average, actually occurred in the 1983 participant homes. (The comparable figure for the 1982 participants was almost 80%.) As discussed in Hirst et al. (1985b), the low savings for 1983 participants were probably due primarily to factors external to the program - changes in electricity prices, household incomes, unemployment, and, therefore, in wood use throughout the Pacific Northwest. After several years of rapid increases in electricity prices, declines in household income, and increases in unemployment electricity prices increased only slightly and incomes increased between 1982/83 and 1983/84. As a consequence, the trend toward greater use of wood for space heating reversed during this period.

Statistical analysis of the actual one-year electricity savings experienced by participant households explains one-third the total variation across homes. The major determinants of savings are preprogram electricity use, the estimated saving for the measures installed by the program, increases in electricity prices, and shifts in primary heating fuel from electricity, all of which are positively related to actual savings; and house floor area, increase in floor area, and presence of air conditioners, which are negatively related to actual savings.

Comparison of large and small saver homes (those that fell in the top and bottom 10% of the distributions of actual electricity savings) showed similar differences to those found in the regression models. Again, large savers had much higher preprogram electricity use, installed more measures with higher retrofit cost, were more likely to switch primary heating fuel from electricity, faced lower electricity prices preretrofit, and experienced larger electricity price increases than the small savers.

Although we are able to explain variations among households when viewed in aggregate, our ability to explain why individual households have anomalously high or low savings is limited. Examination of data for individual households shows the importance of some of the factors identified above. However, there are cases for which counterintuitive changes occurred such as a large saver household that decreased its use of wood after retrofit. Examination of the detailed billing data sometimes reveals patterns that suggest a switch in primary heating fuel, an error in the data, or unusual occurrences in the home (e.g., long vacations, extended visits from relatives, a broken window that is not fixed immediately).

Although the methods used here are inexpensive to apply and provide much useful information on the factors that account for difference in actual electricity savings, more can be done. It might be helpful to conduct postretrofit energy audits among small samples of the outlier homes. These on-site inspections might identify anomalies in the structure, the retrofit measures installed, and/or household behavior that would explain the very large or negative savings. We are aware of only one study that included such postretrofit inspections, conducted as part of an evaluation of the Wisconsin low-income weatherization program by Goldberg, Jaworski, and Tallis (1984). Unfortunately, their "attempts to find differences in the data for these two [high and low saver] groups which might explain their differences in energy savings have, for the most part, been baffled."

Second, we suggest use of submeters to explicitly identify changes in space heating and water heating electricity use, as well as changes in total household electricity use. This additional information on the details of electricity use by end-use should permit better explanation of variations in actual savings.

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TABLE 1
Retrofit Measures Installed by the RWP in 1983

	Percentage of homes in which measure installed	Retrofit cost (1982-$)
Insulation		
outside wall	20	540
roof/ceiling	85	580
floor	73	790
heating ducts	15	230
Storm		
windows	34	1270
doors	9	240
Caulking/ weatherstripping	19	50
Automatic setback thermostat	21	160

Source: Weatherization completion forms for 484 1983 participants.

TABLE 2
Summary Statistics on Actual and Predicted Electricity Savings and Costs for 1983 Participants in the RWP

	Median	Mean	CV[a]
Preprogram electricity use, 1982/83 (kWh/yr)	23,000	24,200	0.40
Actual electricity saving, 1982/83 - 1983/84 (kWh/yr)	2,280	2,740	0.81
Predicted electricity saving (kWh/yr)	5,120	5,820	0.64
Actual/predicted saving	0.44	0.54	2.80
Retrofit cost (1982-$)	1,500	1,740	0.64

[a]CV, the coefficient of variation, is the nondimensional ratio of the standard deviation to the mean.

Source: Energy audits and electricity bills for 484 1983 BPA program participants.

TABLE 3
Regression Results for Models of Actual Electricity Saving (DNAC, kWh/year) for Homes That Participated in the RWP

Explanatory variable	Model coefficients
Intercept	-1220[a]
Preprogram electricity use, NAC_1 (kWh/yr)	0.19[a]
Audit prediction of saving (kWh/yr)	0.13[a]
Heated floor area (ft^2) (-10.3 if area in m^2)	-0.96[a]
Household income (thousand-$)	-0.016
Switched primary heating fuel from electricity	3350[a]
Change in electricity price (¢/kWh)	-2230[a]
Long-run HDD (60F) (16C)	-0.15
Presence of air-conditioning equipment	-1080[a]
Increased house floor area	-2580[a]
R^2	0.33
No. of observations	484

[a]Statistically significant at the 1% level.

[b]Statistically significant at the 5% level.

Source: Scorekeeping model results, weatherization completion forms, and telephone survey responses for households that received BPA financing in 1983.

TABLE 4
Characteristics of 1983 Program Participants, by Amount of Electricity Saving

	Mean values, by group[a]		
	Large savers	Medium savers	Small savers
Preprogram electricity use (kWh/year)[b]	35,400	22,400	22,300
Audit estimate of retrofit saving (kWh/year)[b]	7,260	5,460	4,370
Retrofit cost (1982-$)[b]	2,150	1,660	1,420
House age (years)	20.3	21.0	17.9
Years in present home	10.9	11.7	8.9
No. of household members	3.4	2.9	3.6
Income (1982-$)	28,400	26,000	31,700
Electricity price, 1982/83 (¢/kWh)[c]	3.0	3.2	3.2
Binary variables:			
Switched primary heating fuel			
from electricity[c]	0.08	0.03	0.00
to electricity	0.02	0.02	0.06
Increased floor area	0.02	0.02	0.08
Change (1982/83 - 1983/84) in:			
No. of household members	-0.06	0.04	0.13
Electricity price (¢/kWh)[b]	-0.58	-0.44	-0.17
Wood use (cords/year)[b]	-0.19	-0.09	0.48
Electricity use (kWh/year)[b]	10,810	2,340	-3,310
No. of households	48	242	48

[a]Large savers are those with savings greater than 7600 kWh/year and small savers are those with savings less than -1570 kWh/year.

[b]Difference between the large and small saver means is statistically significant at the 1% level.

[c]Difference between the large and small saver means is statistically significant at the 5% level.

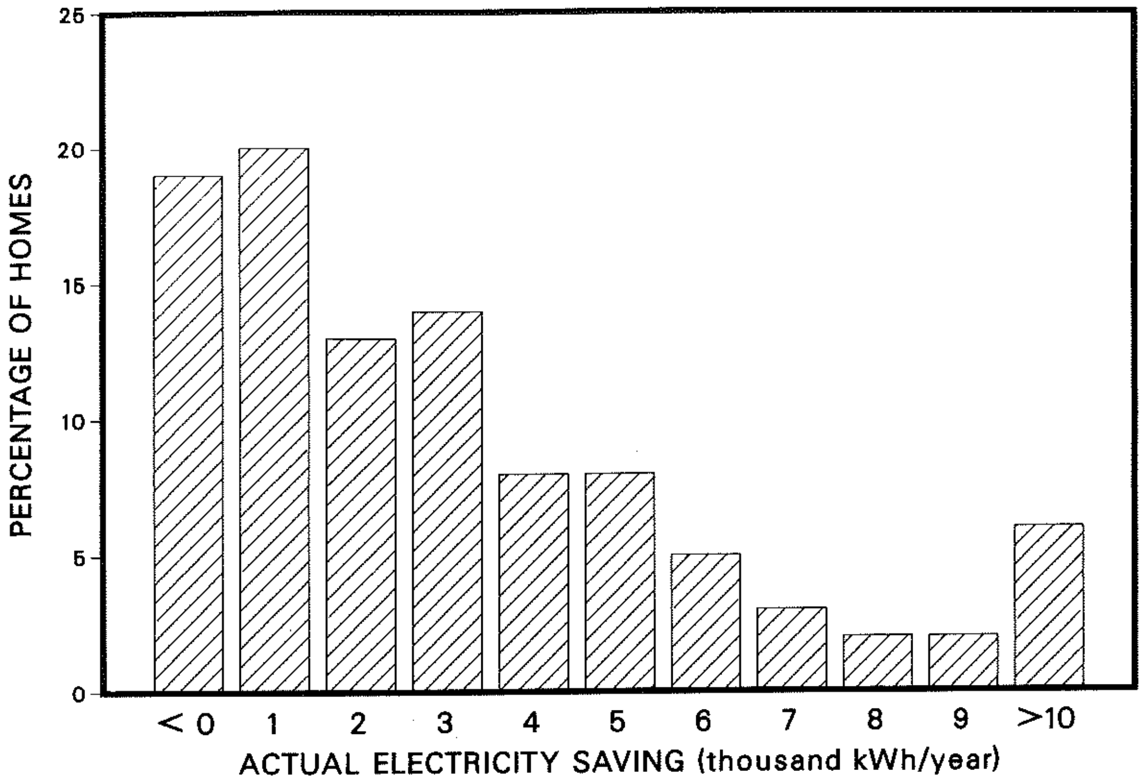

Figure 1. Distribution of actual electricity savings for 484 1983 participants in the program

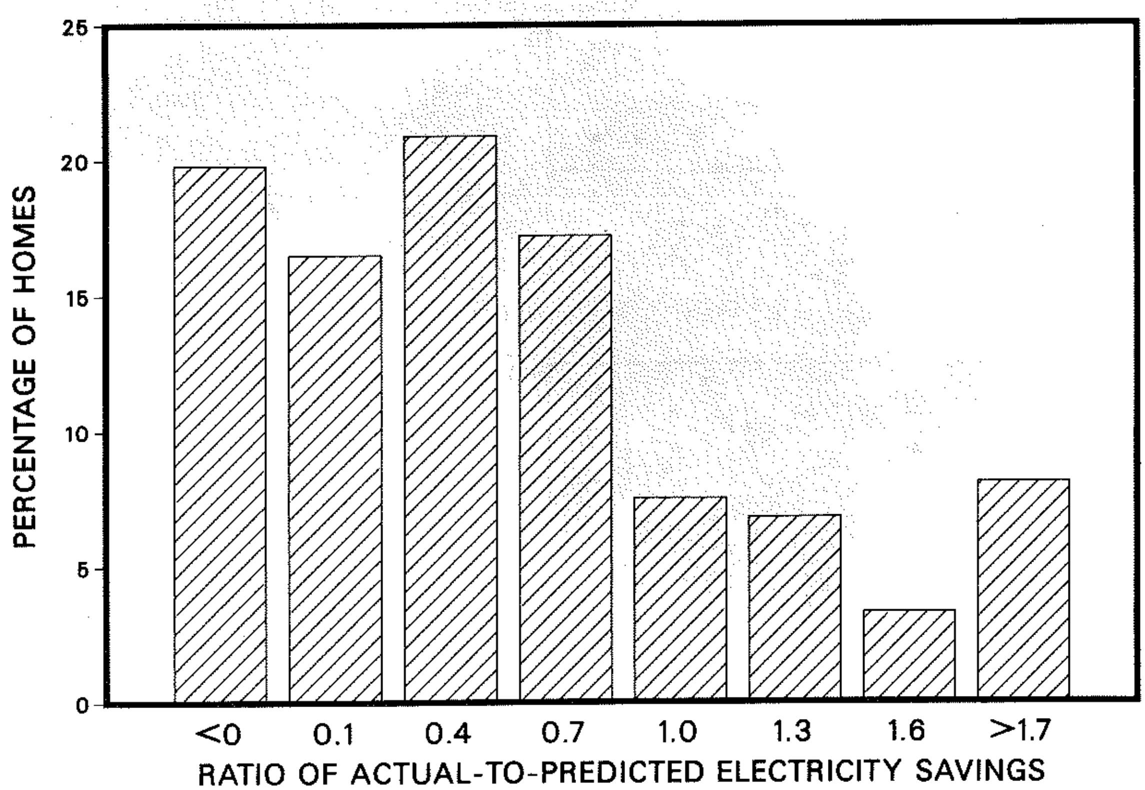

Figure 2. Distribution of ratio of actual-to-predicted electricity savings for 484 1983 participants in the program

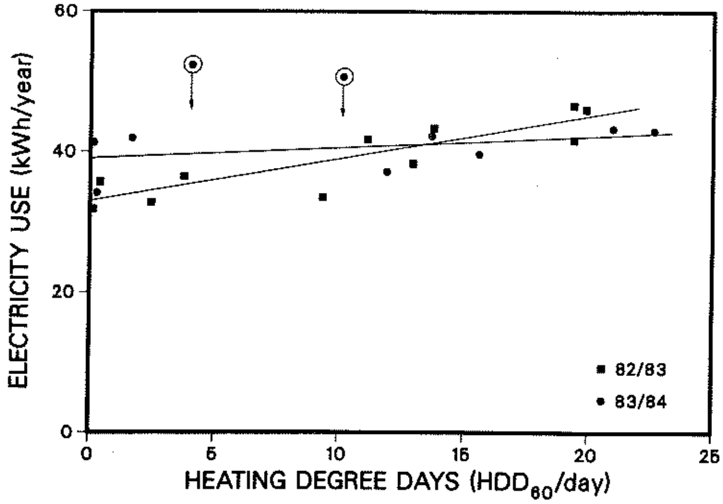

Figure 3. *Monthly electricity billing data as a function of heating degree days for a particular 1983 participant negative saver household. PRISM model results show $R^2 = 0.78$ for the first year, $R^2 = 0.02$ for the second year, and DNAC = -1490 kWh/yr*

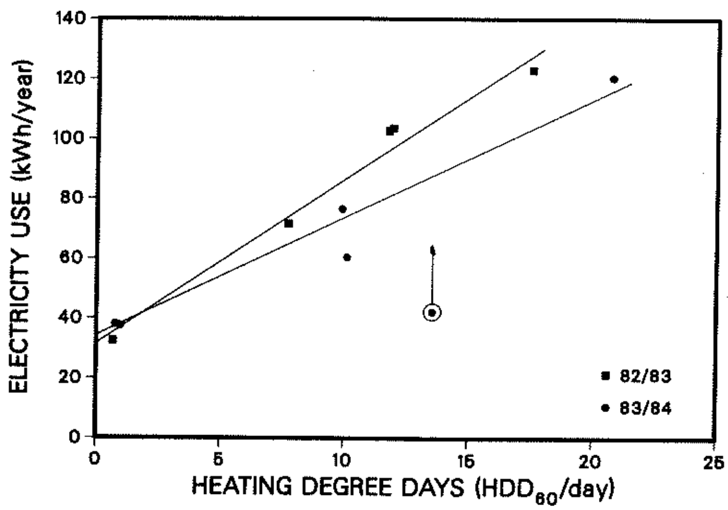

Figure 4. *Bimonthly electricity billing data as a function of heating degree days for a particular 1983 participant large saver household. PRISM model results show $R^2 = 0.98$ for the first year, $R^2 = 0.77$ for the second year, and DNAC = 9480 kWh/yr*

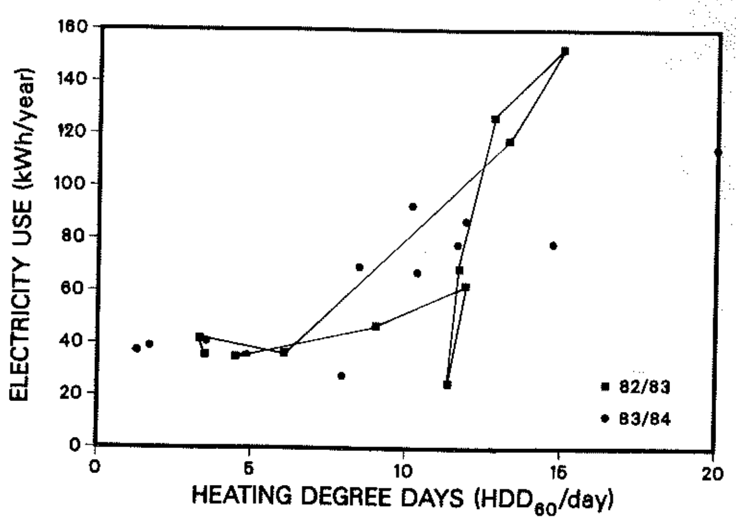

Figure 5. *Monthly electricity billing data as a function of heating degree days for a particular 1983 participant large saver household with unusual month-to-month pattern. First-year data points are connected in chronological order. PRISM model results show $R^2 = 0.93$ for the first year, $R^2 = 0.75$ for the second year, and DNAC = 15,330 kWh/yr*