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Indoor Temperature Changes After Retrofit: Inferences Based on Electricity Billing Data for Nonparticipants and Participants in the BPA Residential Weatherization Program

Eric Hirst
Dennis White

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ENERGY DIVISION

INDOOR TEMPERATURE CHANGES AFTER RETROFIT: INFERENCES BASED ON ELECTRICITY BILLING DATA FOR NONPARTICIPANTS AND PARTICIPANTS IN THE BPA RESIDENTIAL WEATHERIZATION PROGRAM

Eric Hirst
Dennis White

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SUMMARY

The behavioral response (e.g., changes in indoor temperatures, attention to window and door openings) to residential technical efficiency improvements (e.g., attic insulation, storm windows) is largely unknown. Although there is considerable discussion concerning the extent to which households take back some of the energy savings due to efficiency improvements in increased comfort, there is almost no empirical evidence on the subject.

Detailed electricity billing data for three years (from mid-1981 through mid-1984) were analyzed for households that received financial assistance from the Bonneville Power Administration to retrofit their homes in 1982 or 1983, and for eligible nonparticipants. The analysis focused on changes in year-to-year annual electricity use (pre- vs post-retrofit) and the components of these changes (baseload, space heating, and the effect of changes in indoor temperatures). The analysis was limited to homes with "clean" electricity billing data that used only electricity for space heating, 242 homes in all. This limitation was imposed to exclude homes that use wood or other nonelectric fuels for some or all of their space heating. Restricting this study to nonrandom samples of program participants and nonparticipants suggests that the findings developed here may not apply to the population of households in the Pacific Northwest.

The mean retrofit expenditure in participant homes was $1700. The mean one-year reduction in annual electricity use between 1981/82 and 1982/83 was 4300 kWh for the 1982 program participants, of which more than 90% was due to reductions in space heating electricity use. Analysis of the nonparticipant billing data for the same time period showed a mean reduction of only 1300 kWh, of which 75% was space heating. The 1983 participants cut consumption by an average of 3500 kWh between 1982/83 and 1983/84, of which more than 95% was due to reduced space heating electricity use. Nonparticipants increased consumption during this period by 300 kWh. Thus, both participant groups cut consumption by substantially more than did nonparticipants, with net savings of 3000 kWh for the 1982 participants and 3800 kWh for the 1983 participants.

Further analysis of the electricity billing data suggests that the 1982 and 1983 participant households increased their indoor temperature settings after retrofit by about 0.4 and 1.3°F, respectively. The nonparticipants, on average, left their indoor temperatures unchanged between the first and second years and then increased temperatures by about ¼°F between the second and third years. These results indicate that participants increased their temperatures more than did nonparticipants, by roughly 0.4 - 1.0°F, which supports the notion of a take-back effect.

The participant indoor temperature increases led to estimated average losses of 200 and 1200 kWh/year for the 1982 and 1983 households, respectively. In other words, roughly 5% of the energy saving due to retrofit

was taken back in terms of increased comfort for the 1982 participants, and roughly 25% for the 1983 participants.

These results concerning changes in indoor temperatures should be viewed cautiously because of the strong assumptions embodied in the analytical method and the large variation across households.

1. INTRODUCTION

BACKGROUND

The ways in which households behave after retrofits are installed in their houses is an important but unresolved issue. Microeconomic theory suggests that households will "take back" some of the technical efficiency improvements due to retrofits in increased comfort. The reasoning is as follows. Improvements to the structure of a building, its heating equipment, or both, lower the operating cost of the heating system. The rational economic response to this reduced cost is to purchase more of the system's output (i.e., winter warmth) by raising indoor temperature settings, opening up previously closed rooms, and so on.

Psychologists offer other models of household behavior, not all of which are consistent with that of the economically rational person (Stern and Aronson, 1984):

> The Consumer views his property (home, car, boat) as providing amenities, rather than as an investment. Cost and cost-effectiveness considerations are less important than the services provided.
>
> The Group Member is influenced by what others think. Energy-related behavior is affected less by economic factors and more by social values.
>
> The Committed believes in saving energy. Installation of retrofit measures is likely to lead to even lower thermostat settings to ensure that the conservation actions save energy.

Unfortunately, there is virtually no empirical evidence with which to assess the agreement between these different models and actual consumer behavior. Nevertheless, there is considerable discussion and speculation about consumer take back and its likely effect on conservation program energy savings and economics (Stern, 1984).

For example, the federal residential tax credit is intended to encourage people to install retrofit measures in their homes. Engineering calculations are used to estimate the likely energy savings due to installation of these measures. However, if the behavioral response to these efficiency improvements affects, for example, temperature settings, actual and predicted energy savings will differ. Consider the case in which the actual saving is less than predicted. If decisions on implementation of conservation programs are based on traditional engineering calculations (i.e., the savings anticipated due to efficiency improvements assuming no change in household behavior), then the actual program (e.g., tax credits) may not be as economically attractive as originally planned.

The behavioral response can be viewed in two ways. An increase in personal comfort due to higher temperature settings after retrofit is a benefit of the conservation program. Alternatively, if the program is intended to save fuel (for example, a utility's effort to purchase "conservation energy"), household increase in comfort is a program cost.

Two points summarize this discussion. First, the amount of fuel actually saved after retrofit depends on household behavior. Second, the social value of the retrofit may differ from the value of the fuel savings.

PAST RESEARCH

A literature review and discussions with colleagues in other research organizations uncovered almost no information on the direction and extent of this takeback effect (Hirst, White, and Goeltz, 1984).

Meyers and Schipper (1983), in their review of trends in national residential energy use from 1973 through 1982, conclude that "the decline in indoor temperatures has perhaps played the major role in reducing average household energy demand. In 1973, some 85 percent of all households kept their daytime indoor temperature at a cozy 70°F or higher. By 1981, similar heating practice was reported by less than 45 percent of households."

Fels and Goldberg (1983), in their analysis of recent changes in residential natural gas use in New Jersey, obtained consistent findings. They conclude that much of the post-1973 energy saving observed in New Jersey was due to behavioral changes, reflected in lower indoor air temperatures.

Adams and Rockwood (1983) analyzed data on individual households, collected during a 1979 national survey, to estimate the effects of increased thermal performance of residential buildings on energy use. Their analysis suggested that a 20% increase in shell thermal efficiency (equivalent to a 17% decline in space heating energy use due to technical improvements) would yield an 8% energy saving in gas-heated homes and a 14% saving in electrically heated homes. In other words, increases in temperature settings and other behavioral changes would "take back" half the potential gas saving and 20% of the potential electricity saving.

The National Bureau of Standards (Crenshaw and Clark, 1982) collected data on indoor temperatures in their low-income weatherization project. Unfortunately, limited resources prevented them from analyzing the temperature data relative to efficiency improvements to the building shell and its mechanical equipment.

Kempton and Krabacher (1984) measured thermostat settings and indoor and outdoor temperatures in seven Michigan homes. Their study produced a wealth of detailed data on patterns and determinants of thermostat management. Unfortunately, their sample size is extremely small and none of these homes was retrofit during the time of data collection.

Vine (1984) analyzed data on household self-reports of temperature settings and control strategies. These data were obtained from a 1983 survey of major gas and electric utilities and state energy offices. None of the data showed changes in temperature settings from before retrofit to after retrofit.

Stovall and Kuliasha (1985) examined electric utility load data for several homes in four utilities. In some cases, indoor temperatures were measured at the same time that total and space heating electricity loads were measured. Although these data show interesting relationships between temperature settings and outdoor temperatures, house type, and heating system type, no pre- vs post-retrofit data were included.

OUTLINE OF PRESENT STUDY

This report discusses changes in indoor temperatures in response to retrofit improvements. The data on which this analysis is based are from an evaluation of the Bonneville Power Administration (BPA) interim Residential Weatherization Program. The BPA program, operated through participating private and public utilities throughout the Pacific Northwest, offered financial assistance (generally a cash rebate) to encourage installation of energy-efficiency improvements to existing homes in the region. These retrofits included attic, wall, floor and

heating duct insulation; storm windows and doors; clock thermostats; and caulking and weatherstripping. This program, which operated during 1982 and 1983, weatherized 104 thousand homes at a total cost to BPA of $157 million.

In mid-1983, staff at Oak Ridge National Laboratory and Evaluation Research Corporation began an evaluation of the BPA program. The primary focus of this evaluation was assessment of the actual electricity saving that can be attributed to the program (Hirst et al., 1985). These savings estimates were used to help assess the economic attractiveness of the program to participants, the BPA power system, and the Pacific Northwest region as a whole.

To analyze these issues, several types of data were collected (Fig. 1):

— electric utility bills for samples of participants and nonparticipants, 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;

— energy audit reports for participants;

— weatherization completion forms for participants;

— household surveys to collect information on demographic, economic, and structure characteristics, on recent conservation measures installed and practices adopted, and on conservation attitudes.

This report analyzes these evaluation data, especially the electricity billing and weather data, to infer changes in indoor temperature settings. Inferred temperature changes are computed for two time periods: from 1981/82 to 1982/83 and from 1982/83 to 1983/84. Eligible nonparticipants are compared with households that participated in the BPA program during 1982 (i.e., those households who received energy audits and cash rebates for installation of retrofit measures in

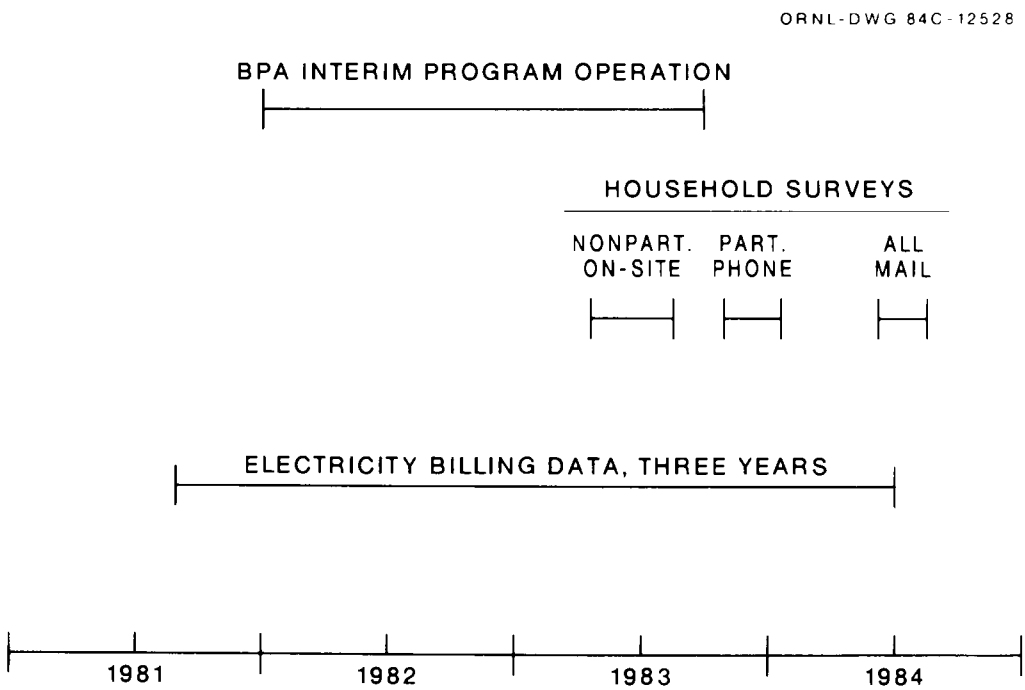

Fig. 1. Timing of BPA interim Residential Weatherization Program and ORNL/ERC evaluation.

mid-1982) in terms of indoor temperature changes between the first and second years. The same nonparticipants are compared with 1983 participants with respect to changes between the second and third years. Thus, the data permit examination of pre- and post-retrofit electricity use and indoor temperatures for participants and nonparticipants, for two different periods of participation.

Conducting this analysis with groups that participated in the program in two different years is useful because several exogenous factors changed during this time (Hirst et al., 1985). In particular, the average real (corrected for inflation) price of electricity increased by 29% between years 1 and 2, but only by 12% between years 2 and 3.

Regionwide, incomes decreased slightly (<1%) between years 1 and 2 and then increased by 3% between years 2 and 3. Winter severity, as measured by heating degree days, also varied from year to year: year 1 was 2% colder than the long-run average, year 2 was 5% milder, and year 3 was 3% colder.

The following chapter discusses the methods used to analyze electricity use and to infer changes in indoor temperatures. Chapter 3 presents results of this analysis, using the data noted above and the methods described in Chap. 2. The final chapter presents conclusions concerning these findings.

2. ANALYTICAL APPROACH

The basic unit of analysis is a string of electric utility bills for an individual household covering a 12-month period (called a household-year). Careful analysis of this data can provide a wealth of information and insights concerning the household's electricity use and the components of that total.

PRINCETON SCOREKEEPING METHOD (PRISM)

Fels et al. (1983) developed a simple method to analyze such energy billing data. Their Scorekeeping model performs two important functions. First, it allows identification of the weather-sensitive (primarily space heating) and nonweather-sensitive (baseload) components of household energy use. This permits one to compute normalized annual consumption (NAC) for each household, which represents the household's consumption of energy at long-run weather conditions (i.e., long-run heating degree days, HDD). In addition, PRISM permits adjustment for temporal misalignment across households in fuel bills (e.g., some records begin on July 1 and some begin on July 29; some billing histories have 325 days and others have 376 days).

PRISM assumes that household energy use (electricity in this case) can be split into components - baseload and heating - and that the heating component is directly proportional to HDD:

$$E_{it} = a_i + b_i HDD_{it}(Tref_i) \ , \qquad (1)$$

where E is average daily electricity use for household i during billing period t (usually one or two months). HDD is the number of heating degree days per day (to base temperature Tref) for the same time period as the

utility bill, for a weather station close to that household.* The reference temperature is defined as that temperature which yields the highest explanatory power (R^2) in estimation of the above statistical model. Physically, Tref is the outdoor temperature below which the heating system must operate to maintain the desired indoor temperature; i.e., no heating is required at temperatures higher than Tref.

The coefficient a_i (kWh/day) reflects the household's use of energy for nonspace heating purposes. The coefficient b_i (kWh/HDD) reflects use of energy for space heating.

The three parameters (a_i, b_i, $Tref_i$) for each household-year serve two purposes. First, as indicated above, they are used to define NAC:

$$NAC_i = 365*a_i + b_i\overline{HDD}_i(Tref_i) \ , \qquad (2)$$

where NAC is normalized (weather-adjusted) annual consumption (kWh/year) for household i and $\overline{HDD}$ is the long-run HDD at base $Tref_i$.

In addition, the three parameters** provide a "fingerprint" of the household that can be used to infer several important energy-related characteristics of the structure, its use of heating fuel, and occupant behavior. For example, model outputs can be used to identify households that may be using supplemental fuels for space heating. In addition, model results and original household-year data can be used to identify

---

*Both E and HDD are normalized by the number of days in the billing cycle to correct for differences (especially across utilities) in the number of days per cycle.

**It is important to recognize that the NAC estimate is by far the most stable and robust output from PRISM. That is, estimates of a, b, and Tref are much more uncertain.

and correct anomalous outliers. These uses of the Scorekeeping method are discussed in Hirst et al. (1984).

CALCULATION OF INDOOR TEMPERATURE CHANGES

For purposes of this report, we examined changes in household electricity use from the preparticipation to the postparticipation period. We examined changes in NAC and its components to identify both the overall change in electricity use after retrofit and the components of that change:

$$NAC_1 - NAC_2 = 365(a_1 - a_2) + [b_1\overline{HDD}(Tref_1) - b_2\overline{HDD}(Tref_2)] \text{ , or}$$

$$DNAC = DBASE + DHEATING \text{ ,} \qquad (3)$$

where 1 and 2 refer to the pre- and post-retrofit years, respectively.

Fels and Goldberg (1984) showed how the change in reference temperature (DTref) can be decomposed into three elements related to change in indoor temperature (DTin), change in baseload, and change in thermal performance of the structure. To quote them:

> The temperature [Tref] at which the furnace is first required is lower than the interior temperature [Tin] because part of the heating load is offset by "free heat" [F] from appliances, occupants, and solar gain. The amount of this offset depends also on the house's "lossiness" [L]; the free heat elevates the indoor temperature by the amount (Tin - Tref) = F/L.

Basically, the difference between indoor and reference temperatures is equal to the internal heat gains from insolation, appliances, and body heat divided by the overall heat loss coefficient* (UA) of the

*This coefficient depends on both conduction and air infiltration.

building shell. The greater the free heat and/or the smaller the lossiness, the larger will be the difference between the two temperatures.

If we assume that DF/F can be approximated by Da/a and that DL/L can be approximated by Db/b, then the change in indoor temperature (DTin) can be written as a function of changes in the PRISM parameters (a,b, Tref):

$$DTin = DTref + 7°F*[(Da/\bar{a}) - Db/\bar{b})] \;.^{*,**} \qquad (4)$$

The 7° incorporates the traditional assumption that maintenence of a 72°F interior temperature is consistent with a 65°F reference temperature (ASHRAE, 1981).

Several critical assumptions underlie use of this equation for DTin. The first involves the veracity of the 7° difference between indoor and reference temperatures. This difference is not a constant but rather a function of the thermal performance of the building shell and the winter base load. For example, as additional insulation and infiltration reduction measures are added to a house, the difference between the indoor and reference temperature will increase; that is, the heating system will turn on at a lower outdoor temperature for fixed Tin.[†]

---

*The difference D is defined as $(\ )_1 - (\ )_2$ and the average $(\bar{\ })$ is defined as $[(\ )_1 + (\ )_2]/2$.

**If Tin - Tref = F/L, then DTin - DTref = DF/L - DL(F/L^2) = (F/L)[DF/F - DL/L] = (Tin - Tref)*[Da/a - Db/b] = 7*[Da/a - Db/b].

†Changing the assumed difference from 7° to 9° or from 7° to 5° causes only slight changes in estimated indoor temperatures. These sensitivity runs show that the qualitative conclusions concerning indoor temperature changes after retrofit are robust with respect to changes in the assumed difference between indoor and reference temperatures.

Second, the formula assumes that baseload and DBASE are independent of season. That is, the change in baseload from one year to the next is assumed constant throughout the year. If the reduction in baseload is, for example, greater in the winter, then the effect on DTref will be larger than calculated. Fels et al. (1984) examined the seasonality of baseload consumption for electrically heated homes in Colorado. They found that nonheating electricity use varied, on average, sinusoidally with a winter peak 10% above the mean baseload and a summer minimum 10% below the mean. If the seasonal variation in nonheating electricity use is similar in Pacific Northwest homes, then eqn. 4 is a useful approximation to reality.

Third, we assume that there are no significant changes in the nonappliance portions of free heat (in particular, contributions from building occupants and solar gain) from one year to the next.*

Fourth, the PRISM coefficients (a, b, Tref) are much less stable (i.e., have relatively higher standard errors) than does the overall NAC estimate. This suggests that our analysis of components of change (DHEATING, DTin, etc.) is much more uncertain than our analysis of overall changes in NAC (Chap. 3).

Changes in indoor temperatures affect energy use for space heating through changes in the reference temperature and therefore in long-run HDD. Because:

$$\text{HEATING} = \text{UA}*\overline{\text{HDD}}(\text{Tref}) \ , \qquad (5)$$

*This analysis is limited to homes that use <u>only</u> electricity for space heating. Homes that use wood or other fuels for some of their heating are excluded to avoid complications in interpretation of base load changes.

changes in Tin will affect electricity use according to:

$$DHEATING_{DTin} = UA*(d\overline{HDD}/dTref)*DTref \ . \qquad (6)$$

Because we focus on the changes in Tref due solely to changes in Tin, dTin/dTref = 1. If we assume that b = UA and recognize that the derivative of $\overline{HDD}$ with respect to Tref is equal to the difference $[\overline{HDD}(Tref_2 + 1°) - \overline{HDD}(Tref_2)]$ then we can write:

$$DHEATING_{DTin} = b_2*[HDD\overline{(Tref}_2 + 1°) - HDD\overline{(Tref}_2)]*DTin \ . \qquad (7)$$

The first factor on the right hand side of eqn. 7 is the heating slope and reflects the thermal performance of the building and efficiency of its heating equipment.* The second factor represents the sensitivity of long-run HDD to changes in reference temperature.** The last factor is the change in temperature setting, as inferred from PRISM results.

In closing, we note that the analysis outlined in this section uses only two data sources - household electricity billing histories and daily temperature data. Data from the households themselves (for example, on their temperature settings) are not required for the present analysis. We consider this a major strength of the present approach because of known problems with accuracy of household self-reports (see Geller, 1981 and Hirst and Goeltz, 1985).

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*Almost all the electrically heated homes in this analysis use resistance heating, the efficiency of which is constant and near 100%.

**This factor is equal to the number of days during which the space heating equipment operates.

3. RESULTS

DATA SET USED FOR THIS ANALYSIS

We applied the analytical methods discussed in the preceding chapter to particular subsamples of the participant and nonparticipant homes in our evaluation data set. These subsamples include only those homes whose electricity billing data are "clean" and that reported, in household surveys conducted in 1983, that they had no air conditioning equipment and used only electricity as their primary heating fuel. "Clean" billing data refers to PRISM results for both years with $R^2 > 0.75$, a and b coefficients statistically significant at the 10% level or better, and Tref less than the maximum (Hirst, Goeltz, and White, 1984).

The restriction to these nonrepresentative samples of participant and nonparticipant homes is related to the desire to examine indoor temperature changes only in homes that use electricity as the primary heating fuel and that use no other fuels for heating. Interpretation of results for homes that use wood for space heating would be difficult; PRISM estimates of Tref and of changes in Tref, for example, would be confounded by changes in wood use (as well as changes in thermal integrity of the house shell and in indoor temperature settings). It is also important, for purposes of this analysis, to restrict attention to households whose billing data closely correspond to PRISM.

The evaluation data set includes 1602 homes with usable electricity billing data (Table 1). Information on household demographics and structure characteristics, obtained from the 1983 household surveys, is available for 84% of these households. Restricting attention to only those households with clean billing data (i.e., billing data that

closely conforms to PRISM, denoted by Goodfit) eliminates another 25% of the original data set. Eliminating households that report electric air conditioners and/or use of fuels other than electricity for heating leaves only 15% of the original households (Primefit). The loss of 75% of the Goodfit households (lower part of Table 1) is due partly to lack of a household survey (nonresponse) or presence of air conditioning equipment, but primarily to use of fuels other than electricity for heating.

Thus, results presented here are not representative of homes throughout the Pacific Northwest. The 242 households examined in this study are a carefully selected subset of households in the Northwest - those that use only electricity for space heating and do not use

Table 1. Household attrition from evaluation data set in analysis of indoor temperature changes

Group definition	Group			
	Participants		Nonparticipants	Total
	1982	1983		
Usable electricity billing data	602	612	388	1602
1983 household survey	464	509	472	1445
Both bills + survey	457	484	388	1329
"Clean" billing data (Goodfit)	405	374	172	951
Present data set (Primefit)	97	113	32	242
Reasons for attritition between Goodfit and Primefit				
No household survey	97	70	0	167
Air conditioning equipment	69	31	55	155
Non-electric heating fuel				
year 1	28	151	10	189
year 2	114	9	75	198

electricity for air conditioning. (The Appendix compares results between the subset of households used here and the full evaluation data set.)

1982 PARTICIPANTS AND NONPARTICIPANTS

Electricity use and changes

Preprogram electricity use for the 1982 participants is almost 10% higher than that for the nonparticipants (Tables 2 and 3):* 27,000 vs 24,700 kWh/year. Space heating accounts for about 55% of the total for both groups.

Not surprisingly, the reduction in annual electricity use is much greater for participants than for nonparticipants: 4300 vs 1300 kWh/year (Figs. 2 and 3). About 4% of the participants increased electricity use and 4% saved more than 10,000 kWh; comparable figures for the nonparticipants are 30% and 0%. These differences are surely due largely to the retrofit measures installed as part of the BPA program.** This assumption is confirmed by the much larger decline in space heating electricity use for participants and the nearly equal decline in baseload electricity use; the primary focus of the BPA program is on installation of measures that reduce space heating electricity use. Total one-year electricity savings for both groups are highly statistically significant (1% level or better); so too is the

---

*Both medians (Table 3) and means (Table 2) are shown because of the large variation across homes. Medians are more robust with respect to a few large outliers than are means.

**The average cost of retrofit measures installed by the program in the homes of 1982 participants was almost $1600.

Table 2. Summary statistics (means) on annual electricity use and savings for nonparticipants and participants in the BPA interim program[a]

	Group		
	Audit + buyback		Nonparticipant
	1982	1983	
Year 1 (1981/82)			
Baseload	11,900		11,600
Heating	15,100		13,100
Total	27,000		24,700
Reference temperature	58.9		57.7
Year 2 (1982/83)			
Baseload	11,500	11,600	11,300
Heating	11,200	15,000	12,100
Total	22,700	26,600	23,400
Reference temperature	58.1	57.8	57.3
Differences (1981/82 - 1982/83)[b]			
Baseload	400		300
Heating	3,900[c]		1,000
Total[d]	4,300[c]		1,300[c]
Reference temperature	0.8[e]		0.4
Indoor temperature	-0.4		-0.2
Saving because of change in indoor temperature	-200		-400
Year 3 (1983/84)			
Baseload		11,500	10,500
Heating		11,600	13,100
Total		23,100	23,600
Reference temperature		57.5	58.0
Differences (1982/83 - 1983/84)[b]			
Baseload		100	700
Heating[d]		3,400[c]	-1,000[e]
Total[d]		3,500[c]	-300
Reference temperature		0.4	-0.6
Indoor temperature		-1.1[e]	-0.3
Saving because of change in indoor temperature		-1,200[e]	0

[a]All figures are in kWh/year except for the temperature figures, which are in °F.

[b]Positive values represent an energy saving or a temperature decrease.

[c]Mean value is statistically significant at the 1% level.

[d]Difference between the participant and nonparticipant means is statistically significant at the 1% level.

[e]Mean value is statistically significant at the 10% level.

Source: Monthly or bimonthly electricity bills for 97 households that participated in the BPA program in 1982, 113 households that participated in 1983, and 32 nonparticipant households.

Table 3. Summary statistics (medians) on annual electricity use and savings for nonparticipants and participants in the BPA interim program[a]

	Group		
	Audit + buyback		Nonparticipant
	1982	1983	
Year 1 (1981/82)			
Baseload	11,900		9,400
Heating	14,500		11,700
Total	25,400		23,800
Reference temperature	60		57
Year 2 (1982/83)			
Baseload	11,500	10,400	11,600
Heating	10,000	13,500	11,700
Total	21,800	23,400	23,100
Reference temperature	58	58	57
Differences (1981/82 - 1982/83)[b]			
Baseload	400		200
Heating	3,800		1,300
Total	3,900		900
Reference temperature[c]	1		0
Indoor temperature	-0.4		0.2
Saving because of change in indoor temperature	-300		200
Year 3 (1983/84)			
Baseload		10,600	10,900
Heating		10,200	11,800
Total		21,000	22,800
Reference temperature		57	57
Differences (1982/83 - 1983/84)[b]			
Baseload		200	600
Heating		3,200	-100
Total		2,900	-200
Reference temperature[c]		0	0
Indoor temperature		-1.5	-0.2
Saving because of change in indoor temperature		-1,200	-300

[a]All figures are in kWh/year except for the temperature figures, which are in °F.

[b]Positive values represent an energy saving or a temperature decrease.

[c]The method used here searches for the best Tref in one degree increments. Thus, the median changes are in integers (either zero or one).

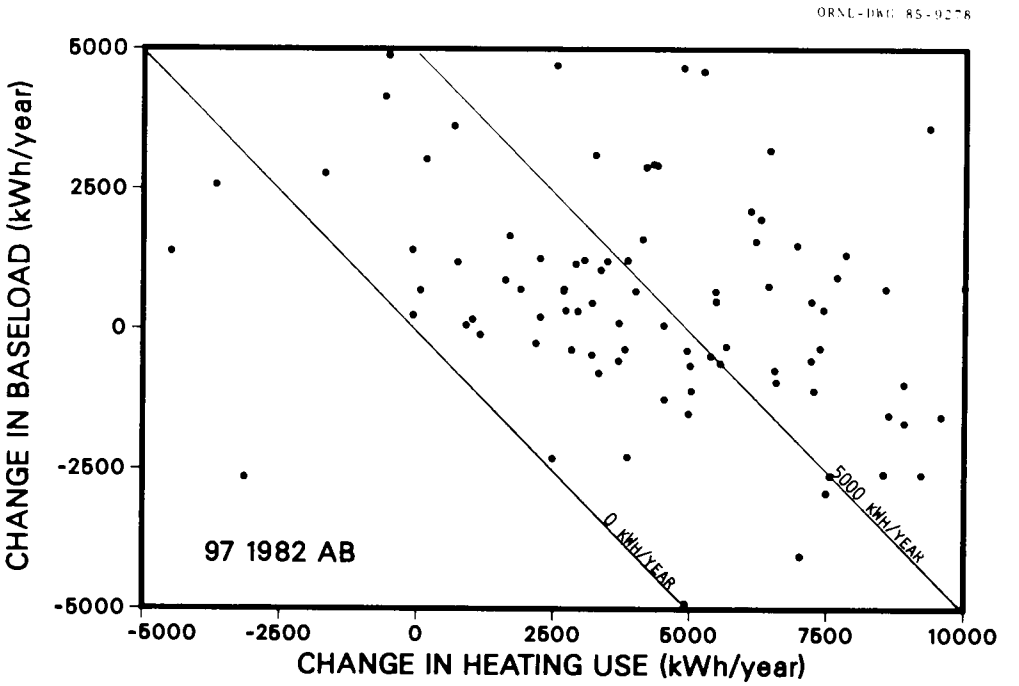

Fig. 2. Reduction in baseload electricity use as a function of reduction in space heating electricity use (1981/82 - 1982/83) for households that participated in the BPA program in 1982. The correlation coefficient (r) between change in baseload and heating uses is -0.55.

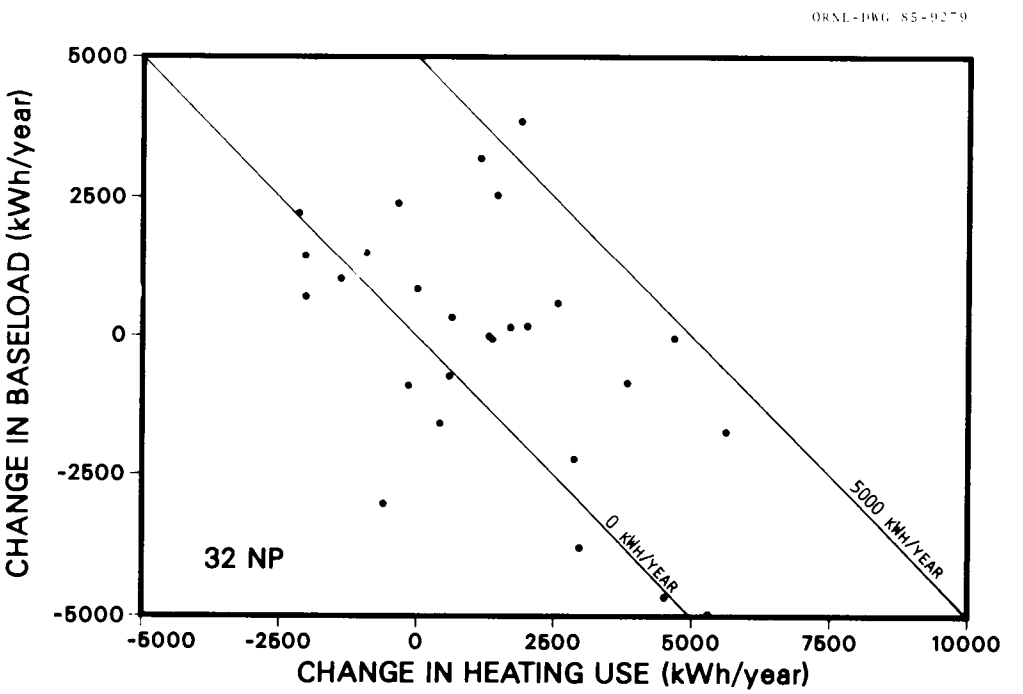

Fig. 3. Reduction in baseload electricity use as a function of reduction in space heating electricity use (1981/82 - 1982/83) for households that did not participate in the BPA program. The correlation coefficient (r) between change in baseload and heating uses is -0.76.

space heating electricity savings for participants and the difference in total saving between the two groups.

Reference temperatures in both groups (57 - 59°F) were below the traditional balance point of 65°F. This suggests that these households had substantially lower indoor temperatures than the conventional assumption of 72°F, by about 7°F.*

Indoor temperature changes

Scorekeeping model results show that the reference temperature dropped an average of 0.8°F in participant homes and 0.4°F in nonparticipant homes between years 1 and 2. Improvements in the thermal performance of participant homes account for an average 1.6° drop in reference temperature; the comparable drop in nonparticipant homes is only 0.5°. This reduction is partly offset by a reduction in baseload in participant homes, which would increase reference temperatures an average 0.3° in participant homes (0° in nonparticipant homes). Thus, on balance, PRISM results (eqn. 4) imply a 0.4°F increase in indoor temperatures for participants, compared to a 0.2°F increase for nonparticipants (Fig.4).** Neither mean increase in indoor temperature is statistically significant. It is unclear whether the large variation in indoor temperature changes is due to limitations in the analytical method used here or due to actual differences among households in postretrofit behavior.

The calculated increase in indoor temperatures leads to an increase in electricity use (relative to what would have occurred if temperature

---

*An alternative explanation is that these homes were all reasonably well insulated.

**-0.42 = 0.83+0.32-1.57 for participants, and -0.18 = 0.38-0.04-0.52 for nonparticipants, using eqn. 4.

settings had remained constant). On average, this takeback effect (eqn. 7) cost participants an estimated 200 kWh/year and nonparticipants 400 kWh/year. Thus, approximately 5% [200/(200+3900), Table 2] of the space heating electricity saving for participants is lost because of their behavioral response to installation of retrofit measures. Similarly, nonparticipant behavior accounts for a 29% [400/(400+1000)] loss of their space heating electricity savings. As with the increases in indoor temperature, these takeback effects are not statistically significant.

The very large variation across households in estimated indoor temperature changes (Fig. 4) suggests considerable caution in interpreting these findings. For example, the standard deviation of the electricity

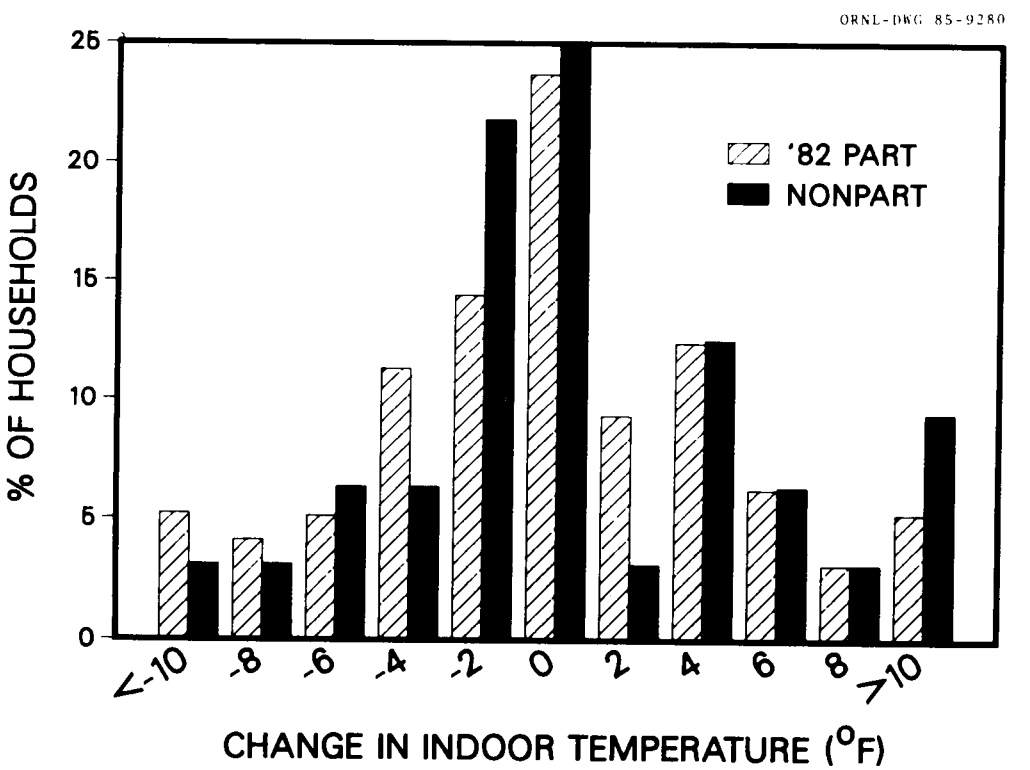

Fig. 4. Distribution of changes in computed indoor air temperatures between 1981/82 and 1982/83 for 1982 participants and nonparticipants.

loss due to the takeback effect is 50% greater than the standard deviation for total electricity saving (4900 vs 3300 kWh/year).

The medians (Table 3) show the same average increase in indoor temperature for the participants (0.4°F) and a slight decline (0.2°F) for the nonparticipants (rather than the 0.2°F increase suggested by the mean value, Table 2). The medians show an electricity loss for participants due to the takeback effect of 300 kWh, compared with an additional saving of 200 kWh for the nonparticipants.

The means and medians paint a consistent picture of indoor temperature changes for program participants - a slight increase in temperatures after retrofit, which leads to a small loss of the space heating energy savings due to the retrofit measures installed in their homes. These statistics show very small, but qualitatively different, results for the nonparticipants. These differences probably occur because the number of nonparticipants in this analysis is so few (32) and because their average change in temperature setting is quite small.

Despite the differences between means and medians, they both imply that participants increased indoor temperatures by more than did nonparticipants, although the difference is not statistically significant. We next examine comparable changes between years 2 and 3 for the 1983 participants and the nonparticipants.

1983 PARTICIPANTS AND NONPARTICIPANTS

Electricity use and changes

Preprogram electricity use for the 1983 participants is almost 15% higher than that for the nonparticipants (Table 2): 26,600 vs 23,400 kWh/year. Space heating accounts for about 55% of the total for both groups.

Again, the reduction in annual electricity use between years 2 and 3 is much greater for participants than for nonparticipants: 3500 vs -300 kWh/year. About 10% of the participants and more than half the nonparticipants (54%) increased electricity use; about 8% of the participants and none of the nonparticipants saved more than 10,000 kWh/year. These differences, once again, are due largely to the retrofit measures installed as part of the BPA Residential Weatherization Program.* This is confirmed by the much larger decline in space heating electricity use for participants (3400 vs -1000 kWh/year) and the much smaller decline in baseload electricity use (100 vs 700 kWh/year); see Figs. 5 and 6. As was true for the prior comparison of 1982 participants and nonparticipants, the space heat and total savings for participants are statistically significant; so too is the difference in total saving between the two groups.

Electricity savings, for both groups, are lower than are the savings between years 1 and 2 (Tables 2 and 3). Although nonparticipants cut electricity use by an average of 1300 kWh/year between years 1 and 2, their average use increased by 300 kWh/year between years 2 and 3. These differences are primarily due to changes in electricity price and household income (Appendix C of Hirst et al., 1985).

Reference temperatures in both groups of homes (57 - 58°F) were substantially below the traditional balance point of 65°F.

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* The average cost of retrofit measures installed by the program in the homes of 1983 participants was almost $1800.

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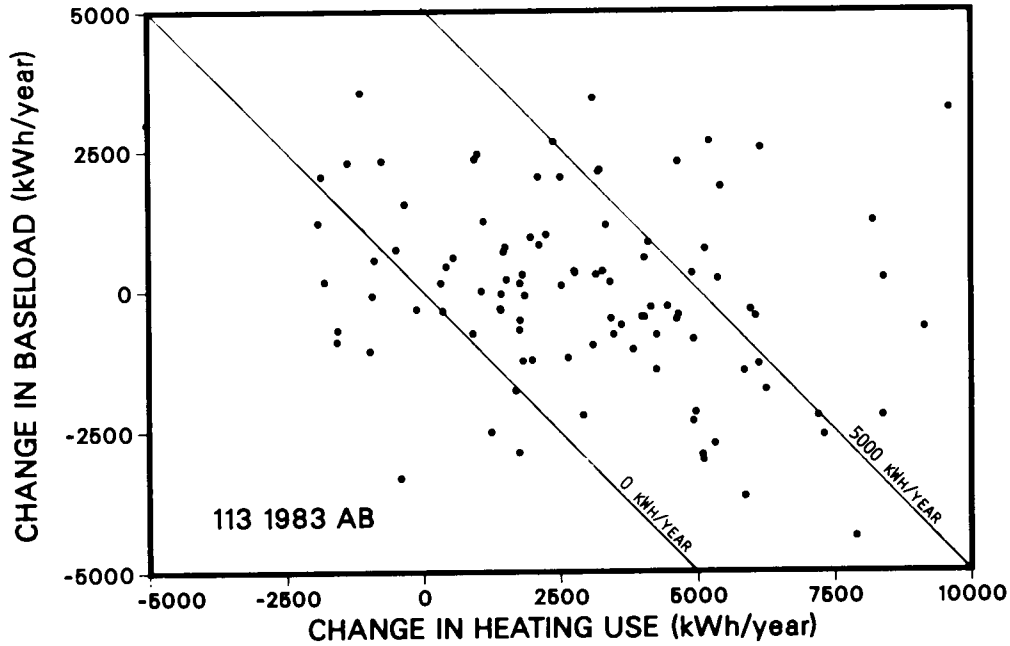

Fig. 5. Reduction in baseload electricity use as a function of reduction in space heating electricity use (1982/83 - 1983/84) for households that participated in the BPA program in 1983. The correlation coefficient (r) between change in baseload and heating uses is -0.43.

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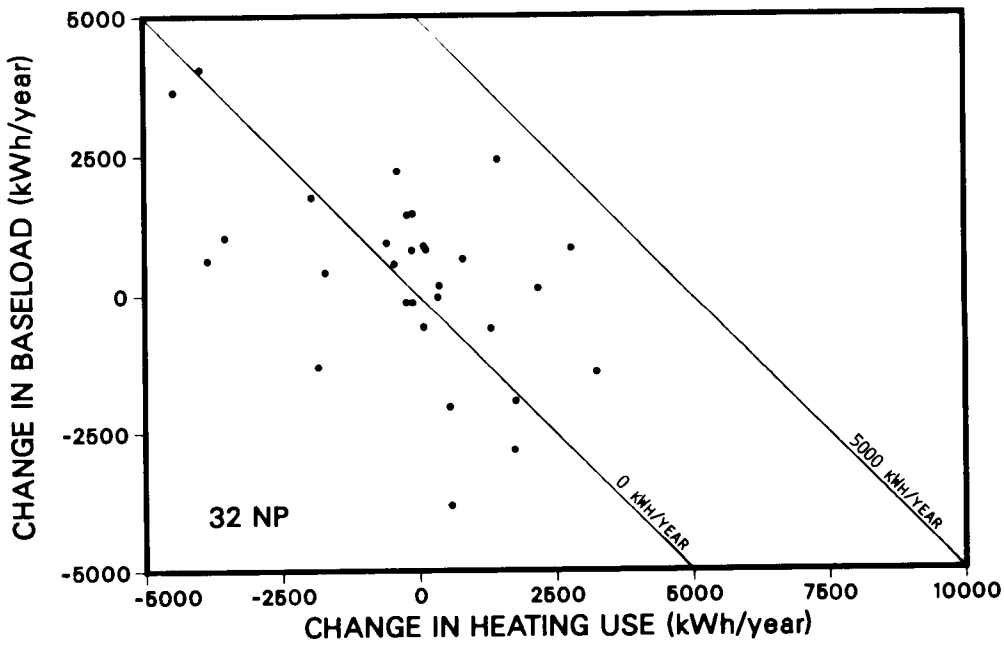

Fig. 6. Reduction in baseload electricity use as a function of reduction in space heating electricity use (1982/83 - 1983/84) for households that did not participate in the BPA program. The correlation coefficient (r) between change in baseload and heating uses is -0.54.

Indoor temperature changes

PRISM model results show that the reference temperature dropped an average of 0.4°F in participant homes and increased 0.6°F in nonparticipant homes between years 2 and 3. Results also show an estimated 1.1°F increase in indoor temperature for participants (significant at the 2% level), compared to a 0.3°F increase for nonparticipants (Fig. 7). Again, participants increased their indoor temperatures by more than did nonparticipants.

The calculated increase in indoor temperatures leads to an increase in electricity use (relative to what would have occurred if temperature settings had remained constant). On average, this takeback effect cost participants an estimated 1200 kWh/year but did not affect nonparticipant

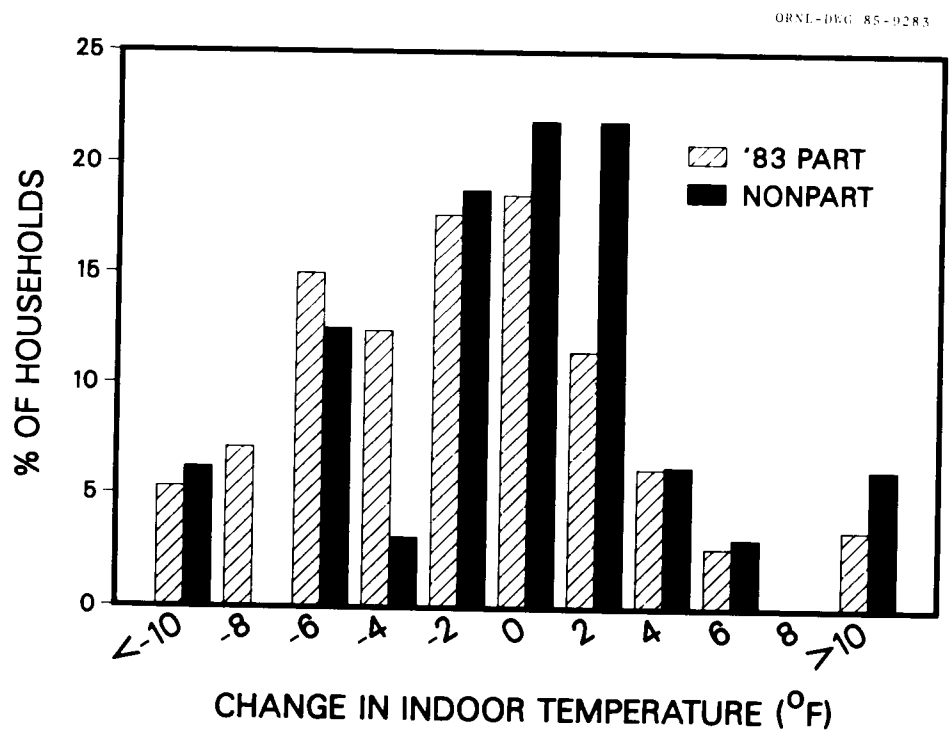

Fig. 7. Distribution of changes in computed indoor air temperatures between 1982/83 and 1983/84 for 1983 participants and nonparticipants.

electricity use. Thus, 26% [1200/(1200+3400), Table 2] of the total space heating electricity saving for 1983 participants is lost because of their behavioral response to installation of retrofit measures.

Again, there is substantial variation across households in estimated indoor temperature changes (Fig. 7), which suggests caution in interpreting these findings. The medians show a slightly larger increase in indoor temperature for the participants (1.5°F) and a slightly smaller increase (0.2°F) for the nonparticipants. The medians show an electricity loss for participants due to the takeback effect of 1200 kWh, compared with a loss of 300 kWh for the nonparticipants.

The means and medians both show a substantial (greater than 1°F) increase in indoor temperature after retrofit for the 1983 BPA program participants. Nonparticipants increased their indoor temperatures by much less, roughly ¼°F. Thus, the two sets of comparisons - 1982 participants vs nonparticipants and 1983 participants vs nonparticipants - yield qualitatively similar findings. In both comparisons, the participants increased indoor temperatures after retrofit, and did so by more than the nonparticipants. The difference, however, is more pronounced for the 1983 participants than for the 1982 participants.

COMPONENTS OF ELECTRICITY SAVINGS

We next examined the relationships between total electricity savings and takeback effect for the 1982 and 1983 participants. We did not analyze the nonparticipant savings in this fashion because there were so few nonparticipant households in this data set.

There was no statistically significant correlation between indoor temperature change and total electricity saving for the 1982 participants. However, there was a significant and positive correlation between indoor temperature change and total electricity saving for the 1983 participants (r = 0.20, significant at the 4% level); similarly the correlation between the energy lost due to the takeback effect and total electricity saving (Fig. 8) was significant (r = -0.23, 1% level).

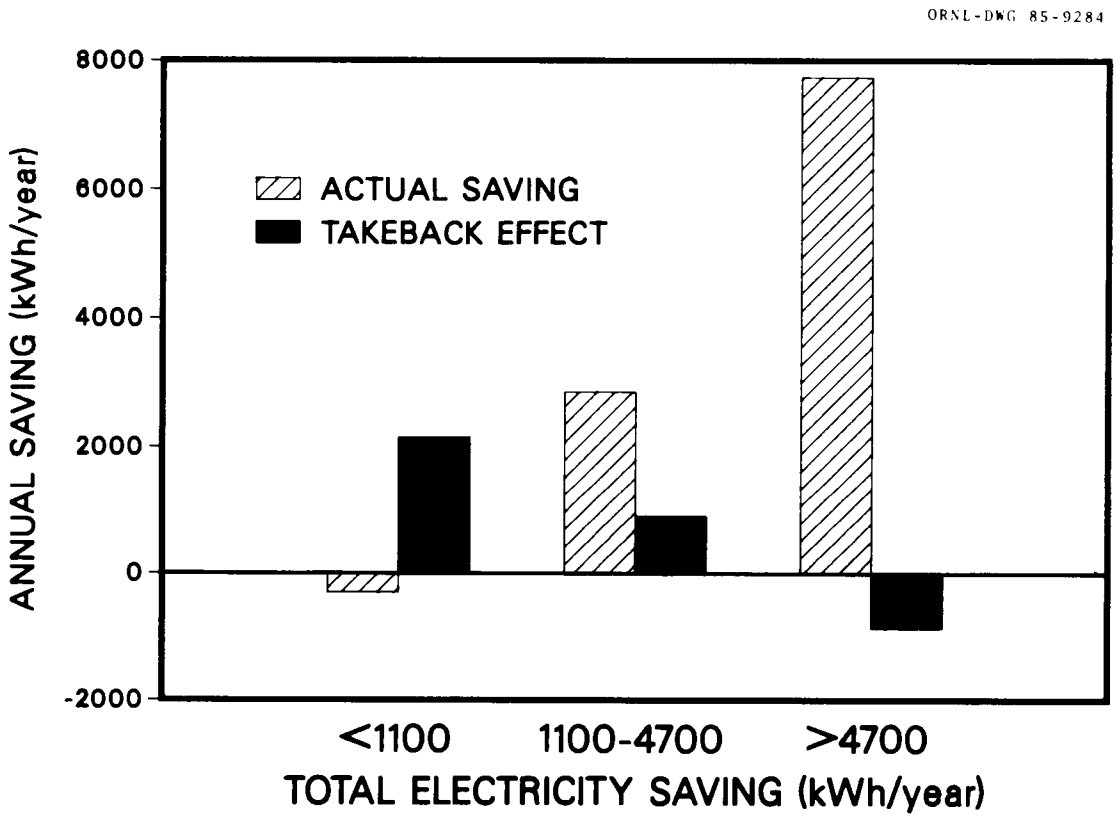

Fig. 8. Actual electricity saving and its components for 113 households that participated in the BPA program in 1983. The households are split into three groups by total saving: bottom 25%, middle 50%, and top 25%. (A similar figure for the 1982 participants is not presented because the results show virtually no relationship between total saving and takeback effect.)

The 1983 participant homes whose actual electricity savings were in the bottom 25% of the distribution (mean saving of -300 kWh/year) also had the largest increase in indoor temperature setting (2.7°F) and, consequently, the greatest lost saving because of the takeback effect (2100 kWh/year). The middle 50%, whose mean saving was 2900 kWh, increased their indoor temperatures by an average of 1.3°F, which led to a takeback loss of 900 kWh/year. The top 25%, whose mean saving was 7700 kWh, reduced indoor temperatures after retrofit by an average of 0.2°F, which led to a takeback saving of 900 kWh. To summarize, the homes with the largest electricity saving lowered their thermostats (and saved more electricity) after retrofit; homes with the smallest (negative) savings did just the opposite. These correlations show that, for the 1983 participants, but not the 1982 participants,* homes that experience small energy savings do so in part because of behavioral changes made after retrofit.**

We also examined the relationship between electricity saving and preprogram electricity use. There is a strong positive relationship

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*We are not sure why the expected relationship between indoor temperature changes and actual electricity saving was not observed for the 1982 participants. Perhaps, their small average change in temperature (0.4° vs 1.1° for the 1983 participants) obscured the underlying relationship.

**Alternatively, homes in which many retrofit measures were installed are likely to be more comfortable at lower indoor temperatures, because increased insulation reduces radiant heat transfer between the occupants and the walls of the house and may also reduce infiltration (drafts). In general, the energy savings due to retrofit might affect indoor temperature settings through at least three mechanisms: radiant and convective heat transfer, a psychological sense of control over one's fuel bills (leading to lower temperatures), and an economic response (leading to higher temperatures).

between actual saving and preretrofit use. The relationship between baseload saving and total saving is positive, but weak. On the other hand, heating saving and total saving are strongly correlated. That is, only the space heating electricity savings are closely related to preprogram electricity use. Finally, there is no relationship between changes in indoor temperature and preprogram electricity use.

4. CONCLUSIONS

The extent to which actual energy savings after retrofit correspond to the estimates prepared by home energy auditors is an important and hotly discussed issue. Limited evidence suggests that, on average, actual energy savings are less than that predicted in energy audits. Perhaps more important, there is enormous variation across households in their actual energy savings and in the relationship between predicted and actual savings.

Many factors may account for these large differences: errors in audit methodologies, errors in auditor data collection and interpretation, installation of inappropriate retrofit 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. Unfortunately, little is known about the importance of these factors.

Occupant behavior is likely to be an important determinant of actual energy savings, primarily because small changes in such behaviors can have large effects on household energy use. For example, a 2°F reduction in indoor temperature will cut annual space heating energy use by about 10% in regions of the U.S. with 5000 heating degree days (65°F base).

This report analyzed electricity billing data for 242 homes in terms of estimated changes in indoor temperature settings. Two hundred ten of these homes received free energy audits and financial assistance from the Bonneville Power Administration for retrofit improvements (e.g.,

attic insulation, storm windows, caulking and weatherstripping), as part of the BPA Residential Weatherization Program. Of the 210 program participants, 97 received assistance in mid-1982 and 113 participated in mid-1983. The remaining 32 homes were eligible for the program but did not participate.

Before summarizing results of this analysis, it is important to emphasize the speculative nature of the findings. Estimates of changes in indoor temperatures and of space heating electricity use induced by these temperature changes are approximate. They are based on analysis of electricity billing data only; that is, neither household surveys nor independent measurements of indoor temperatures are included in this study. Imputation of indoor temperature changes from electricity use data alone requires strong assumptions. Further, the results obtained with the method show large variation across households. Finally, the results are based on small nonrandom samples of participants and eligible nonparticipants for the BPA Residential Weatherization Program. Nevertheless, these results are worth reporting because, as far as we can determine, no other empirical data exists with which to assess the effects of residential retrofits on subsequent changes in indoor air temperatures.

The analysis of billing data showed a mean reduction in annual electricity use of 4300 kWh (median saving of 3900 kWh) for the 1982 participants and a mean saving of 3500 kWh (median of 2900 kWh) for the 1983 participants. These homes were retrofit during mid-1982 or mid-1983 at an average cost of $1700; the billing data include the pre- and post-retrofit years.

Reductions in space heating energy use (as opposed to baseload use) accounted for more than 90% of the total saving in these homes. This is consistent with our expectation that the observed savings were primarily due to the BPA-financed retrofits.

The nonparticipants had much smaller electricity savings: mean savings of 1300 and -300 kWh (median savings of 900 and -200 kWh) between years 1 and 2 and between years 2 and 3, respectively.

The data and PRISM results suggest average increases in indoor air temperatures after retrofit, of 0.4°F for the 1982 participants and 1.3°F for the 1983 participants. These temperature increases imply a loss of 200 kWh for the 1982 participants and 1200 kWh for the 1983 participants of electricity saving. This is equivalent to 5% and 25%, respectively, of the space heating energy saving due to the technical efficiency improvements (retrofits). Nonparticipants had smaller increases in indoor temperatures than did the participants during both time periods, by 0.4 - 1°F. Because these average changes in indoor temperatures are small and the variation across households is large, these results should be viewed cautiously.

In our view, the qualitative result obtained here — that households, on average, slightly increase temperature settings after retrofit — is probably correct. However, the exact numbers may not be.

The paucity of data on measured changes in indoor air temperatures and the possible importance of the take back phenomenon argue for more data collection and analysis. The ongoing Hood River Conservation Project in Oregon involves collection of detailed monitoring data on 320 homes (Pacific Power and Light, 1983). The data being collected include total, space heating, and water heating electricity uses, and

indoor air temperatures; these data will be collected for a year before retrofit (1984/85) and a year after retrofit (1985/86). These detailed data, when combined with weather data, household survey responses, and information on measures installed will permit careful analysis of the relationship between efficiency improvements and household behavior.

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APPENDIX
COMPARISON OF RESULTS WITH DIFFERENT DATA SUBSETS

The samples of households used in analysis of changes in indoor temperatures were selected using stringent criteria. As a consequence, these nonrandom samples are not representative of households throughout the Pacific Northwest.

This Appendix presents statistics obtained with three different data sets: the original set of 1602 households for which usable billing data were obtained, the subset of 951 households with "clean" billing data, and the subset of 242 households with both clean billing data and survey responses that showed use of no fuels other than electricity for space heating and no air conditioning equipment (the subset used in the present analysis).

Comparison of reductions in total electricity use across data sets (Table A-1) shows some variation. However, the variation in change in indoor temperature is far greater.

Comparison of the standard deviations for these two measures (change in electricity use and in indoor temperature) shows even more starkly the differences among these data sets. The standard deviation of electricity saving declines slightly as the sample size gets smaller and "cleaner," from 4600 to 3300 kWh for the 1982 participants, for example. The decline in standard deviation for the change in indoor temperature is much more dramatic, from about 30 to 5°F.

These comparisons illustrate two points. First, the subsamples used in the present analysis differ from the overall samples selected for evaluation of the BPA Residential Weatherization Program. Second, use of these carefully selected subsamples greatly reduces the standard

deviation of the variable of greatest interest in this study, indoor temperature changes.

Table A-1. Comparison of Scorekeeping model results, by sample

Group/ results[a]	Means (standard deviations in parentheses), by group		
	Participants	Nonparticipants	No. of households
All households			1602
1982 differences			
Electricity use	5160 (4570)	1710 (4400)	
Indoor temperature	21.2 (577.3)	-1.3 (16.9)	
1983 differences			
Electricity use	2790 (3750)	-20 (3620)	
Indoor temperature	-2.6 (25.6)	-1.7 (18.8)	
Clean data			951
1982 differences			
Electricity use	5210 (4010)	360 (2960)	
Indoor temperature	-0.5 (7.5)	0.1 (7.0)	
1983 differences			
Electricity use	3030 (3410)	520 (2520)	
Indoor temperature	-2.0 (7.2)	-0.3 (7.0)	
Present data set			242
1982 differences			
Electricity use	4300 (3260)	1330 (2410)	
Indoor temperature	-0.4 (5.5)	-0.2 (4.5)	
1983 differences			
Electricity use	3460 (3630)	-280 (2000)	
Indoor temperature	-1.1 (5.1)	-0.3 (5.5)	

[a]All differences refer to one-year changes (1981/82 - 1982/83 or 1982/83 - 1983/84).

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