PREDICTORS OF INEFFICIENT RETROFITS IN HOOD RIVER HOMES

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ABSTRACT

This paper profiles homes which increased electricity usage after retrofit, in contrast to the majority of homes which exhibit electricity savings.

A second classification -- postretrofit usage per square foot for non-wood heated homes -- defined winners and losers as homes registering one standard deviation (4.5 kWh/ft^2) below and above mean usage (11.7 kWh/ft^2) per square foot after removal of outliers.

Winners and losers, as determined by each of these criteria, are profiled according to a number of physical and demographic variables. Significant differences between these groups are discussed, as are differences which were expected but not found.

No systematic structural criteria for predicting which homes are likely to increase usage after retrofit were identified. It appears that behavioral factors play a large part in determining what portion of potential technical savings is achieved.

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INTRODUCTION

The Hood River Conservation Project (HRCP) was designed to test the reasonable upper limits of energy conservation which could be obtained in a residential retrofit weatherization program. Conservation measures aimed at the building shell and the water heater were installed in nearly all of the electrically heated homes in the town of Hood River, Oregon. These retrofits were analogous to building a "conservation power plant" within the community. The program did not include an educational component, relying instead on weatherization technology to achieve the conservation resource.

The primary goal of this analysis is to characterize those homes which demonstrate an apparently ineffective application of residential weatherization. A secondary analysis looks at the highly successful retrofit applications: those homes with the highest demonstrated energy efficiency. Such characterizations can be of use in future program design to the extent that they identify situations where technology alone is not likely to result in energy savings, either because of resulting increased usage (customer "take backs") or because the home is already fairly efficient and substantial additional savings are unlikely.

BACKGROUND

Energy consumption data collected before and after weatherization show that project efforts were more successful in some cases than in others. Although 65 percent of all weatherized homes clearly reduced electricity use as a result of the retrofits, a segment of the homes did not. Specifically, weather-adjusted electricity bills indicate that 18 percent of the homes used more electrical energy after retrofit than before, with another 17 percent alternating between savings and increased use.

While previous studies of HRCP data have addressed the question of take back (changed household behaviors which result in the full energy saving potential of conservation measures not being achieved), the analyses have been based on detailed monitored data from a subset of approximately 300 weatherized homes (Dinan, 1987; Stovall and Fuller, 1988). The current study begins with the full set of nearly 3,000 weatherized homes and bases analysis on weather-normalized energy consumption data derived from monthly utility bills.

An additional contrast to these earlier studies is in the focus of the work. Dinan looked at changes in monitored indoor temperatures, building an econometric model to predict a household's preferred temperature choice. Stovall and Fuller looked at the ability of take back behavior, specifically higher indoor temperatures, to explain the discrepancy between audit-estimated and actual energy savings. The current analysis looks at those homes with demonstrated take back shown by increased electricity use following retrofit work, and uses audit-estimated savings as an explanatory variable.

Structural and demographic variables are systematically examined in order to determine general descriptive characteristics of these homes. No attempt is made to quantify the effect of take back behavior on annual energy use, and in fact take back behavior is not limited to households with increased electricity use. For example, 63 single-family customers were identified who switched from use of wood for space heating to primarily electric space heat, yet still achieved savings from the retrofits.

ANALYTIC APPROACH

Two energy-use variables which are frequently used to measure weatherization program success were chosen as the basis for defining retrofit effectiveness. The first, gross weather-normalized electricity savings, answers the question of how much conservation was achieved. Those homes with negative savings (indicating an increase in electricity use following weatherization) were termed energy "losers"; all others were termed "winners". Savings were calculated by subtracting annual electricity use for each of two post-retrofit years (1985/1986 and 1986/1987) from annual electricity use for the base pre-retrofit year (1982/1983).

The second energy-use variable, annual electricity use per unit floor area, looks at the energy use of the homes after they were weatherized. In this case, homes more than one standard deviation above the mean value were classified as losers, while those more than one standard deviation below the mean were winners.

Previous analysis of HRCP data has shown that the characteristics of different housing types (single-family, multifamily, and mobile home) are sufficiently different that combination tends to obscure important information. Thus, single-family homes and mobile homes were compared separately. Multifamily dwellings were originally included as well, but it was found that the available sample was too small for meaningful results. Dwellings included in the analysis had the same family continually occupying the residence from July 1982 through December 1986, and had usable billing data for the years running from July through June for 1982/1983, 1985/1986, and 1986/1987.

For each criterion, those sites more than two standard deviations from the mean value of the criterion variable were labeled as outliers and excluded from subsequent analyses. In addition, the second analysis excluded homes using a significant amount of wood heat so that electricity use per square foot more accurately represents the total energy use of the home.

Since approximately two-thirds of all HRCP homes used some wood heat but this energy was only measured in a sample of 100 homes, the process described by Hirst and Goeltz (1986) was used to identify those homes using a significant amount of wood heat. Briefly, those sites with good correlation between the Princeton Scorekeeping model (PRISM; see Fels, 1986) and actual billing data were assumed to have a negligible amount of wood heat. Table I shows attrition losses and final cell sizes, and Figure 1 shows the frequency distribution for each criterion.

Table I. Final sample sizes for analyses.

	Single-family Homes	Mobile Homes
Original sample[1]	1,431	382
After data exclusions[2]	917	250
After outlier exclusions[3]	764	203
Criterion No. 1: Electricity Savings		
Winners	580	145
Losers	184	58
Criterion No. 2: Annual Energy Use per Square Foot		
After wood heat exclusion	132	28
Midrange	88	-
Winners	22	-
Losers	22	-

1 Excludes homes with incomplete billing data between July 1982 and June 1987
2 Excludes homes with household moves between July 1982 and December 1986
3 Outliers defined as those values more than two standard deviations from the mean

Data were available for floor area of home; window area; utility service area (private or public utility); type of heating system (central or zonal); age of home; cost of weatherization measures; audit-predicted electricity savings; whether the retrofit included insulation measures, infiltration measures, and window measures; owner versus renter occupied; number of residents; income level; wood used for heating (yes/no); and electricity use for the years 1982/1983 through 1986/1987. All electricity usage was weather-normalized using PRISM.

Discrete data were analyzed using t-tests, comparing the losers with the winners for each variable. Grouped data (type of heating system, age of home, owner versus renter occupied, and income) were analyzed using the chi-square test. For a difference to be considered meaningful, it had to be significant for both postretrofit years (1985/1986 and 1986/1987).

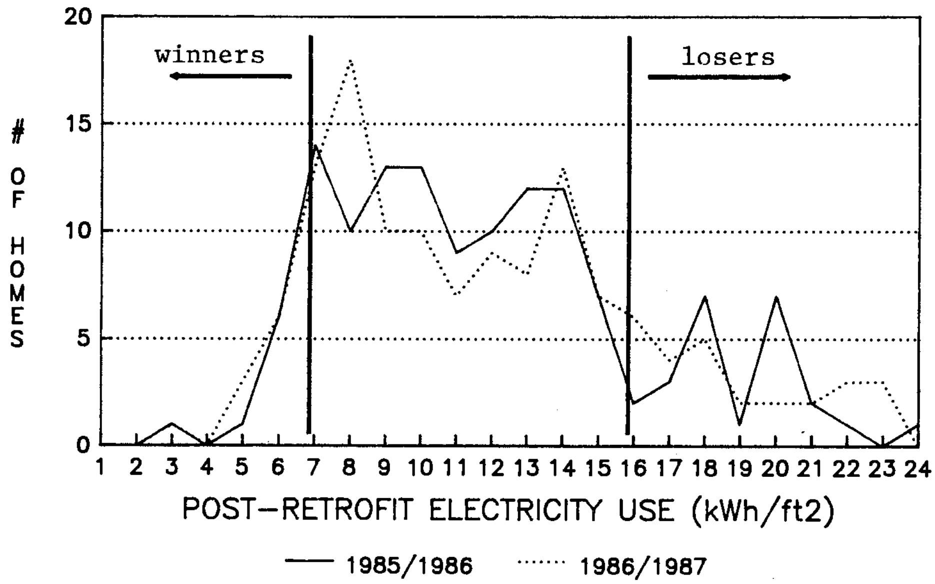

Figure 1a. Frequency distribution of DNACs.

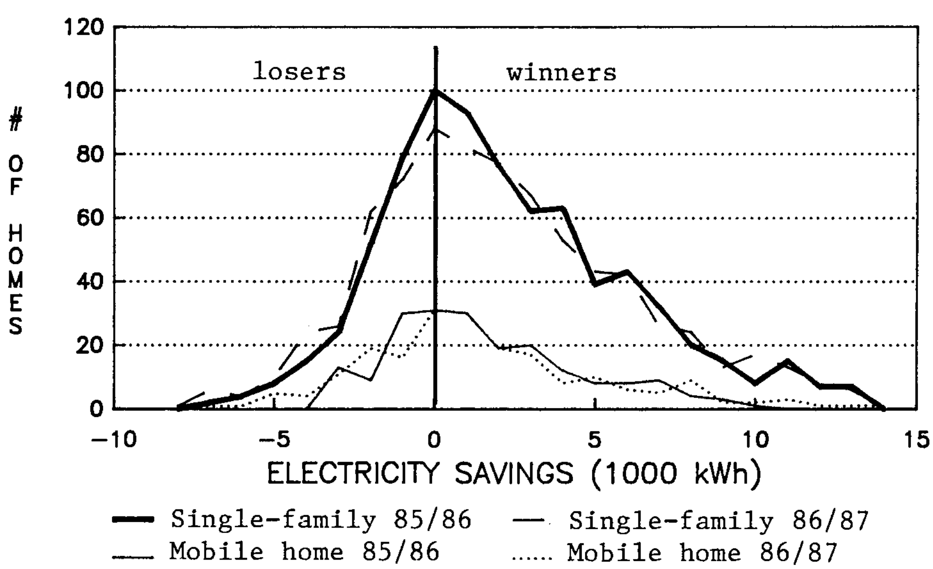

Figure 1b. Frequency distribution of kWh/ft² for single-family homes.

RESULTS

The results of each analysis are presented separately. Homes that were classified as winners or losers according to one criterion were not necessarily so classified under the other.

Gross Savings (DNAC)

Results of the gross savings analysis for two post-retrofit years are summarized in Table II. Significant differences between winners and losers were not found for floor area; window area; type of heating system; cost of retrofit; installation of insulation, infiltration, or window measures; owner or renter occupied; income; and use of wood for heating.

Single-family homes. The losers group, those with increased usage following retrofit, used significantly less energy prior to retrofit than did winners (alpha = 0.01[1]) -- almost 4,000 kWh less in 1982/1983. Losers also had larger households, 3.2 occupants compared to 2.8 occupants for winners (alpha = 0.01). Based on audit predictions, losers were also expected to save about 800 kWh less as a result of retrofit (alpha = 0.05). In addition to those variables listed above, significant differences were not found for age of home. A difference in utility service area was found for losers based upon 1985-1982 DNACs, however this difference did not carry through to the 1986-1982 DNAC comparison.

Mobile homes. The losers group used significantly less energy prior to retrofit (alpha = 0.01), 4,000 kWh less than winners in 1982/1983. The audits predicted that losers would save about 700 kWh less than winners (alpha = 0.03). One-third of the losers (36%) lived in the public utility service area, compared to over half (56%) of the winners (alpha = 0.01). Losers tended to be much newer than winners, with 29 percent of the losers built after 1979, but only 12 percent of the winners (alpha = 0.01). Significant differences were not found for number of residents, in addition to the list above.

Fuel switching. One theory that has been posed to explain increased electricity usage following retrofit is that households reduced the use of wood for space heating and relied more heavily upon electricity. Two-thirds of the homes in the HRCP used some wood for space heating, so fuel switching was presumed to be an important factor in energy-use analysis, as it would be in any community with wide-spread wood use. Fuel switching, between almost exclusive use of electricity and use of electricity with supplementary wood heat, was common in both the winners and losers groups of single family homes. While 14 percent of the losers switched from electricity to wood and 11 percent switched from wood to electricity, fully seventy-five percent of the losers remained consistent in choice of

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[1] Alpha is a measure of the probability that the difference in means between two groups is effectively zero. An alpha of 0.05 or less indicates high confidence that observed differences are real.

fuel between 1982/1983 and 1985/1986 (alpha = 0.01). The percentage of households which switched was higher in 1986/1987, with only 67 percent of homes showing no change from 1982/1983, 18 percent switching from electricity to wood, and 15 percent switching from wood to electricity (alpha = 0.01).

Among the winners group, 70 percent showed no fuel switching between 1982/1983 and 1985/1986, while 17 percent switched from electricity to wood and 13 percent from wood to electricity (alpha = 0.01). These percentages also changed in 1986/1987 -- 64 percent did not switch, 21 percent changed from electricity to wood, and 15 percent changed from wood to electricity (alpha = 0.01).

While all these changes are statistically significant, the number of losers changing from wood to electricity is not. Fuel switching is not a cause of increased electricity usage after retrofit.

The losers group of mobile homes showed 67 percent not changing fuel between 1982/1983 and 1985/1986, 20 percent changing from electricity to wood, and 13 percent changing from wood to electricity (alpha = 0.07). The percentages changed when comparing 1982/1983 to 1986/1987--69 percent showed no change, 18 percent changed from electricity to wood, and 13 percent from wood to electricity (alpha = 0.02). The results for mobile home winners were almost identical. The percentages were <u>not</u> significant when comparing 1982/1983 with 1986/1987, leading us to conclude that a number of mobile home residents who had changed primary fuel changed back again a year after retrofit.

Table II. Significant differences between winners and losers -- DNAC.

	Losers	Winners	Statistical Significance Level
<u>Single-family homes</u>[1]			
n	184	580	
Audit estimated savings (kWh/yr)	6,800	7,600	0.05
Number of residents	3.2	2.8	0.01
Electricity use in 1982/83 (kWh)	17,200	21,200	0.01
<u>Mobile homes</u>[1]			
n	58	145	
% in public utility service area	56	36	0.01
% built after 1979	29	12	0.01
Audit estimated savings (kWh/yr)	1,900	2,600	0.03
Electricity use in 1982/83 (kWh)	16,100	20,100	0.01

[1] Values for 1985-1982 DNAC. Results for 1986-1982 DNAC were almost identical.

Post-retrofit Usage Per Square Foot

The results of this analysis are given in Table III. The table includes only single-family homes since there were insufficient data to analyze mobile homes under this criterion. Utility service area, cost of retrofit, amount of audit estimated savings, type of heating system, and the types of retrofit measures received did not exhibit significant differences.

Only three variables showed significant differences for single-family homes. Losers had larger households than did either winners or mid-range homes, and their homes were smaller. Pre-retrofit usage for losers was higher than either of the other groups.

Window area, age of home, owner or renter occupied, and income level showed differences in the 1982/1983 to 1985/1986 comparison, but the differences did not carry through to the 1986/1987 comparison.

Table III. Significant differences between winners and losers -- NAC/FT^2.

	Losers	Midrange	Winners
1985/1986 electricity use			
n	22	88	22
Floor area (ft^2)	1,340***	1,730**	2,190***
Number of residents	4.1***	3.0*	2.6**
Pre-retrofit usage (kWh/yr)	27,800**	20,700***	15,500***
1986/87 electricity use			
n	23	87	22
Floor area (ft^2)	1,340***	1,770**	2,060***
Number of residents	3.7**	3.0	2.7**
Pre-retrofit usage (kWh/yr)	27,700**	20,700***	15,200***

* Significant at the alpha = 0.10 level
** Significant at the alpha = 0.05 level
*** Significant at the alpha = 0.01 level

NOTE: Significance level refers to comparison to the right (losers to mid-range, mid-range to winners, winners to losers)

SUMMARY AND DISCUSSION

A number of variables (window area; type of heating system; cost of weatherization; installation of infiltration, insulation, or window measures; owner versus renter occupied; and use of wood for heating) were not significant for either criteria. Pre-retrofit usage and the number of residents were the only consistently significant variables. Floor area, age of home, audit-estimated savings, and utility service area were significant some of the time.

Structural variable differences between groups were not found for the first definition of losers (increased usage after retrofit), but some demographic variable differences were identified. Losers used much less electricity than other homes prior to retrofit; households in this group apparently relaxed their conservation behavior, resulting in savings take backs. Fuel switching was common within this group, indicating that post-retrofit behavior related to energy use had not stabilized by the second year.

Under the second definition (post-retrofit electricity usage per unit floor area), pre-retrofit usage was higher for losers and homes were smaller. These factors in combination with larger households, all contribute to the higher electricity use per square foot which distinguishes losers from the midrange in this criterion. Winners used much less energy prior to retrofit, have larger homes, and smaller families.

Gross Savings

Prior to retrofit, the losers group of single-family homes used 19 percent less electricity than the winners group and their audit-predicted savings were 11 percent lower. Since homes in the two groups are not significantly different in size, the difference in audit estimates of savings indicates that loser homes were structurally more energy efficient than winner homes prior to retrofit. In addition, it appears that the loser households managed their energy use in order to reduce electricity consumption. The most common strategies are using wood for space heating, reducing thermostat set points, and closing off rooms.

While there is some switching between wood heat and electricity following retrofit, a greater percentage of the homes switched from electricity to wood than from wood to electricity. This implies that decreased wood use cannot account for increased electricity use for the losers group as a whole. Previous analyses by Dinan (1987) and Stovall and Fuller (1988) do not indicate that there is an overall temperature-related take back effect. However, their analyses are based on monitored data from a 10 percent subset of HRCP homes. In addition, they do not conduct a separate analysis of homes with increased post-retrofit electricity use. Thus, their findings do not preclude significant take back due to thermostat set point changes for the loser group identified in this analysis.

Postretrofit Usage Per Square Foot

It is not surprising that larger homes with fewer people were winners according to this criteria. The combination of characteristics makes selective heating of the home more feasible, without sacrificing comfort.

In addition, is reasonable to assume that there would be a less intensive use of appliances in such a home, and a corresponding smaller base load.

CONCLUSION

Those homes with the lowest preretrofit usage tended to use more energy rather than less following weatherization. It appears that behavioral factors play a large part in determining what portion of potential technical savings is achieved. The Hood River Conservation Project involved only structural improvements to participating homes; inclusion of an educational component could have resulted in greater savings. However, savings resulting from structural modifications are much more stable than those which depend on developing energy-conscious behavior in consumers.

No systematic determination of ineffective retrofits can be identified based upon structural characteristics of HRCP homes. This finding indicates that weatherization program planners will not be able to exclude certain types of housing stock based on probabilities of increased electricity usage after retrofit, rather the program manager can only target homes which have demonstrated high usage patterns.

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