THE EFFECTS OF A MUNICIPAL ENERGY AUDIT PROGRAM ON ELECTRICITY CONSUMPTION IN SINGLE-FAMILY RESIDENCES

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ABSTRACT

An evaluation of the effectiveness during the cooling season of the residential energy audit program of a small municipality in Missouri is summarized. Impacts of the program on both electricity consumption and conservation activity are statistically estimated by comparing appropriate quantities for treated test and untreated control groups. The study is used as an example of how such an evaluation may be done. Some of the problems encountered both in carrying out the evaluation and in interpreting the results are presented, and selected solutions and their significance are discussed.

INTRODUCTION

In January 1982, the City of Ballwin, Missouri, a small municipality in St. Louis County, initiated a Residential Energy Audit Program (REAP). Energy audits were made available free of charge, upon request, to all residents of Ballwin. Aerial thermograms were used to identify houses that appeared to have the highest heat losses during the heating season and thus the greatest potential for energy savings. The residents of these houses were contacted directly and informed of the audit program. The program was publicized in several ways including articles in local newspapers, a display in City Hall, fliers sent with other information on local services to new residents, and presentations at local fairs and schools.

The audit consisted of interior and exterior inspections of the structure. The auditors checked the exterior for the presence and condition of weatherstripping, caulking, storm windows, attic ventilation, and penetrations of the exterior envelope (e.g., by air-conditioning hoses, gas lines, dryer vents, etc.). Measurements of the building dimensions were made in order to determine the areas of the walls, floor, and roof. The interior inspection consisted of checking the thermostat setting, measuring all windows and exterior doors, and inspecting the heating unit and water heater. The condition, type and amount of wall and attic insulation were also determined.

Information from the audit and fuel consumption data from the previous year were used to estimate fuel requirements for water heating and heat losses during the heating season associated with each major building component (the attic, doors, walls, and windows). The results were sent with a list of suggestions for energy conserving improvements to each residence. Suggestions included both no-cost and low-cost measures and devices that are considerably more costly. Among the recommended measures were the use of thermostat setback in winter, caulking, insulation for the water heater, attic insulation, and improved maintenance of the air conditioner.

This study was undertaken to evaluate the effectiveness of REAP in reducing energy consumption in audited residences. Because sufficient data for heating-fuel consumption could not be obtained, the study was restricted to impacts on electricity consumption during the cooling season. Both actual energy savings and the number and kinds of energy conserving actions that were implemented as a result of REAP were measured statistically. Comparison of actual savings with energy-conservation activity provided preliminary information concerning the effectiveness of the actions that were implemented.

METHOD OF EVALUATION

Measurement Strategy

This study was designed to measure the impact of REAP on energy consumption and on the efforts of residents to save energy. The ultimate objective of any energy-conservation program should be to decrease energy consumption compared to energy usage that would occur in the absence of the program. However, once the program is implemented, the consumption without the program does not occur and, therefore, cannot be measured. A simple comparison of energy consumption during seasons before and after treatment (i.e., auditing) by the households does not adequately control for changes in factors other than the program that influence energy consumption (e.g., weather, energy prices, political climate, and conservation activity that would occur even in the absence of the program). One method for overcoming this difficulty is to compare the change in energy consumption between seasons before and after treatment for a group of treated test dwellings with the change in energy consumption over the same time interval for a group of untreated control residences that are identical in every respect except for participation in the program. Matching test and control groups is simple in concept, but difficult in practice. When program participants are self-selected, as in the Ballwin program, the treated households may have an innate propensity to conserve energy and may have conserved more than the control households, even without the program. In this case, the impact of the program would be overestimated. On the other hand, awareness of the program by non-participants may in some way affect their energy consumption, possibly causing them to conserve and decreasing the measured savings, thus causing too little to be attributed to the program. Our results are interpreted in view of these potential problems.

To reduce variances in the data associated with differences in house sizes and to give equal weighting to all houses, changes in electricity use were expressed as a fraction of the electricity consumption (E_i) during the cooling season before audits were performed. The average savings attributable to the audit program were estimated by the expected value of the random variable

$$S = (\Delta E/E_i)_T - (\Delta E/E_i)_C.$$

Here, $\Delta E = E_f - E_i$ represents the difference between seasonal total electricity consumption for cooling seasons before (E_i) and after (E_f) audits of the test houses, and the subscripts T and C identify variables for test and control residences, respectively. The estimated fractional savings are then just the difference between the mean values of $\Delta E/E_i$ for the test group and the control group, with savings taking negative values. Statistical tests for differences in means were used to establish the significance of any savings measured. The relative energy-conservation activity of the test and control groups was measured by comparing the proportion of each group implementing specific energy saving measures. Statistical tests for differences in proportions were used to establish the significance of any differences in observed activity.

Rather than trying to predict the savings likely to result from auditing more residences in the future (which would be required for utility load management and planning), the objective of this study was to measure, as a first step, the savings that had occurred in those particular residences that were treated. As the result, the test households included in the study were considered a 100% sample, and the control residences were a small sample from a very large population of possible control households. If the test households were considered a sample from a very large population of possible test houses, then the uncertainty in the results would be greater and statistical significance would be more difficult to achieve.

Data Requirements and Collection

The test group consisted of residences that had received audits between January and May of 1982. The pre- and post-audit cooling seasons were defined as June through September of 1981 and 1982, respectively. Therefore, any measurable energy savings were the result of a relatively rapid response to the audit. As a result, this study could not detect any long-term effects of REAP, including savings associated with conservation measures implemented during the fall of 1982, prior to the first winter following the audits.

Four types of data were required for each household: data to establish qualifications for inclusion in the test or control group, data to match the test and control groups, electricity-consumption data for the pre-audit and post-audit cooling seasons, and data concerning energy-conservation activity. For inclusion in the study, the dwelling had to be a detached single-family residence located in the City of Ballwin, using air conditioning during the summer, having natural-gas heat (because originally a study of the heating season was planned), and for the test group, acknowledging having received an energy audit from the city. Other characteristics of the structure and the occupants were used for matching the test and control groups. Data for establishing qualifications, matching, and characterizing conservation activities were obtained by using a mail survey. Although response to a mail survey is usually lower than response for telephone and personal surveys, the cost of a mail survey is significantly lower. Survey packets consisting of a questionnaire, a utility-bill release form, a cover letter, and a stamped return envelope were mailed to a total of 265 test-group candidates and 600 control-group candidates. To encourage participation in the study, the questionnaire was simple, requiring respondents only to mark appropriate responses to each question. A signed letter from each participant to the electric utility, requesting that consumption records for the period from October 1980 through April 1983 for their residence be released to us was necessary. We provided a form letter for this purpose that was signed and returned to us with the completed questionnaire, and all letters then were submitted together to the utility company. Candidates were eliminated from the study if electricity consumption records were not available. Questionnaires were returned by 118 test and 144 control households. After eliminating ineligible households, 88 test and 81 control residences remained.

Matching

Energy savings during the cooling season and fractions of the test and control groups that implemented selected energy-conservation measures were first estimated using all eligible test and control residences. The analyses were then repeated using smaller better matched groups, thus eliminating more factors unrelated to REAP that represented potential sources of bias.

Factors that affect electricity consumption and, therefore, may introduce bias into the results if different for the test and control groups, were identified by statistically comparing (using one-way analysis of variance) the electricity consumptions of groups of households with different characteristics. For example, average electricity usage per residence by households with basements was compared to consumption by households without basements. Comparisons were made using data for the pre-audit cooling season, with all households (test and control) grouped together. A conservative approach was taken to ensure that all factors that might affect electricity consumption were identified. If the probability that the electricity consumptions by the groups of households with and without the characteristic under consideration were identical, that specific characteristic was assumed to affect electricity consumption.* For characteristics with only two possible values (e.g., the presence or absence of a basement), a test for differences between two means was used. For characteristics with more than two possible values (e.g., the number of fireplaces), a test for at least one difference existing between more than two means was used.(1) The variables that were found to possibly affect household electricity consumption during the cooling season are listed in Table 1. Some of these factors (e.g., the presence of wall insulation and the number of windows) have a clear relationship to cooling loads and electricity usage for cooling; others (e.g., the presence of a heated attic or basement) have a less obvious relationship to cooling loads. For example, the presence of a heated attic may be an indication that the attic is also air-conditioned (however, to limit the length of the questionnaire this was not asked specifically).

Preferably, matching over all variables that affect electricity consumption would be done simultaneously. This might be done using pair-wise matching; however, with a large number of variables, the necessary pool of control candidates would be prohibitively large, even when the test group is a 100% sample. Alternatively, regression techniques might be used to investigate the

*Strictly, the characteristic could not be assumed to not affect electricity consumption at the 5% significance level.

Table 1. Factors Affecting Electricity Consumption During the Cooling Season

Type of roof/ceiling combination
Heated attic
Heated basement
Number of rooms
Number of fireplaces
Attached garage
Heating of an attached garage
Number of windows
Number of occupants
Change in occupancy level in the last three years
Occupancy during the daytime on weekdays
Total household income
Source of energy used for cooking
Use of thermostat setback during sleeping hours
Number of rooms air-conditioned (excluding garages and patios)
Wall insulation
Presence of a thermostat for the air conditioner
Automatic thermostat setback

significance of the audit as well as other variables. In this study, both the test and control group sample sizes were decreased and the groups made more homogeneous by eliminating those residences that did not share predominant characteristics. Predominant, one-sided, characteristics were those characteristics shared by 90% or more of the households. The 32 test residences and 38 control residences remaining had central air conditioning, a basement, natural-gas heating, ceiling or attic insulation, no automatic setback thermostat, and if an attic or attached garage were present it was not heated. Although the remaining groups were more homogeneous, only three of the predominant characteristics significantly affected electricity use during the cooling season (compare Table 1). However, further matching would have led to unacceptably small groups and statistically insignificant results, and the results for these partially matched groups did support the previous results.

RESULTS

Estimated fractional energy savings are shown in Table 2, together with several intermediate results. Electricity savings and decreases in consumption take negative values. Both sets of results show that while the test group increased electricity consumption slightly (by less than 2%) on average, the control group decreased electricity consumption by 6.5 to 8.1%. The resulting values for the fractional energy savings are positive, indicating that no savings were obtained. The probability is less than 1% that these data would have been obtained if savings actually existed. These results indicate with high confidence that during the first cooling season following the audits, no savings were obtained as a result of the program; in fact, the program may have had a detrimental effect. These estimated savings and corresponding probabilities do not represent the expected savings or probability

Table 2. Estimated Energy Savings During the Cooling Season.

Number of test-group residences	88	32
Number of control-group residences	81	38
Average monthly electricity consumption during the pre-audit cooling season per residence (kwh/month)		
Test group	1267.1	1231.6
Control group	1365.7	1343.3
Average monthly electricity consumption during the post-audit cooling season per residence (kwh/month)		
Test group	1277.7	1253.3
Control group	1276.2	1239.7
Unbiased estimate of the fraction change in electricity consumption		
Test group	0.0084	0.0176
Control group	-0.0655	-0.0812
Unbiased estimate of the fractional energy savings*	0.0739	0.0987
95% confidence interval for savings	[0.0186, 0.129]	[0.0178, 0.180]
Probability that savings were obtained by the test group	0.59%	0.84%

*Savings take negative values.

of savings in other households; they only refer to the particular households included in the test groups.

Results for the analysis of energy-conservation activity are shown in Table 3 for conservation measures that should decrease air-conditioning loads. All measures implemented between completion of the audit in Spring 1982 and about June 1983 are included. The results for the complete test and control groups with 88 test residences and 81 control residences show that at the 5% significance level, a greater fraction of the test residences installed ceiling insulation, wall insulation, weatherstripping, caulking, and switchplate and outlet gaskets. These measures should all decrease energy consumption for both air conditioning and heating. The results for ceiling insulation and caulking were also significant at better than the 1% level. At better than the 1% significance level, a greater proportion of the test group implemented at least one conservation measure (see the last row of Table 3). However, a greater proportion of the control residences installed storm doors and probably improved air-conditioner maintenance and decreased lighting levels. The results for the smaller, more homogeneous groups are statistically not as conclusive, but do indicate the same general trends. Overall, the results shown in Table 3 indicate that the program had a positive effect on the audited households and stimulated conservation activity.

DISCUSSION

The results for energy savings during the cooling season and for conservation activity appear contradictory; the test group implemented more energy-conservation measures after the audits, yet increased electricity usage during the cooling season. Closer inspection of the data reveals that most of the conservation measures taken by the test residences were implemented during the fall of 1982, following the post-audit cooling season. Energy savings would be expected during the heating season and the next cooling season, but not for the cooling season before the installations were completed. Therefore, the results are not inconsistent, but indicate that sufficient time is required for program participants to respond. A follow-up study could confirm this.

In spite of greater conservation activity during the fall, the test group increased electricity consumption between the pre- and post-audit cooling seasons (see Table 2). This increase cannot be attributed to warmer weather during the summer of 1982 because the weather was milder. The total number of cooling degree days for the summers of 1981 and 1982 were 1277 and 1107, respectively.(2) The lack of conservation by the test group may be associated with the emphasis on heating-fuel consumption by the energy audit. No specific information concerning energy use for air conditioning was given in the reports to the households, although the suggestion to keep the air-conditioning unit clean was included. Decreased electricity usage by the control group could indicate a greater propensity to conserve energy; however, this would be contrary to conventional wisdom in which self-selection for participation in an energy-conservation program is believed to indicate a propensity to conserve energy. The method by which this program was publicized, with targeting of households shown in aerial thermograms to have high heat loss, may have resulted in a test group that was self-selected, but that had a lower propensity to conserve energy than a self-selected group from the general

Table 3. Proportions of the test and control groups (P_T and P_C) that implemented specific energy-conservation measures after the audit and the probability that $P_T > P_C$.

Conservation Measure Installed or Implemented	Results for 88 test residences and 81 control			Results for matched 32 test residences and 38 control residences		
	P_T	P_C	$P[P_T>P_C]$	P_T	P_C	$P[P_T>P_C]$
Ceiling insulation	0.148	0.037	99.76	0.184	0.000	99.65
Wall insulation	0.057	0.000	98.68	0.053	0.000	90.82
Weatherstripping	0.114	0.049	96.71	0.132	0.031	95.35
Caulking	0.239	0.099	99.84	0.237	0.125	93.19
Switchplate and outlet gaskets	0.102	0.025	98.90	0.079	0.000	95.05
Storm windows	0.045	0.037	63.68	0.026	0.000	82.38
Storm doors	0.011	0.037	1.25	0.000	0.031	0.00
Sunscreens or window film	0.011	0.012	42.41	0.026	0.000	82.38
Improved air-conditioner maintenance	0.034	0.062	8.21	0.053	0.000	90.82
Increased thermostat setting during the cooling season	0.057	0.062	42.07	0.053	0.063	40.13
Reduced lighting	0.011	0.025	11.31	0.026	0.000	82.38
Fraction of households taking at least one measure	0.557	0.401	99.67	0.632	0.375	99.86

population of households. Initially high heat loss may indicate a general disregard for saving energy. Although not possible as part of this study, this potential problem might be resolved by studying in detail the actual composition of the test group or by surveying the test and control groups to reveal attitudes toward energy conservation.

Our results show that the most commonly installed energy-conservation measure by either group was caulking which 23.9% of the test group and 9.9% of the control group installed (for the smaller matched groups, 23.7% of the test group and 12.5% of the control group). During the winter approximately 19% of the infiltration in a residence occurs around doors and windows. Properly installed weatherstripping may eliminate up to 46% of the energy losses associated with infiltration around doors and windows, or about 8.7% of total infiltration.(3) Caulking around doors and windows may eliminate up to 54% of these energy losses, or 10.3% of total heat losses associated with infiltration.(3,4) For a house in which infiltration represents 40% of the heating load, heating-fuel consumption would be reduced by about 7.6% by properly installed weatherstripping and caulking alone. If 20% of the homes install weatherstripping and caulking on all doors and windows, heating-fuel consumption for the group should be decreased by about 1.5%. During the cooling season, average windspeeds are generally lower and infiltration usually represents a smaller fraction of the load. Therefore, the effect is smaller and more difficult to detect, but other conservation measures also have been installed which should increase savings.

A mail survey was used to collect data for characterizing the residences and the conservation activity stimulated by the audits. In this study, the mail survey provided no apparent problems other than a relatively low response rate (24%) for the control group. Response rates are considerably greater for telephone and personal interviews; however, substantially greater costs precluded the use of these alternatives for this study. For evaluations that do not involve on-site inspections, misrepresentation and false reporting of actual conservation activity can occur and may lead to apparent inconsistencies between reported activity in test homes and measured energy savings. For example, if participants in REAP had reported installing conservation measures after the audit but before the post-audit summer of 1982 and we had obtained the results shown in Table 2 for estimates of energy savings, we could only have concluded that the devices were ineffective, were installed incorrectly, or were not installed at all. On-site verification of the claimed conservation activity would be required to distinguish among these possibilities. False reports on surveys can be partially controlled by designing questionnaires to check internally for consistent responses. Verification of reports at reasonable cost is sometimes possible by carrying out inspections for a random subsample of the group, rather than for the entire group.

The energy savings and incremental conservation activity estimated in this study are for the specific homes included in the test group. The results cannot be assumed to apply to other residences that might be audited in the future. The homes are, however, very much like the average home in Ballwin, 84% of which are air-conditioned.(5) The methodology could be extended to estimate the savings for all homes with characteristics similar to those in the test group by assuming that the test group is a sample from a large test-group population. This was not done because no statistically significant savings were found for the test group itself. Extending the study would only introduce greater uncertainty.

This study addresses energy savings associated primarily with air conditioning during the cooling season immediately following audits that were completed during the late winter and the spring. The impact on fuel usage during the heating season may be more substantial than effects during the cooling season. Most conservation measures installed by participants in REAP were installed during the fall after the first post-audit cooling season. Consequently, savings should result during subsequent cooling seasons and the heating season, even though none were measured in this evaluation. This study, therefore, represents a first step in evaluating REAP, and the results cannot be used alone to guide major changes in the program. As in all evaluations, both short- and long-term impacts must be measured to evaluate program effectiveness. This study should serve as an example of how that might be done and highlights some of the problems encountered and methods by which they may be overcome.

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