Weatherization Program Short-Term Evaluation Methods

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Procedures were developed and tested to conduct a quick and reliable evaluation of weatherization program energy savings using heating system run-time loggers. This project performed: (1) a statistical analysis to determine the measurements and assessment constraints on short-term run-time monitoring, and (2) a field test of the data collection procedures with three weatherization providers. The primary purpose of the short-term performance assessment was to provide an enhancement to the State of Minnesota M200 weatherization process through the development of a timely and consistent system of feedback and accountability. The streamlined process developed for this purpose can be applied to any government or utility funded weatherization program where the goal is accurate savings estimates produced in a short time period.

In developing a procedure to determine the cost-effectiveness of the installed energy saving measures, two approaches can be employed: (1) comparing usage from a group of treated houses with the usage from a set of untreated control houses measured over the same period, or (2) measuring pre- and post-weatherization usage for individual houses and calculating the weather-corrected energy savings. For this project, Monte Carlo simulation statistical studies established the level of uncertainty in projected energy savings for the two approaches. Considerations such as sample size, length of monitoring period, and time of year were examined for each approach. Software has been developed to streamline field data collection and analysis. Preliminary results have been obtained from three weatherization providers installing improvements during the 1994/1995 and 1995/1996 heating season.

INTRODUCTION

Through the history of the low-income weatherization assistance program, the trend has been to assess program efficacy exclusively in terms of energy savings and program costs, such as simple paybacks and savings to investment ratios. This approach is further reinforced by the guidelines set forth by US DOE in the approval process for the 60/40 waver audit, as defined by 10-CFR-440. In response to this, greater emphasis within weatherization programs is being placed on the delivery of justifiably cost-effective energy saving measures (Shen, Linner, Bohac 1995). The principal goal is to achieve the greatest energy savings per dollar invested. This can be done by: (1) targeting homes with a large potential for energy savings, (2) prioritizing the treatments by impact, and (3) providing feedback and quality control through predicted and short term measured savings. This project responds to program feedback issues by considering procedures that can assess the cost-effectiveness of the installed energy savings measures in a timely fashion.

The goal of this project was to develop the framework for and evaluate the use of noninvasive heating system run-time loggers as an on-going performance measurement tool for the Minnesota Low-Income Weatherization Assistance Program. This work is part of an effort to develop a consistent system of feedback and accountability within the program. This project was designed to determine the feasibility of several different simplified approaches to short term savings assessment for weatherization measures on single family houses. Savings calculations were based on monitoring daily heating system run-times for three months or less. This effort was motivated by two features of commonly used evaluation methods that make them poorly suited for widespread application by low income weatherization provider staff. First, existing methods require a higher level of staff training and a larger time commitment than many low income weatherization providers can budget for an impact evaluation. Second, methods based on analysis of monthly utility bills require about a year of data both before and after the retrofits to obtain usable information about both heating and non-heating energy use and to achieve high statistical reliability. It was hoped that using more frequent measurements of only heating system energy use would yield comparably precise savings estimates in a much shorter time frame.

The implementation of a short-term assessment methodology must consider several factors:

- What error or confidence level can be expected from short-term measurements?
- What is the minimum number of monitored houses needed to provide a reliable assessment?

- What is the shortest length of time allowable to collect accurate data during the pre- and post-weatherization monitoring periods?

- How will monitoring affect actual production?

- How will production constraints influence the ability to collect data and the integrity of that data?

In developing a procedure to determine the cost-effectiveness of the installed energy savings measures, two approaches were considered: (1) Control/Treatment; comparing usage from a group of treated houses with the usage of a set of untreated control houses measured over the same period, and (2) Pre/Post; measuring pre- and post-weatherization usage for individual houses and calculating the weather-corrected energy savings. For this project, statistical studies established the level of uncertainty in projected energy savings for the two approaches. Other considerations such as sample size and length of monitoring period for each approach were also examined. A pilot test of the two approaches was conducted by three Minnesota low income weatherization providers at the end of the 1994/1995 heating season and over the 1995/1996 heating season using run-time loggers (also called event or time-of-use loggers) connected to natural gas fired furnace and boiler heating systems. The pilot test objectives were to determine the difficulties of incorporating the evaluation into typical weatherization procedures and gain further information on the measurement uncertainties. The results discussed in this paper summarize the information presented in the phase I final reports (Shen et al. 1995a; Shen et al. 1995b).

METHODOLOGY

This study examined Pre/Post and Control/Treatment evaluation methods. For the Pre/Post method, it was expected that the same set of houses are monitored over approximately the first and third month of a three month participation and monitoring period. A regression of daily heating system heating fuel use to outside temperature is used to estimate the annual space heating use of each house. The sum of the annual space heating use for the group of houses before and after weatherization is used to compute the group average savings. Individual house savings estimates can also be computed. The Pre/Post method is expected to have more statistical power than the Control/Treatment method, but it requires weather normalization to adjust for month-to-month weather differences.

For the Control/Treatment method, two separate groups of houses are monitored over the same time period. The relative savings are computed by comparing the total energy use during the test period of all houses in the treatment group (i.e. post weatherization) to the total use of the control group (i.e. pre weatherization). The absolute savings are then computed from the product of the group average savings for the period and the ratio of the heating degrees days in the monitoring period to the total annual heating degree days. This analysis method reduces concerns about secondary seasonality effects that would not be captured in a simple analysis of heating use versus temperature, but it raises greater concerns about matching of treatment and control groups and about having adequate statistical power. This method allows for simpler analysis of relative and absolute savings, but does not allow the savings to be computed for individual houses.

Statistical Analysis of Uncertainty

Because of the complexity of the assumed energy use model and the diversity of the target population, it was not considered appropriate to directly calculate the uncertainty of savings results for all the permutations of sample size and monitoring duration. Instead, large scale Monte Carlo (or randomized) simulations were performed based on residential heating energy use characteristics inferred from two large samples totaling 257 low income weatherization clients (Shen et al. 1993; Carmody 1986). These two samples had been evaluated using the PRISM (Fels 1986) weather normalization software and monthly utility billing data. The results were used to determine the heating slope and reference temperature probability distributions of low-income, single family residences before and after weatherization.

The Monte Carlo approach uses a specially adapted random number generator to systematically provide housing samples such that the distribution of the heating slope and reference temperature of the sample of houses is representative of the entire housing stock. The heating slope, reference temperature, outside temperature data, and appropriate ‘‘noise’’ are used to compute the daily heating use for all the sample houses. The daily energy use data is then analyzed by each evaluation approach to estimate the annual energy savings and this value is compared to the actual savings for each house. This process is repeated numerous times for the simulated housing samples to determine the accuracy of the evaluation approach.

This project analyzed numerous permutations in the evaluation approach including: (1) Pre/Post and Control/Treatment methods, (2) starting dates from September 1 through April 1, (3) combinations of ten different numbers of houses in a sample group ranging in size from 10 to 100, and (4) six different lengths of monitoring periods ranging from 10 to 35 days in increments of five days. The accuracy and attrition rate of the Pre/Post method applied to individual houses were also analyzed. Each combination was repeated up to two hundred times to get reliable estimates of the variability and accuracy of results.

The pre-weatherization energy use model was generated by randomly selecting a heating slope (β) and a reference temperature (τ) from a normal distribution of τs and a log-normal distribution of βs. Statistical analyses indicated that these distributions fit the previous weatherization data quite well.[1] The values of β and τ were used to calculate predicted energy use at the daily average temperature associated with each day of the specified period in a Typical Meteorological Year file for the local weather station. These values were also used to determine the annual space heating use:

$$\text{annual space heating use} = \beta * HDD(\tau) \quad (1)$$

Given the randomly generated pre-retrofit heating use model, further regression relations from the data set of low-income weatherized houses made it possible to estimate reasonable values for the percent savings and the change in τ. The average and standard deviation of the normally distributed ''noise'' that was randomly added to the two variables was determined from the weatherization data set. The required change in β was then calculated directly from the percent savings and new τ. Given the post period β and τ, post period energy use could be generated and analyzed in the same manner as for the pre period, then the apparent change in heating use could be calculated and included in the summary statistics for each set of simulated cases. Savings values were only calculated for cases with usable regressions in both the pre and post periods. This required that there be at least three data points left after any necessary deletions and that the regression yielded a reference temperature in the 99% confidence interval range of the weatherization data set (61°F $\pm$ 12°F).

Daily variations in factors such as wind speed, solar gain, appliance use, and occupancy behaviors cause deviations in the energy use from that predicted by the linear heating use model. To account for these deviations, or ''noise'', a daily error value was added to the predicted use values based on a normal distribution whose range was directly proportional to β. The overall scale of variability of daily use, and its relation to other use measures, were estimated from a set of comparable daily monitoring data derived from a previous evaluation of radon mitigation heating energy penalty in five single family houses (Bohac et al. 1993). There was some concern about whether this set of middle income houses was comparable to the target population of low income homes, but they were thought to at least provide a reasonable and empirically based starting point. In order to cover the worst likely range of appropriate variability values, a second set of simulations were performed with doubled errors.

Once the pre-period daily use values were generated, they were analyzed by an iterative, linear, least-squares regression of natural gas use to outside temperature with automated outlier rejection. Data were deleted if they were close to or above the τ and if they were atypically far from the trend of the remaining points (i.e., a normalized residual greater than 2.0). A regression of the final sample of daily points on outside temperature yielded estimated values of τ and β, then a lookup table of season average temperature and season length for each τ permitted calculation of the estimated annual total heating use.

Pilot Test of the Evaluation Method

A field test was designed to determine the feasibility of monitoring, collecting, and analyzing space heating use data from selected single family, natural gas heated homes using run-time loggers. Run-time loggers were placed on natural gas furnaces and boilers to measure daily average heating system run-times. These values were multiplied by the metered heating system input rate to compute the daily natural gas use. Agency staff installed the loggers and verified proper operation. Pacific Science & Technology, Inc. Time-Of-Use CT loggers were used to measure the daily on-time of the heating system burners. The run-time was indicated by placing the current transformer around the appropriate gas valve control wire. Other manufacturers can provide similar monitoring equipment and it is possible to use light or magnetic field sensors to indicate burner operation.

There were three main objectives to involving the agencies in preliminary data collection using run-time loggers. The first objective was to test the data collection schedule and protocol in a field setting. The second objective was to gain input from agency staff on how to incorporate the use of run-time loggers into existing weatherization activities. The third objective was to use the data collected to test and demonstrate Pre/Post and Control/Treatment analysis methods using field data.

Monitoring Schedule and Protocol

Figure 1 displays the logger rotation schedule for a series of monitoring periods. During each period, the heating system run-time data is collected from a set of treatment houses and a set of control houses. The control houses are monitored for a specified period of time to collect pre-weatherization data and the treatment houses are used to collect post-weatherization data. The group of houses classified as controls in the previous period are then weatherized and this group becomes the next month's treatment group. The run-time loggers are removed from the set of houses which had previously been the treatment group and are installed in upcoming control group houses. This schedule allows Control/

Figure 1. *Data Logger Installation and Removal Schedule Before, During, and After Weatherization (Wx)*

	Houses in Group 1	Houses in Group 2	Houses in Group 3	Houses in Group 4	Houses in Group 5	Houses in Group 6	Houses in Group 7
Period 1	*Install Log. Loggers A*	Install Log. Loggers B	Install Log. Loggers C				
Period 2	*Post Data Loggers A*	<u>Perform Wx Loggers B</u>	Pre Data Loggers C	Install Log. Loggers D			
Period 3	*Remove Log. Loggers A*	*Post Data Loggers B*	<u>Perform Wx Loggers C</u>	Pre Data Loggers D	Install Log. Loggers A		
Period 4		*Remove Log. Loggers B*	*Post Data Loggers C*	<u>Perform Wx Loggers D</u>	Pre Data Loggers A	Install Log. Loggers B	
Period 5			*Remove Loggers C*	*Post Data Loggers D*	<u>Perform Wx Loggers A</u>	Pre Data Loggers B	Install Log. Loggers C

Install Log.	Loggers are installed in each house in the specified group.
Pre Data	Loggers are left in the houses to record pre-weatherization consumption data on unweatherized homes.
Perform Wx	Crews perform all mechanical system and shell weatherization measures during this period. Auditors download pre data logger results
Post Data	Loggers record post-weatherization consumption data on weatherized homes.
Remove Log.	Post data logger results are downloaded. Loggers are then transferred from one group of houses to a new group.
Loggers A	**Houses with regular font are not weatherized.**
Loggers A	***Houses with italics have already been weatherized.***
<u>Loggers A</u>	<u>**Underlined houses are in the process of being weatherized.**</u>

Treatment data to be collected immediately after loggers are installed in the first three groups of homes (see the Period 2 column in Figure 1). The first complete set of Pre/Post weatherization data can be collected from Group 3, after the data is downloaded in Period 5 (see the Group 3 row and the Periods 1—5 columns in Figure 1).

The participating weatherization auditors were trained to choose homes for the study, install the loggers, download the data using laptop computers, record necessary dates, rotate the loggers, and run custom software which analyzes logger results.

Houses had to satisfy the following criteria to be considered for run-time logger monitoring:

(1) Single family houses, owned by the homeowner. Duplexes, multifamily buildings, mobile homes, and townhouses were excluded.

(2) Space heating needs fueled by natural gas. Heating oil and dual fuel houses were excluded.

(3) 24 VAC gas control valves. Millivolt and power pile systems were excluded.

(4) Houses were randomly selected whenever sufficient client pool allowed.

(5) Only houses which required mechanical system or building shell improvements were included. Houses which required only health and safety or only no-cost/low-cost measures, such as low-flow shower heads, were excluded.

(6) Houses scheduled for heating unit change outs were excluded.

(7) Houses threatened with having the natural gas fuel supply shut off were excluded.

The criteria were selected to limit the variability in the sample group. Not all the restrictions are necessary in order to use the run-time logger evaluation approach.

RESULTS

Statistical Analysis of Uncertainty

The variability or error in the space heating use savings computed by the evaluation methods was examined by performing at least 200 cases, or iterations, of each method. A set of iterations were conducted for a range of sample house quantities and test period durations for each evaluation method. Among other variables, the standard deviation and the average absolute error between the actual and computed Pre/Post or Control/Treatment annual space heating use savings were computed for each set of iterations. The average absolute error (AAE) is expected to be the best indicator of the expected uncertainty in the savings estimate for a particular evaluation method. It is important to note that these results are only valid for the climate surrounding the weather station (i.e., Minneapolis/St. Paul) and the housing stock represented by the houses included in the previous low income weatherization evaluation used to generate the heating model distributions. A similar analysis would have to be conducted in order to determine the accuracy of the evaluation methods for other locations.

Figure 2 displays the variation in average absolute error with the number of houses in a test group for both evaluation methods. The results are shown for 10 and 30 day durations of the monitoring period with the pre-period starting December 1st and the post-period starting February 1st. The average absolute error for the Control/Treatment method ranges from 12.4% for groups of ten houses down to 3.2% for 100 houses. In general, there is little improvement in the uncertainty for longer monitoring periods. This indicates that the daily variability in the heating use has relatively little effect on the uncertainty of the Control/Treatment method. Increasing the number of houses in the test group from 10 to 100 reduces the uncertainty by about a factor of three. However, much of the improvement occurs as the number of houses increases from 10 to 30.

The uncertainty of the Pre/Post method varies from 4.0% to 1.2% for a 10 day monitoring period and from 1.7% to 0.5% for 30 days. Thus, increasing the test period from 10 to 30 days reduces the uncertainty by more than 50%. The relative decrease in the uncertainty with increasing number of houses is similar to that for the Control/Treatment method. For the 10 day monitoring periods the uncertainty of the Pre/Post method is 2.5 to 3.0 times less than for the Control/Treatment and for the 30 day period it is six to eight times less. This indicates that if the linear heating use to outside temperature model is valid, the Pre/Post method achieves considerably more accurate results than the Control/Treatment method. The average absolute error of savings was also computed for individual house Pre/Post measurements. For a 10 day monitoring period the uncertainty is 10.3% and for a 30 day period it is 4.7%. This indicates that the Pre/Post method will often give accurate savings estimates for monitoring periods that span at least 30 days.

Figure 3 displays the average absolute error averaged over all numbers of houses and days for each monitoring period over the different starting months. These results indicate that September starts give worse results than the other months. The error for the Pre/Post method increases steadily for each month after January. This is due to the fact that the Post period will be two months later than the Pre period or the Control/Treatment test with the same nominal start date. However, the Pre/Post method gives error results at least as good as the Control/Treatment method for starting months from September through April. The 30 year average number of monthly heating degree days for Minneapolis/St. Paul

Figure 2. *Comparison of Average Absolute Error of Savings for Control/Treatment and Pre/Post Methods December 1 Pre Start—February 1 Post Start*

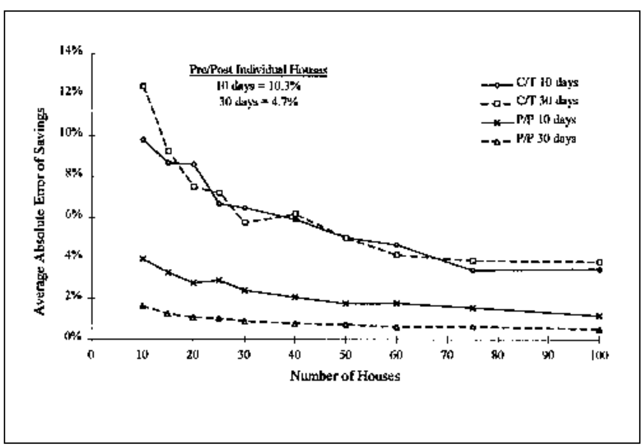
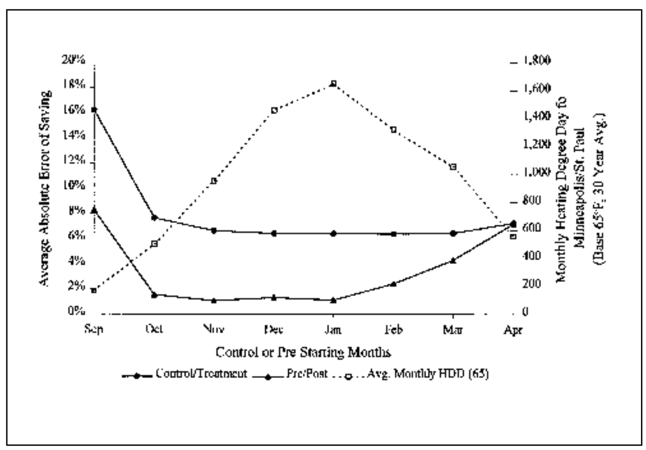


Figure 3. *Average Absolute Error of Savings by Starting Month and Monthly Average Heating Degree Day$_{65}$ for Minneapolis/St. Paul*



(base 65°F—HDD_{65}) are included in Figure 3. All months with an average HDD_{65} over 500 yield nearly the same level of accuracy. This indicates that the evaluation methods will likely produce similar accuracies for other locations during months with HDD_{65} greater than 500.

Further analysis showed that a doubling of the daily use ‘‘noise’’ level (i.e., deviations in daily use from a linear model) had very little effect on the accuracy of the Control/ Treatment method, but a pronounced effect on the Pre/Post method. The Pre/Post method with greater ‘‘noise’’ only produces reliable results from October through January.

If it is desired to use the Pre/Post method for determining individual house savings, three factors need to be considered. First, for the group sample approaches, it has been assumed that unrealistic parameter estimates will be averaged out in a sufficiently large group of cases. This assumption is not appropriate for single cases, so their modeling results need to be scrutinized with additional care and used with caution rather than uncritical acceptance. Second, attrition rates vary with starting month and number of days, so the likelihood of being able to analyze savings for some particular case will vary by time of year and monitoring duration. Figure 4 shows attrition rate results by number of days of data for the expected level of daily ‘‘noise’’ in the daily heating use with separate lines for each starting month. October through February starts provide about ten percent attrition rates for monitoring periods of twenty days or greater. The attrition rates for the earlier and later months range from 20 to 50%. When the noise levels are doubled, the attrition rate is about the same for October through January, but is about doubled for the remaining months and is more sensitive to the number of days in the monitoring period.

The third consideration is the average absolute error obtained by the analysis. Figure 5 shows average absolute error values for the individual house Pre/Post method with expected daily noise levels. For monitoring periods of 20 days or greater, October through February starts provide average absolute errors of ten percent or less and the three coldest periods (November to January starts) provide average absolute errors of about five percent. Due to all three factors, evaluation of savings for individual houses should be limited to October through February starts and the savings confidence values must be considered when interpreting the results.

Pilot Test Findings

To test the feasibility of the run-time logger protocols and schedule rotations in the field, a limited pilot study was conducted during the end of the 1994/1995 heating season. Two of the three participating agencies each rotated six loggers, the other agency used twelve loggers. Due to the small sample size, warm weather, and short monitoring periods, none of the results proved to be statistically significant. This process did provide the necessary feedback from weatherization providers to improve the data collection process.

As should be expected, several logistical, operational, and communication problems were encountered during the initial run-time logger data collection and analysis period. Of the 39 houses which were monitored, the data sets from 20 houses were used for statistical analysis. A malfunctioning computer, a misunderstanding of the project’s run-time logger scheduling, and a short test period accounted for most of the unusable data. Contacting clients and arranging to retrieve the run-time loggers were also barriers due to the field test’s short time frame. However, none of these, or other problems encountered during the test period, presented

Figure 4. *Pre/Post Method Attrition Rates by Months and Days for Individual Houses*

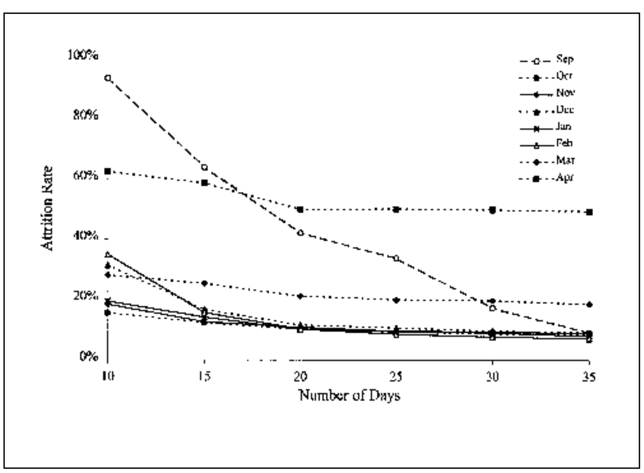
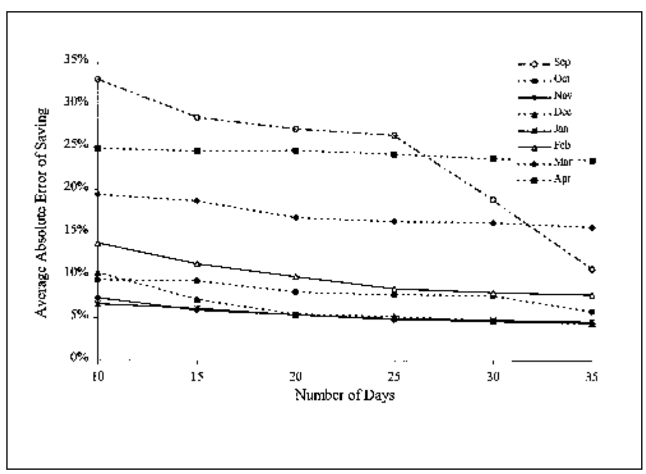


Figure 5. *Pre/Post Method Average Absolute Error Values by Months and Days for Individual Houses*



insurmountable barriers to the successful implementation of a short-term performance assessment approach.

The pilot project was expanded to include the 1995/1996 heating season from October through April. Three agencies have incorporated run-time logger monitoring into their normal production schedules. Two agencies are rotating 12 run-time loggers between monitoring periods, the third has eight loggers. Each monitoring period is scheduled for 21 days. This allows the participating agencies a full three weeks to schedule and complete all mechanical system and building shell improvements during the periods specified for weatherization

It is important that the participants understand the time periods needed for data collection and that they accurately record start and end dates. Dates are included in the pre or post analysis periods only if run-time data cover a complete twenty-four hour period. Dates are excluded when weatherization work, either mechanical system or building shell measures, occurred since this period is outside the pre- and post-weatherization monitoring periods. On the dates of logger installation and removal, the auditors were instructed to clock and record the input to the heating system from the natural gas meter before and after weatherization measures.

To minimize trips to the pilot study sites, auditors attempted to schedule logger installations to correspond with initial house energy audits. If loggers were installed before the deadline of the following period, the logger collected data for longer than the scheduled 21 days. These data were included in the Pre/Post analysis, as were any additional post-weatherization days recorded beyond the 21 day minimum.

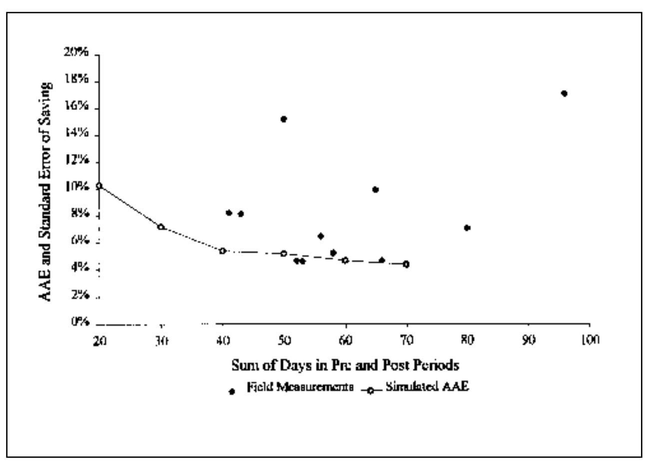
The schedule in Figure 1 was expanded to include 11 periods for 10 groups of houses. If all Pre/Post data are collected properly, this would yield eight Control/Treatment groups and eight Pre/Post groups for analysis. To date, significantly less data have been collected and recorded within the scheduled time periods. In almost all of the completed time periods, at least one of the three participating agencies has failed to meet the required deadlines for the run-time logger schedule. Some of the installation delays can be attributed to the slow down in agency production due to threats of federal funding cuts. These delays severely limited the pool of available houses which met the study's criteria. In addition, one run-time logger malfunctioned and one agency had consistent problems downloading data that otherwise would have been valid.

Due to the limited amount of data available for analysis, it has not been possible to analyze any Control/Treatment data. The Pre/Post data collected to date have provided 11 cases that have sufficient data to conduct pre and post period regression analyses. Observed savings for the Pre/Post data ranged from $+57.7\%$ to -27.8% with average savings of 10.3% and an insignificant group p value of 0.1 to 0.2. The grouped Pre/Post data were not statistically significant; however, 4 of the 11 individual cases had statistically significant savings and had p values of 0.05 or less. Results from a greater number of houses are required before attempting a comparison of the observed and energy audit estimated energy savings.

The monitored data collected for this study provided the opportunity to compare the accuracy predicted by the simulation analysis to that found through field monitoring. Figure 6 displays the uncertainty of the relative savings for the 11 cases and the predicted accuracy for the Pre/Post method applied to individual houses. Data collected from mid-November 1995 through January 1996 had savings uncertainties from 4.6% to 17.1%. These relative uncertainty levels of computed savings can be compared to the simulation estimates of 4.7% uncertainty for 60 days of data to 10.3% uncertainty for 20 total days in both pre and post periods. The field test uncertainties are somewhat higher than were predicted by the simulation results. These findings indicate that the day-to-day variability in heating system run-times is somewhat greater than what was assumed for the simulation runs.

Several challenges to the Control/Treatment monitoring method were discovered during the field test. The weatherization providers in the pilot study found it difficult to meet the strict time constraints required for the Control/Treatment method because it requires the simultaneous monitoring of large samples of houses. For instance, if a specific auditor installed a run-time logger even one day after the required deadline for a Control/Treatment monitoring period, that particular site was not available for analysis. However, the Pre/Post method provides more flexibility since it only

Figure 6. *Simulated Average Absolute Error (AAE) and Standard Error of Field Measurement Savings; Based on 11 Sites from Three Weatherization Agencies*



requires that a minimum number of days be included in the monitoring period. Because of this flexibility, the Pre/Post method can be more easily incorporated into existing weatherization production schedules. The Control/Treatment method is not recommended except for weatherization providers that serve at least 75 customers per month whose homes can be monitored by the run-time logger method.

CONCLUSIONS

The statistical analysis found that the relative accuracy of the Control/Treatment method to measure program savings is most greatly influenced by the sample size and shows little sensitivity to the measuring period duration, daily consumption deviations, and time of year of the monitoring. It should be possible to use this method in almost any month of the heating season (except early September) as long as an adequate sample size is used. It yields an average absolute error of three to twelve percent in particular simulations or six to eight percent averaged over all numbers of houses and days. It is recommended that a sample size of about 60 houses per group, or a total of 120 houses will produce statistically significant results for an expected savings of 12%.

The reliability of the Pre/Post method to measure program savings is somewhat sensitive to the starting month and the number of houses and more sensitive to the test duration. The Pre/Post method yields an average absolute error of one to seven percent in particular situations or one to four percent averaged over all numbers of houses and days (for starting months from October to March). For comparable test situations, the Pre/Post method always yields more accurate results than the Control/Treatment approach. To achieve significant results, the Pre/Post method should be used with a test period of at least 20 days and a minimum group of 10-20 houses, depending on which months will be monitored.

The Pre/Post method can be used to determine savings for individual houses with the following considerations: meaningful and significant results will only be obtained for a limited portion of the heating season, a longer monitoring period is required, and the results for at least ten percent of the houses will be invalid. Since this method can provide savings results within one month after work has been completed, the method can be used to determine when additional resources should be applied to a house and give direct feedback to work crews. However, the method must be applied in coordination with additional information about the house (such as comparison to energy audit predicted savings, results from diagnostic tests, post-weatherization inspections, job book review, a phone survey to identify lifestyle changes, and possibly a second site visit) and consideration given to the indicated reliability of the computed savings.

The field test results suggest that collecting Pre/Post run time logger data in a production setting is dependent on well informed staff who are dedicated to producing timely data and have access to a wide pool of qualified houses. With one exception, the gaps in collected data during this pilot project can be attributed to operator error. Detailed data tracking sheets and intensive training may increase the amount of usable data during production based monitoring.

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ENDNOTE

1. Analysis showed that the weatherization evaluation distributions had non-significant skewness and kurtosis and a non-significant result from a Kolmogorov-Smirnov test against a true normal distribution with the same mean and standard deviation. There was a slight intercorrelation between the and that was considered numerically unimportant compared to other sources of variation and was thus ignored for simplicity.