AN EVALUATION OF THE PERFORMANCE OF THE NEAT AUDIT AS IMPLEMENTED IN THE IOWA WEATHERIZATION PROGRAM

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Contents

EXECUTIVE SUMMARY

The National Energy AudiT (NEAT) is a computer audit tool developed for the Department of Energy by Oak Ridge National Laboratory (ORNL). It is used to identify cost-effective measures to be installed through the Weatherization Assistance Program (WAP). The audit tool provides estimates of annual heating and cooling energy savings and bill savings for weatherization measures and reports a list of recommended measures based upon their cost-effectiveness. NEAT's engineering algorithms are based on those originally developed for Lawrence Berkeley Laboratory's Computerized Instrumented Residential Audit (CIRA)

Our evaluation is based upon the 1994 WAP, which used NEAT Version 4.3[1]. The evaluation assesses three aspects of NEAT performance including: 1) differences between NEAT predicted and measured savings for gas heating measures; 2) the nature of these differences, i.e., are they implementation-based or due to limitations or inaccuracies in NEAT algorithms; and 3) whether the differences are great enough to have affected the measures which NEAT recommends. We also compare NEAT estimated savings with those from the Statewide Low-Income Collaborative Evaluation (SLICE) to determine whether NEAT savings estimates provide a more accurate basis of estimating program savings than the algorithms currently used.

Our analysis compared NEAT's predicted savings with measured natural gas fuel savings. The NEAT predicted savings were not adjusted to fuel bills at the time of the audit and are therefore based solely on NEAT's engineering algorithms. Measured savings were derived from an analysis of fuel bills using the PRISM method, and adjusted for non-space heating savings. We used a comparison group composed of 549 participants from the 1995 WAP program.

Measures savings as a percentage of NEAT's predicted savings ranged from 39% (±3% at 90% confidence[2]) for the overall program to 54% (±11%) for a subset of houses with data that compared very well between the NEAT data and the tracking system. The major factor contributing to the low realization or predicted savings was the tendency for NEAT to overpredict pre-retrofit heating consumption and underpredict post-retrofit heating consumption, resulting in inflated estimates of savings. Factors related to NEAT's implementation also reduced the realization of predicted savings.

We found that measured natural gas heating savings were about 39% (±3%) of NEAT's predicted heating fuel savings for 408 treated houses. Forty two of the 408 houses matched well between tracking system data and the NEAT data for wall and attic insulated area (within 5%), furnace replacements or tuneups, and air leakage rates (within 300 CFM50 in both the pre-retrofit an post-retrofit periods). This group also excluded houses for which the default value for steady state furnace efficiency (56%) was used. We found that measured savings were 54% (±11%) of NEAT's predicted savings for this refined dataset.

[1] Version 4.3 is similar to the current version in its thermodynamic calculations for measures installed by the WAP in 1994. Personal communication with Mike Gettings of ORNL.

[2] Throughout this report we present the 90% confidence interval in parentheses.

We found a modest drop in the realization rate, from 54% (±11%) to 50% (±7), after we increased our refined dataset by 20 houses that used a default value of steady state furnace efficiency, but were otherwise consistent with the criteria used to develop the refined data.

We found a substantial drop in the realization of predicted savings, from 54% (±11%) down to 44% (±8%), after we added 51 houses with air leakage rates that differed from tracking system values by more than 300 CFM50, but were otherwise consistent with the criteria used to develop the refined data. However, the reduction in realization rate appeared to be in driven by the inclusion of houses that had very high overpredicted savings with only a moderate difference in air leakage rates relative to the other houses. This suggests that the air leakage rate was not the only factor reducing the realization rate for this group of houses, but it was unclear what other factors were causing the high predicted savings that led to the low realization rate.

We found no 'magic-bullet' explanation for the low realization rate for NEAT's predicted savings. However, for the refined dataset, we found that NEAT tended to overpredict the annual heating consumption by about 8% in the pre-retrofit period and underestimate it by about 11% in the post-retrofit period, resulting in overpredicted savings. This analysis suggests that NEAT overpredicts annual heating fuel consumption for houses with lower overall thermodynamic efficiency, and underestimates it for houses with better efficiency.

We identified two additional operational aspects of the program that would affect our findings of realization rates. These included higher levels of insulation than NEAT modelled in attic spaces and the installation of high density insulation (for which NEAT does not allocate infiltration reduction savings). If NEAT had been operated to account for these differences, its predicted annual heating consumption in the post-retrofit period would have been even lower, resulting in greater overpredictions of savings than we observed.

NEAT's high predicted savings resulted in recommendations of some measures that were not cost-effective. We could not develop estimates of what portion of the total expenditures were for non-cost-effective measures, but found that the cost-effectiveness of attic insulation and infiltration reduction measures were more sensitive to overestimates of savings than was wall insulation.

We found that the algorithms used by SLICE to predict overall program impacts were better predictors of program savings than NEAT's estimates. We found that measured savings were 113% of the SLICE estimates for the 408 houses in the treatment group, compared with a value of 39% for NEAT's predicted savings

Recommendations for Further Study

NEAT results should be compared to results from well-calibrated engineering models that accounts for as much structural detail as possible (e.g. DOE2 models) to examine why NEAT tends to overpredict annual heating consumption prior to weatherization and underpredict consumption after. Such a study would help to identify reasons for the large differences in NEAT's predicted annual heating consumption for some houses relative to others. It would also help to identify whether factors foreign to the engineering model inputs are major contributors to errors in predicted annual consumption

To further examine operational factors that could result in large errors for individual houses, the study should include a review of the data after the audit but prior to treatment, and a post-retrofit inspection. The data from the tracking system, the NEAT data, the post-audit inspection, and post-weatherization inspection should be reviewed for accuracy and consistency.

Report Organization

This report is organized in five sections: (1) an introduction which includes a brief description of NEAT's implementation in the WAP, (2) a discussion of operational issues that affect NEAT's performance, (3) a discussion of methodology, (4) results, and (5) a conclusion. Appendix A details the default NEAT data used in the WAP, and Appendices B and C detail regression analyses referenced in the results section.

1. INTRODUCTION

The National Energy AudiT (NEAT) is a computer audit tool developed for the Department of Energy by Oak Ridge National Laboratory (ORNL). It is used to identify cost-effective measures to be installed through the Weatherization Assistance Program (WAP). The audit tool provides estimates of annual heating and cooling energy savings and bill savings for weatherization measures and reports a list of recommended measures based upon their cost-effectiveness. NEAT's engineering algorithms are based on those originally developed for Lawrence Berkeley Laboratory's Computerized Instrumented Residential Audit (CIRA)

Little is known about how well NEAT predicted savings compare to observed savings in a program setting. ORNL conducted a field test of an early version of the NEAT audit on houses completed through the North Carolina WAP in 1990 (see *The North Carolina Field Test: Field Performance of the Preliminary Version of and Advanced Weatherization Audit for the Department of Energy's Weatherization Assistance Program*. 1994. T.R. Sharp. Oak Ridge National Laboratory). That study compared NEAT predicted annual energy consumption and savings with measured values for eighteen houses and found that "predicted consumption rates below 80 MBtu and savings below 40 MBtu are very close to measured values in most cases; when above these limits, predicted consumption and savings often are considerably higher than measured values" (p.103). After correcting for overstated values for the heated square footage in some houses, the study found mean predicted savings of 24.4 MBtu, compared to measured savings of 13.9, a realization rate of 57% (p. 96). The report did not discuss reasons for the high predicted savings. However the sample was small (eighteen houses) and discussions with ORNL personnel indicate that the overall results are highly sensitive to impacts from only a few of the houses[1] .

NEAT recommends measures if the predicted fuel bill savings exceed the costs over the life of the measure. If savings are in error, then this raises questions of the cost-effectiveness of measures recommended by NEAT. This study sought to answer questions of how well NEAT predicted savings compare with observed savings, and to identify whether differences may be due to NEAT algorithms or to whether they are attributable to how weatherization operators make use of the NEAT recommendations. Note that the predicted savings studied in this analysis were not adjusted to fuel bills by the auditor, and are therefore based solely on engineering relationships.

Specifically, this evaluation assesses three aspects of NEAT performance including: 1) differences between NEAT predicted and observed savings for gas heating measures; 2) the nature of these differences, i.e., are they implementation-based or due to limitations or inaccuracies in NEAT algorithms; and 3) whether the differences are great enough to have affected the measures which NEAT recommends. We also compare NEAT estimated savings with those from the Statewide Low-Income Collaborative Evaluation (SLICE) to determine whether NEAT savings estimates provide a more accurate basis of estimating program savings than the current SLICE algorithms[2].

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[1] Comments from Mike Gettings, ORNL, June 13, 1996.

[2] SLICE savings are based upon billing-adjusted engineering algorithms.

Description of NEAT's Use in the Iowa WAP

The Iowa WAP began using NEAT in 1993. The WAP utilizes services of eighteen weatherization agencies and one local government to treat about 4,000 houses annually, at a cost of approximately $10,000,000. Since 1992, the program has been implemented as a joint effort between the Iowa Division of Community Action Agencies (DCAA), the major investor-owned utilities in Iowa, and the state's nineteen weatherization operators. The measures installed through the joint program include attic and wall/kneewall insulation, floor and foundation insulation, and air infiltration reduction, low-flow showerheads, faucet aerators, pipe wrap, compact florescent and halogen lighting, and waterbed mattress pads. NEAT makes recommendations for furnace replacement, insulation, and air infiltration reduction measures. These measures comprise over 60% of the total program expenditures, with the remainder allocated for water heater and lighting measures, health and safety measures, repairs, and program support.

Currently the WAP uses NEAT Version 5.2, however most of the houses completed in the 1994 study period were completed using NEAT Version 4.3. Although NEAT Version 5.2 has some additional features and an enhanced user interface, there are no substantive differences between the results produced by the two different versions for the study houses[3].

Each of the nineteen weatherization operators are assigned one of six different NEAT weather data locations. Figure 1.1 shows the weather data locations and the agencies that are assigned to them.

The DCAA has prepared an instruction manual, the NEAT Users Manual for Iowa, to augment the NEAT Energy Audit Manual that accompanies the software. This manuals clarifies procedures to be used across the Iowa WAP program. The manual provides operating instructions, and elaborates on specific data items in the data input screens and report screens.

In addition, the manual lists default data that is to be used by the weatherization operators. In 1994, the Iowa WAP used statewide average costs for materials and labor rather than agency-specific costs. These data are entered as one of the setup files used by NEAT. Additional default information that is contained in NEAT setup files include fuel costs and fuel escalation rates, measure eligibility, and miscellaneous default values. Appendix A provides snapshots of the NEAT setup files that were used for the 1994 audits.

[3] Personal communication with Mike Gettings, Oak Ridge National Laboratories.

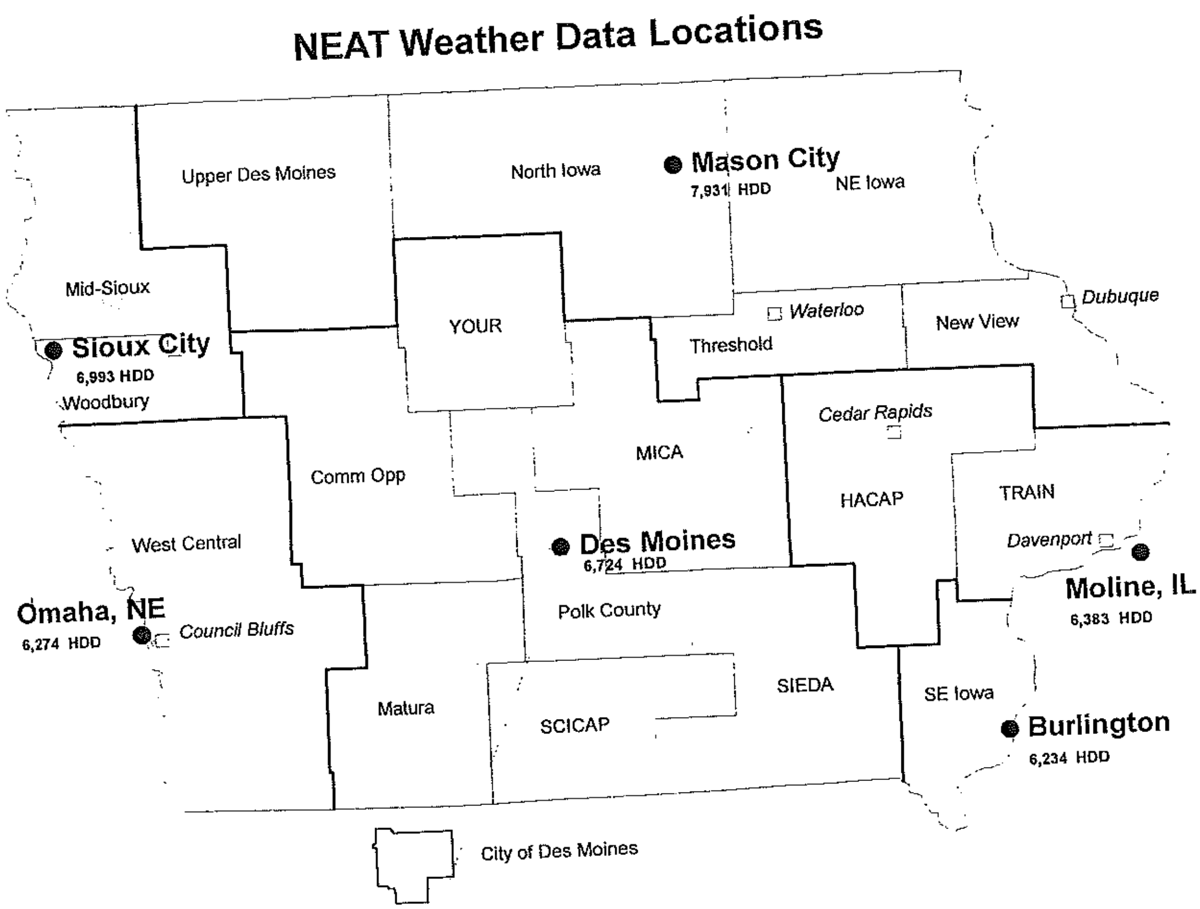

Figure 1.1 NEAT weather data regions used in the Iowa WAP

2. DISCUSSION OF OPERATIONAL ISSUES THAT AFFECT NEAT'S PERFORMANCE

In this section we discuss three aspects of the NEAT's implementation that could affect NEAT's ability to predict savings: (1) comparability of recommended and installed measures, (2) use of estimated air leakage rates, and (3) use of default values for steady state furnace efficiencies. The impacts of these factors are examined later in this report.

Comparison of Recommended and Installed Measures

Our NEAT data included 1,092 houses which could be matched on fuel and end-use in the tracking system. 861 of these houses heated with natural gas. Figure 2.1 shows the breakdown of NEAT predicted savings for recommended measures. Wall and attic insulation account for about 50% of predicted savings. Infiltration reduction measures contribute another 25%. Heating system savings from furnace replacements and furnace tuneups account for an additional 14% and 9%, respectively. Bandjoist insulation, floor insulation, and duct insulation make up about 3% of total predicted savings.

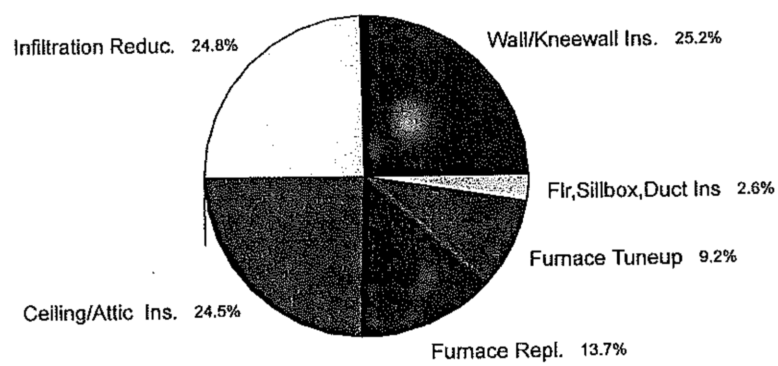

Figure 2.1 Breakdown of NEAT predicted savings by measure.

In some cases measures that have energy impacts did not have NEAT predicted savings. In the case of infiltration reduction measures, the auditor can specify whether they should be included in NEAT's calculations of cost-effectiveness; NEAT predicts savings only if they are included. According to DCAA personnel, the agencies currently operate the audit to predict infiltration reduction savings, however this was not done consistently during the early periods of NEAT usage in 1994. We found that 12% of the houses had air infiltration measures with no predicted savings. A large proportion of these (65%) were audited by a single agency.

Another reason for measures lacking predicted savings was incorrect measure identification in the NEAT data. As a consequence NEAT does not recognize the measure and does not estimate savings for it. This occurred most frequently for furnace tuneup measures (about 15%, all from a single agency) and rarely or not at all for ceiling and wall insulation and furnace replacements.

Table 1.1 Installation Rates and Costs of Recommended and Installed Measures

Measure Type	NEAT Predicted Savings?	Count of Houses with Recommended Measure	NEAT Estimated Cost	Count of Houses with Installed Measure	SLICE Actual Cost
Attic (Ceiling) Insulation	No	1	300	1	498.00
	Yes	735	305,940	731	319,445
	Total	736	306,240	732	319,943
	Average Cost/House		416		437
Wall/ Kneewall Insulation	No	3	2,313	3	3,149
	Yes	534	350,319	557	386,804
	Total	537	352,632	560	389,593
	Average Cost/House		657		696
Furnace Replacement	No	0	0	0	0
	Yes	201	346,923	291	558,253
	Total	201	345,923	291	558,253
	Average Cost/House		1,721		1,918
Furnace Tuneup	No	75	6,288	74	5,981
	Yes	534	28,200	426	40,417
	Total	609	34,488	500	46,398
	Average Cost/House		57		93

Table 1.1 compares the installation rates and installed costs of the major insulation and heating system measures recommended by NEAT with those for which we have cost information in the materials tracking system database.

We found that the installation rates for attic and wall insulation were similar between the NEAT data and the tracking system. However, the tracking system showed ninety houses received furnace replacements that were not recommended by NEAT (201 recommended, 291 installed); NEAT recommended furnace tune-ups rather than furnace replacements for forty-eight of these. Overall NEAT recommended 108 furnace tuneups that were not identified in the tracking system (534 recommended, 426 installed).

The actual costs of installed measures tended to exceed NEAT estimated costs. We found the greatest difference for furnace replacements, where actual costs per installed furnace were about $200 more than estimated. The mean household installed cost of measures was $21 greater than estimated for attic insulation, $39 greater for wall/kneewall insulation and $36 for furnace tuneups.

Comparison of Attic and Wall Insulated Area and Quantity
Table 1.1 provides counts of houses that received a measure of a certain type. We could not compare specific measures recommended by NEAT (e.g. R-30 attic insulation in one ceiling space, and R-38 in another), since the tracking system data does not include data for the installation rates of specific materials.

We were able to get a better idea of how many of the installations were completed for wall and ceiling insulation by comparing the total insulated area (the area insulated is tracked in MAT and in the material list portion of the NEAT report). About 99% of wall insulation measures and 98.5% of ceiling insulation measures have a value for area insulated in the tracking system.

The total area insulated compared within 5% between NEAT and the tracking system for about 64% of houses receiving wall insulation and 67% of houses receiving attic insulation. Increasing the error band to 10% increased the number of houses with wall insulation to about 69% and about 70% for houses receiving attic insulation.

In houses where the data may have matched on insulated area, we found that in many cases the attic insulation was installed more intensively than was modelled by NEAT (which recommends no more than R-38 for attic insulation).

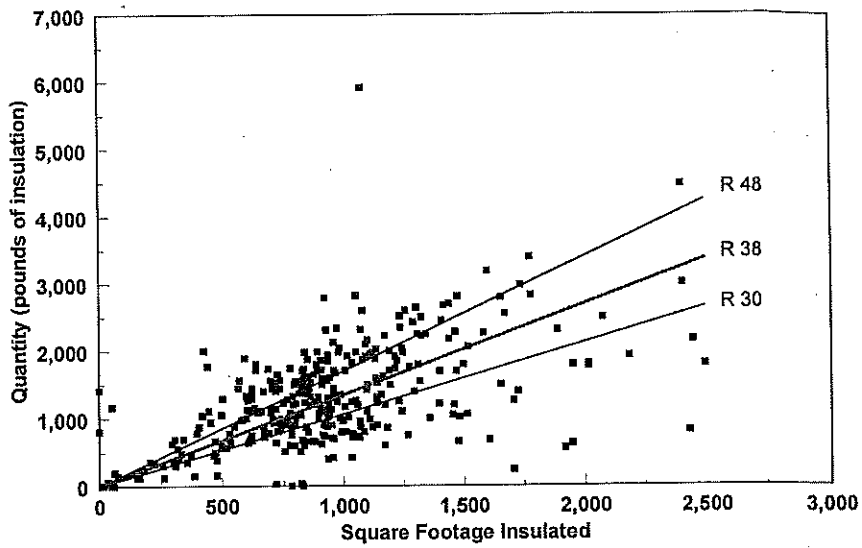

Figure 2.2 Density of installed attic insulation

By examining the quantity (pounds) of insulation installed and the square footage insulated, we estimated the R value of the installed insulation. We found that the R value of installed insulation exceeded R 38 in many houses (see Figure 2.2). Conversations with DCAA personnel confirm that some agencies were using outdated 'bag charts' (the reference chart that tells the installer the proper installation density), which resulted in over-insulation of some houses.

A related situation exists for wall insulation. The weatherization program installs high density wall insulation whenever possible (see Figure 2.3). High density wall insulation has greater insulating value than typical blown wall insulation owing to more complete filling of the insulated cavity and because of it ability to reduce infiltration. NEAT models wall insulation with assumptions of complete cavity coverage (consistent with high density insulation) but does not account for infiltration reduction that may be due to high-density wall

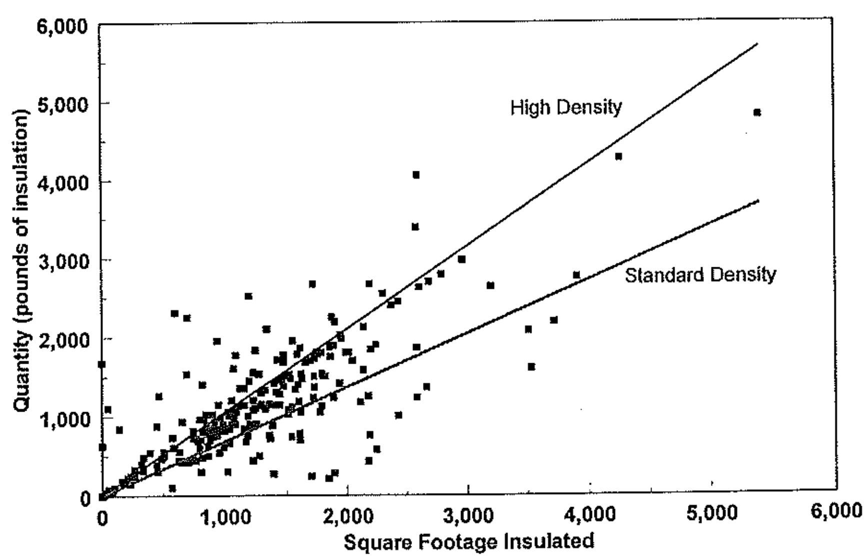

Figure 2.3 Density of installed wall insulation

insulation[1].

Comparison of NEAT Data and Tracking System Values of Air Leakage Rate

Another variable with a potentially large influence savings on estimates is the air leakage rate. Figure 2.4 shows a plot of the NEAT data for pre-retrofit CFM50 against the values entered in the tracking system. The line represents a 1 to 1 correspondence. Although many values are the same in both data sets, there is considerable error for others, and NEAT reported values tend to be higher than BWR values. The cases where the BWR and NEAT values are identical suggests that in some cases the auditor went back and re-entered actual blower door readings into NEAT. Twenty-three percent of the pre-retrofit blower door readings differed between NEAT data and the tracking system by more than 300 CFM50. The mean and median difference was 94 CFM50 and 0 CFM50, respectively. The difference ranged from a low of -6,385 CFM50 to a high value of 2,310 CFM50.

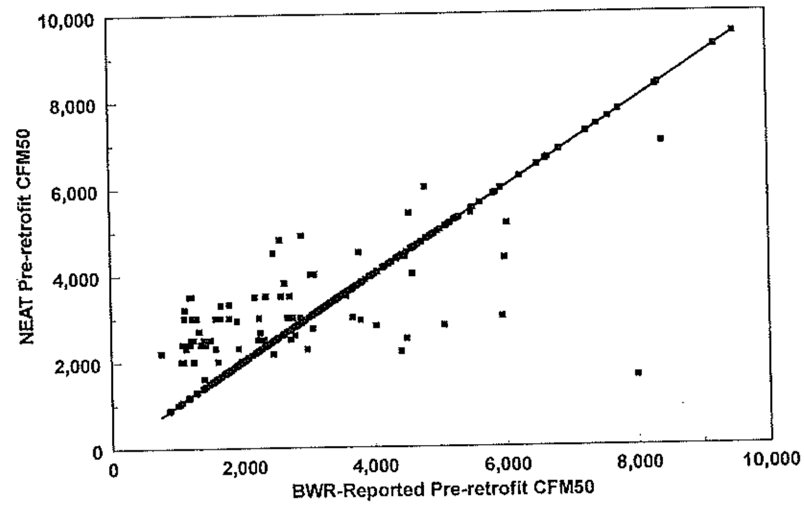

Figure 2.4 NEAT data for pre-retrofit CFM50 vs. the tracking system values

[1] I discussed this with Mike Gettings, of ORNL. They considered accounting for infiltration reduction resulting from high density wall insulation, but found that those savings tend to occur in specific circumstances where there were unexposed or otherwise hidden areas that could not otherwise be sealed. Consequently they did not feel that a general adjustment factor was appropriate.

The difference between measured values of the post-retrofit air leakage rate and NEAT values are likelwise a potential source of error, and could become as source of bias if they are consistently under or overestimated. Figure 2.5 shows how the NEAT values for post-retrofit CFM50 compared to the tracking system values.

The values of post-treatment blower door readings may be estimated by NEAT (a default value of 2500 cubic feet per minute is used) or measured post-air sealing values may be entered; the study data showed 29% of houses were entered using the default value.

Fifty-five percent of the post-retrofit blower door readings differed between NEAT data and the tracking system by more than 300 CFM50. The mean and median difference was -43 CFM50 and 0 CFM50, respectively. The difference ranged from a low of -6,405 CFM50 to a high value of 4,165 CFM50.

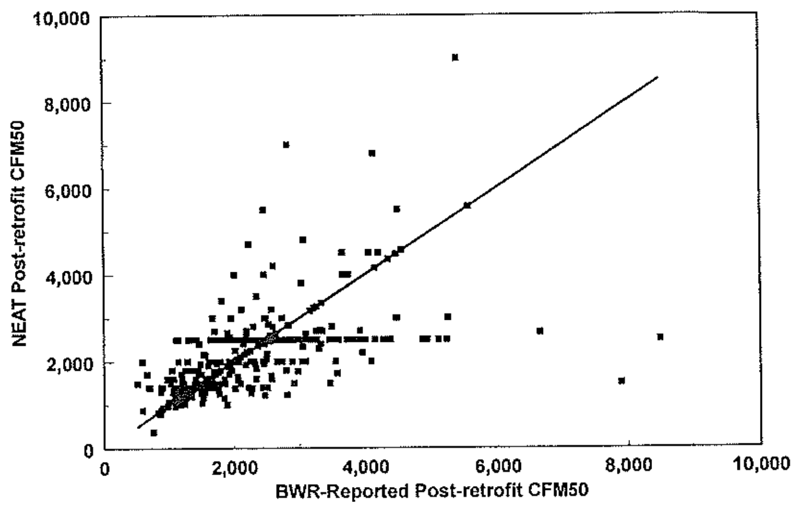

Figure 2.5 Comparison of NEAT and tracking system values for post-retrofit CFM50

Review of the Values of Steady State Furnace Efficiencies in the NEAT Data

Another key input variable is furnace efficiency -- an error in specifying the pre-retrofit furnace efficiency often has large impacts on predicted savings. For example, understating the furnace efficiency at 65% in a house with an actual furnace efficiency of 75% overpredicts annual fuel consumption by approximately 15%. A 15% error is substantial, given that the mean annual savings from our PRISM analysis is approximately 27% of the pre-retrofit annual heating consumption. Post-retrofit efficiencies are often better known (because furnaces are replaced or tuned-up).

Figure 2.6 shows a plot of steady state efficiency against the calculated efficiency (output capacity divided by input energy) for the large study group. The line represents a 1 to 1 relationship for the ratio of output capacity and input rating. Twenty percent of all houses used the default value of 56% (not all of these are apparent in the figure since they plotted on top of each other).

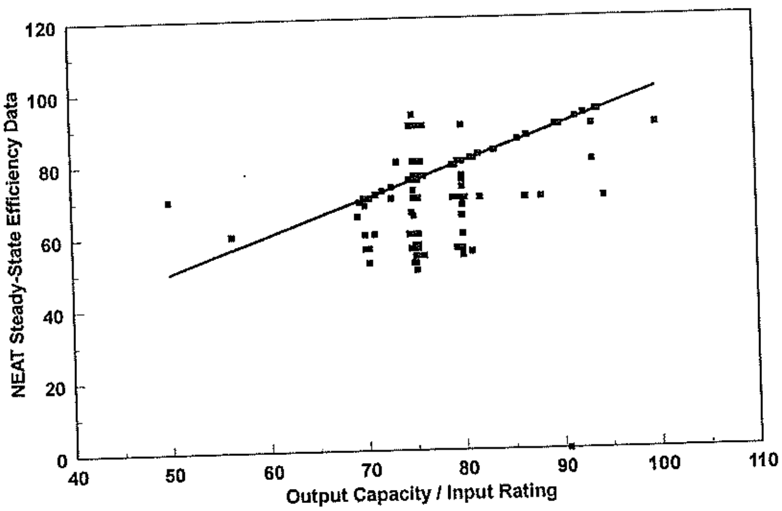

Figure 2.6 NEAT data for pre-retrofit furnace efficiency vs.calculated

3. METHODOLOGY

A major objective of this evaluation is to determine how well NEAT's predicted savings compare with measured savings. If differences exist, then they may be due to many factors which tend to fall into three different categories: (1) differences between recommended and installed measures, (2) bias in the estimated or default inputs used by the weatherization program; and (3) bias due to NEAT's algorithms.

Our initial comparison of NEAT predicted and measured savings was comprised of a sample of 408 houses with NEAT data and billing histories (the development of this data is discussed later in this section). This provided an overall assessment of predicted and observed savings for the weatherization program. We used subsets of our overall group to assess error which may arise from NEAT's algorithms and from bias due to the use of estimated or default inputs.

Unlike operational aspects of the program which could affect the predicted savings for some houses but not others (1 and 2 above), bias in NEAT's algorithms tend to be reflected across all predictions of savings (unless NEAT's algorithms are biased for specific measures, a factor which we could not determine in this analysis). We determined the degree of "baseline" error that is attributable to NEAT's algorithms with a refined dataset developed by limiting our sample to houses that are well-matched for attic and wall insulated area (within 5%), furnace replacements and tuneups, and air leakage rates (within 300 CFM50), and eliminated houses which used the default value of 56% for steady state furnace efficiency. We assume that any error that remains is random, and will introduce greater uncertainty in the results but will not bias them.

Error due to the use of estimated or default data could arise from many sources, but we limited our examination to two potentially significant sources, default values for steady state furnace efficiencies and estimated air leakage rates. The auditors are not required to test for furnace efficiency, although some do. Consequently we cannot be certain whether the steady state efficiency entered into NEAT is an estimated or test reading. However, the agencies did use a default value of 56% in all situations that required furnace replacements. This value is low, causing NEAT to recommend furnace replacements in nearly all instances where an unsafe furnace is found.

To examine the degree to which the use of the default steady state efficiency affected predicted savings, we developed a realization rate for a dataset similar to the refined dataset in all respects except for inclusion of houses where the default value for furnace efficiency was used. Differences in the realization rates between these two datasets reflect the impacts of using the default value of steady state furnace efficiency.

NEAT calculates infiltration reduction based upon the values entered for pre-retrofit and post-retrofit air leakage rates. The procedures in the DCAA *NEAT User's Manual* call for the actual values of the pre-retrofit readings and estimated values of the post-retrofit readings be entered. NEAT uses a default value of 2500 CFM50 for the post-retrofit blower door reading if it is not entered. We found that 75.3% of houses matched exactly between the tracking system and NEAT values for the pre-retrofit CFM50, and 81.6% matched within 300 CFM50. For the post-retrofit readings, we found that 16.3% matched exactly, and 49.0% matched within 300 CFM50.

Our approach to examining the impacts of the use of estimated air leakage rates on predicted savings is similar to the one used for examining the impacts of using default furnace efficiencies, i.e. we compared the realization rate of our refined data with the rate from a dataset that was consistent with our refined dataset in all respects except without the restrictions on close agreement between the tracking system and NEAT values for air leakage rate.

The remainder of this section discusses the approach we used to determine the measured values for savings and the development of our study groups.

Approach To Determining Measured Savings

Our primary approach compares NEAT predicted savings with net savings determined from an analysis of actual fuel usage. We used a standard pre/post with comparison group analysis to arrive at whole house changes to usage. As a secondary approach we used regression analysis to confirm our whole house savings results and to examine the how well NEAT predicted savings compared to observed savings for specific measures.

We determined net savings using the PRInceton Scorekeeping Method, commonly known as PRISM. PRISM provides estimates of whole-house energy usage from fuel consumption records. Using piece-wise linear regression methods, PRISM separates the part of energy usage that fluctuates with changes in ambient temperature from constant (baseload) energy usage. The result is a model of fuel usage based upon known fuel consumption and temperatures during the study period. The model is applied to long-term normal temperatures to give the normalized annual consumption (NAC), which is the primary measure of energy usage reported by PRISM. Fuel savings for an individual house are calculated as the difference between the NAC prior to and after weatherization. When calculated for a large group of houses, the mean (or median) of the savings provides a well-defined estimate of change in energy usage for those houses.

In addition to measuring fuel consumption (NAC), PRISM provides three indicators of energy usage. These are the normalized annual heating consumption (NAHC), the baseload energy consumption, and the balance point of the house. The NAHC is the part of annual consumption that fluctuates with changes in temperature. The baseload estimate is usage that stays constant month-to-month throughout the year. The balance point is an estimate of the temperature at which heating fuel is required for a house.

NAC is the primary measure of fuel usage reported by PRISM; the others are generally used as indicators of the reliability of the PRISM models rather than as actual measures of energy consumption. The reason is that energy usage varies seasonally for many reasons, including seasonal changes in solar azimuth, cloudiness, and shading from trees, all of which affect the solar gain for a house. In addition, groundwater temperature fluctuations affect water heater energy usage. PRISM cannot separate seasonal fluctuations of these and other factors from seasonal fluctuations in ambient temperature. These factors tend to have noticeable influence on the NAHC, baseload and balance point results, but have relatively little impact on the estimates of NAC.

We established ten weather zones in Iowa for our PRISM analyses, as shown in Figure 3.1. All houses within a weather zone were analyzed using daily average temperature date from a single weather station. These weather zones were established for the SLICE evaluation, and represent both the climate variation within the state and the geographic variation in program activity. For example, Polk and Warren counties constitute a single weather zone, because so many households are treated in

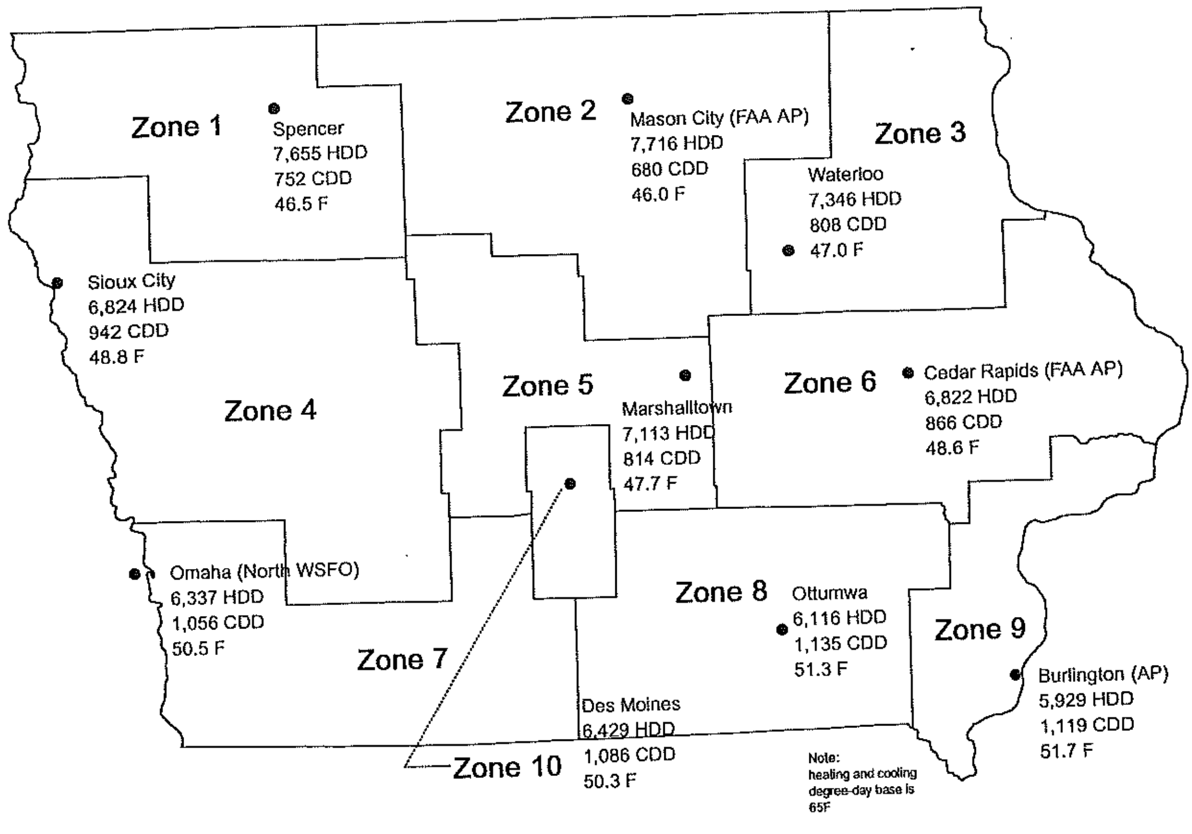

Figure 3.1 Weather zones used in the billing analysis

the Des Moines metropolitan area each year. Although these weather data locations do not match the NEAT weather zones exactly (see Figure 1.1), the heating degree days correspond reasonably well with the values in the NEAT regions. The PRISM weather regions provide a finer gradation in weather and program delivery across the state and provide a superior basis for determining observed energy savings.

Comparison Group Adjustment

We used a comparison group to account for non-program impacts on energy usage. Net (program-induced) savings are calculated as the difference between the treatment group energy savings and the comparison group energy savings.

Our comparison group consisted of houses treated by the WAP in 1995. By selecting clients from the 1995 WAP we are able to ensure reasonable comparability to the 1994 treatment group. Billing histories for 1995 WAP clients were collected for the same time frame as for the treatment group (1993 through 1995). For each house in the comparison group we defined a pseudo-treatment date in 1994 which was one year prior to actual treatment in 1995. Billing data prior to the pseudo-treatment date constituted the pre-treatment period, fuel use after that date was post-treatment usage. The predicted savings for the comparison group houses total zero during the pseudo pre/post treatment periods.

Adjustment for Water Heater Measures and Waterbed Mattress Pad Savings

NEAT predicts savings for space heating measures, but the PRISM results include impacts for all measures that affect natural gas usage, including water heater measures and, indirectly, waterbed mattress pads which reduce heat provided to the house through the waterbed heaters. Before comparing PRISM results with NEAT estimated savings, we had to account for savings from these measures.

For the PRISM-based analysis, we adjusted the PRISM-derived estimates of savings with the SLICE project estimates[1]. Although this correction adds a source of error, it is not significant. Average SLICE-predicted water heater measure and waterbed mattress pad savings impacts constitute a small percentage of the average NEAT predicted savings, about 3.8% and -0.2%, respectively. If the SLICE estimates are off by a small amount it will not significantly affect the realization of savings for NEAT estimates.

For the regression models we specified distinct variables for the SLICE estimates of water heater measure savings and waterbed mattress pad savings.

Development of the Study Groups

Our data consisted of 861 houses which heated with natural gas and for which we had NEAT data files and billing histories. We used several screens to eliminate houses with poor PRISM diagnostics. We removed houses with greater than 10% uncertainty in NAC at 90% confidence, a coefficient of variation of NAC greater than 10%, fewer than eight observations in both the pre-retrofit or post-retrofit periods, and less than approximately 2000 degree days in both the pre-retrofit and post-retrofit periods. We were left with 408 of the original 861 houses; this data became our program-level dataset.

We selected a subset of our overall group to assess error which may arise from NEAT's algorithms. We limited this sample to houses that are well-matched on recommended and installed measures, and eliminated houses which used default values of furnace efficiency or where the air leakage rates are not reasonably close to the tracking system values. The tracking system provided the data on installed wall and attic insulation and furnace replacements and tuneups. We compared the total insulated area between the NEAT recommended wall and attic insulation and the tracking system to identify houses well-matched for these measures. We found that the total insulated area compared within 5% between NEAT and the tracking system for about 64% of houses receiving wall insulation and 67% of houses receiving attic insulation. Increasing the error band to 10% increased the number of houses with wall insulation to only about 69% and about 70% for houses receiving attic insulation. We selected well-matched houses based upon the 5% level of agreement between the two data sets.

We eliminated houses that did not match on recommended and installed furnace measures. Nearly 70% of houses matched up on furnace replacement or tuneups. Most of the difference was accounted for by furnaces being replaced instead of the recommended furnace tune-ups. We also eliminated houses that used the default value of [illegible]6% for the furnace efficiency.

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[1] The SLICE algorithms are based upon billing analysis adjusted engineering estimates of a sample of houses treated by the program.

We had no suitable measure of quantity for infiltration reduction measures, but since NEAT uses the pre-retrofit and post-retrofit blower door readings directly in its calculations, we could compare these values to the tracking system values. We selected all houses where both the pre-retrofit and post-retrofit blower door readings in the NEAT data were within 300 CFM50 of the values in the tracking system. We excluded houses where the auditor had "turned off" predicted savings for infiltration reduction measures.

We were left with 42 houses in this group, which we will refer to as the refined dataset.

For examining the effects of using the default value for furnace efficiency, we developed a dataset similar to the refined set in all respects except for inclusion of houses where the default value for furnace efficiency was used. This added an additional 20 houses to the 42 houses in the refined dataset.

We used a similar approach for assessing the error from using estimated air leakage rates. Our study group was similar to our refined data set, but without restrictions on how well the air leakage rates compared between the BWR and NEAT data. This dataset included 93 houses, including the 42 that were included in refined dataset.

Study Sample Characteristics

Table 3.1 presents summary information for the study samples and the 1994 and 1995 program populations. The study groups compare well with the overall population averages. The major notable exceptions are the relatively lower average pre- and post-retrofit blower door readings for the refined dataset; the average pre-retrofit reading is 73% of the population average and the post-retrofit reading is 80% of the population average. One other notable difference is the greater percentage of furnace replacements the study group that included houses with the default furnace efficiencies, but this is a necessary outcome of selection criteria.

Table 3.1 Summary Statistics for Population and Refined Data Study Samples

	Population 1994	Population 1995	Comparison Group	All Treated Houses	Refined Data Treated Houses	Refined Dataset with Defalut Furnace Eff.	Refined Dataset with Poorly Estimated Air Leakage Rates
n	4,058	3,693	549	408	42	62	93
Housing Type (%)							
Single-Family Home	88.7	87.9	90.5	100	100	100	100
Mobile Home	5.3	5.4	4.4	0	0	0	0
Apartment	1.9	3.2	5.0	0	0	0	0
Unknown/Other	4.2	3.5	0.1	0	0	0	0
House Heated Volume (Average ft^3)	13,996	14562	14,014	15,163	13,988	14,259	14,520
Heating System Type (%)							
Nat. Gas	75.0	76.1	100.0	100.0	100.00	100.00	100.00
Propane	15.4	13.7	0	0	0	0	0
Fuel Oil	5.1	4.2	0	0	0	0	0
Electricity	2.9	4.1	0	0	0	0	0
Other	1.6	1.8	0	0	0	0	0
Blower Door Readings (Average CFM50)							
Pre	3,469	3,523	3,460	3,313	2,525	2,837	3,040
Post	2,242	2,299	2,267	2,231	1,792	1,936	2,123
Installation Rates (%)							
Wall Insulation	52.4	56.7	55.0	62.2	47.6	54.8	45.2
Ceiling Insulation	71.2	71.7	72.0	83.1	71.4	80.6	66.7
Heating System Replacement	26.3	27.9	31.0	37.0	21.4	46.8	18.3
Number Household Members (Average)	2.9	2.8	2.6	2.6	2.5	2.4	2.6

4. RESULTS

This section provides results of the comparisons between NEAT predicted savings and measured savings. First we present a discussion of the PRISM analysis results. This is followed by a discussion of our investigation into measure-level realization rates. The final section presents an analysis of how overestimates of NEAT's predicted savings may have affected the cost-effectiveness of installed measures.

PRISM Results

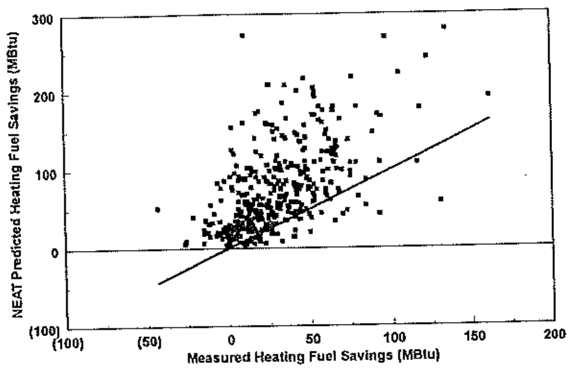

Figure 4.1 NEAT Predicted Savings vs. Observed Heating Measure Savings for the Program Group

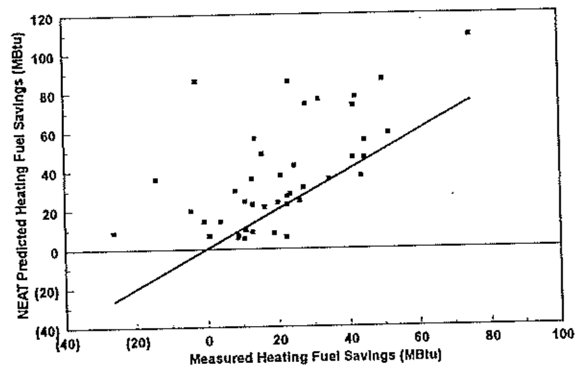

Figure 4.2 NEAT Predicted Savings vs. Observed Heating Measure Savings for the Refined Dataset

Figures 4.1 and 4.2 show predicted savings plotted against observed savings for the program and refined datasets, respectively[1]. The line shows a 1 to 1 relationship between predicted and observed savings in these charts. Both groups show that predicted savings tend to exceed observed savings. An evaluation of the energy savings for clients treated by the Iowa weatherization program in 1994 found that natural gas heating and water heating measure savings are 27.1% (±1.6%) of pre-treatment natural gas heating fuel usage (see *An Evaluation of the 1995 Iowa Low-Income Collaborative Weatherization Program*, Wisconsin Energy Conservation Corporation.1996. p 3-2). We found that NEAT's predicted percent savings of heating fuel savings alone are considerably greater than this value. For the program study group, we found that on average NEAT predicted savings of 48.3% of its predicted annual heating consumption, and 67.8% of the PRISM-derived Normalized Annual Heating Consumption[2] (NAHC). The predicted percent savings for the refined dataset were closer to the evaluation levels but still high: 35.5% of NEAT's predicted annual heating consumption and 41.3%

[1] Observed savings are adjusted for savings from water heaters and waterbed mattress pads.

[2] The PRISM normalized annual heating consumption, or NAHC, is not as robust of an estimator as the normalized annual consumption (NAC) is, however it provides a measure of heating fuel consumption with which to compare with the NEAT-predicted values of annual heating consumption. The NAHC may introduce a small bias due to the tendency to include seasonality in water heater fuel consumption for houses with natural gas water heaters, but this should not be a significant factor in this analysis.

of the NAHC.

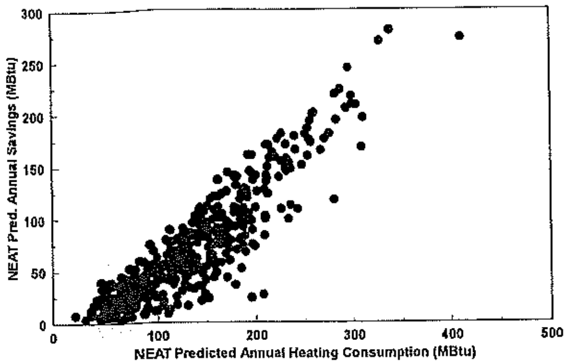

Figure 4.3 NEAT predicted savings vs. NEAT predicted pre-retrofit annual heating consumption, program dataset

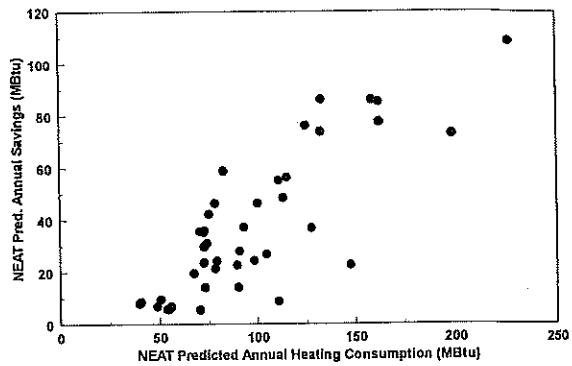

Figure 4.4 NEAT predicted savings vs. NEAT predicted pre-retrofit annual heating consumption, refined dataset

Figures 4.3 and 4.4 show predicted savings against NEAT's predicted annual consumption for the program and refined datasets, respectively.

The overall results of the PRISM analysis are shown in Tables 4.1 and 4.2. Table 4.1 shows the results of our comparison of NEAT predicted savings and measured savings for the program group (408 houses). Table 2 provides a similar comparison for the refined dataset.

We found that measured savings are about 39% of NEAT's predicted savings for the overall program, and 54% for houses in our refined dataset. The program group had 11.8% greater fuel consumption in the pre-retrofit period than the refined dataset and 5.7% greater consumption than the comparison group. The mean adjustment for water heater savings and waterbed mattress pads reduced savings by 30 therms per year in the program group and 19 therms per year in the refined dataset. This adjustment is small relative to predicted savings and predicted annual heating consumption; it is less then 5% of NEAT-predicted savings and about 2% of NEAT predicted pre-retrofit consumption for both of program group and the refined dataset. The comparison group showed a small amount of reduction in consumption, about 1% of NEAT-predicted savings in the program group and 1.8% of NEAT-predicted savings in the refined dataset.

We examined the refined dataset using regression analysis and found a realization rate of 49%, which is reasonably close to the value of 54% from the PRISM analysis (see Appendix B).

Table 4.1 PRISM Analysis of NEAT Recommended Measure Savings -- Program Study Group

	n		Whole House Impacts: Pre-retrofit NAC (therms)	Whole House Impacts: NAC Savings (therms)	Whole House Impacts with NAC Savings Reduced by the SLICE Estimated Water Heater and Waterbed Mattress Pad Savings: Adjusted NAC Savings (therms)	NEAT Predicted Savings (therms)	Realization of Predicted Savings (%)
treatment	408	mean	1,307 (36)	323 (22)	293 (22)		
		median	1,223 (42)	278 (29)	252 (28)		
comparison	549	mean	1,236 (31)	7 (11)	7 (11)		
		median	1,145 (38)	8 (9)	8 (9)		
net savings		mean		314 (24)	286 (24)	725 (43)	39% (3%)
		median		264 (31)	244 (24)	586 (57)	41% (4%)

NOTE: 90% confidence interval in parentheses

Table 4.2 PRISM Analysis of NEAT Recommended Measure Savings -- Refined dataset

	n		Whole House Impacts: Pre-retrofit-NAC (therms)	Whole House Impacts: NAC Savings (therms)	Whole House Impacts with NAC Savings Reduced by the SLICE Estimated Water Heater and Waterbed Mattress Pad Savings: Adjusted NAC Savings (therms)	NEAT Predicted Savings (therms)	Realization of Predicted Savings (%)
treatment	42	mean	1,169 (94)	229 (50)	210 (48)		
		median	1,123 (83)	226 (51)	206 (54)		
comparison	549	mean	1,236 (31)	7 (11)	7 (11)		
		median	1,145 (38)	8 (9)	8 (9)		
net savings		mean		223 (52)	203 (50)	373 (69)	54 % (11%)
		median		218 (44)	198 (54)	304 (104)	65 % (19%)

NOTE: 90% confidence interval in parentheses

Table 4.3 shows results for the refined dataset expanded to include houses specified using the default steady state furnace efficiency (56%). The mean realization rate dropped slightly, from 54% to 50%. This relatively small change from our refined dataset suggests that use of the default value was a reasonable approximation for the houses in which it was specified and did not contribute a large amount of error to NEAT's predicted savings.

Table 4.3 PRISM Analysis of NEAT Recommended Measure Savings--Refined Dataset Expanded to Include Houses Specified Using The Default Steady State Furnace Efficiency (56%)

			Whole House Impacts		Whole House Impacts with NAC Savings Reduced by the SLICE Estimated Water Heater and Waterbed Mattress Pad Savings		
	n		Pre-retrofit NAC (therms)	NAC Savings (therms)	Adjusted NAC Savings (therms)	NEAT Predicted Savings (therms)	Realization of Predicted Savings (%)
treatment	62	mean	1,232 (81)	314 (50)	293 (49)		
		median	1,185 (77)	261 (73)	250 (68)		
comparison	549	mean	1,236 (31)	7 (11)	7 (11)		
		median	1,145 (38)	8 (9)	8 (9)		
net savings		mean		307 (53)	286 (52)	570 (95)	50% (7%)
		median		253 (80)	242 (78)	426 (115)	57% (14%)

NOTE: 90% confidence interval in parentheses

Table 4.4 shows results for refined dataset expanded to include houses for which the air leakage rates did not match well between NEAT and the tracking system. The realization rate dropped considerably, from 54% in the refined dataset alone to 44%.

Table 4.4 PRISM Analysis of NEAT Recommended Measure Savings--Refined Dataset Expanded To Include Houses For Which The NEAT Blower Door Readings And The Tracking System Are Not Well-Matched

		Whole House Impacts			Whole House Impacts with NAC Savings Reduced by the SLICE Estimated Water Heater and Waterbed Mattress Pad Savings		
	n		Pre-retrofit-NAC (therms)	NAC Savings (therms)	Adjusted NAC Savings (therms)	NEAT Predicted Savings (therms)	Realization of Predicted Savings (%)
treatment	93	mean	1,203 (85)	249 (50)	224 (49)		
		median	1,116 (72)	220 (51)	190 (49)		
comparison	549	mean	1,236 (31)	7 (11)	7 (11)		
		median	1,145 (38)	8 (9)	8 (9)		
net savings		mean		242 (50)	217 (50)	496 (81)	44% (8%)
		median		212 (59)	182 (56)	356 (65)	50% (15%)

NOTE: 90% confidence interval in parentheses

When we compared the air leakage rates entered in NEAT data with those in the tracking system we found some large differences, however the mean value for groups were close to zero (we discuss this in Section 2 of this report). This suggests that the differences in the values for air leakage rate between measured and NEAT data would affect some houses to a great degree, but would have little impact on an overall realization rate. We expected to see closer agreement between the 54% realization rate of the refined dataset and this set. Consequently, we examined the data to determine whether large differences between measured air leakage rates and NEAT data were in fact the reason behind the relatively lower realization rate in this group.

We found that the houses with the greatest differences in air leakage rates did not appear to be the ones driving the realization rate downward. Figures 4.5 and 4.6 show bubble plots of the predicted savings as a function of measured savings. The larger the bubble, the larger the absolute difference between the NEAT data and measured air leakage rate. The bubbles are weighted on the difference in pre-retrofit values of air leakage rate in Figure 4.5 and post-retrofit values in Figure 4.6. The line represents a 1 to 1 relationship for measured savings.

Both figures show that predicted savings are relatively close to measured savings in houses with large differences between NEAT data and the measured leakage rate. In fact, the houses that were driving the realization rate downward were houses which were exact matchedes for the pre-retrofit air leakage rate, and showed only moderate differences between NEAT data and measured values for the post-retrofit air leakage rate. We cannot conclude that large differences between the NEAT data and measured air leakage rates are the cause for the relatively low realization rate in this group.

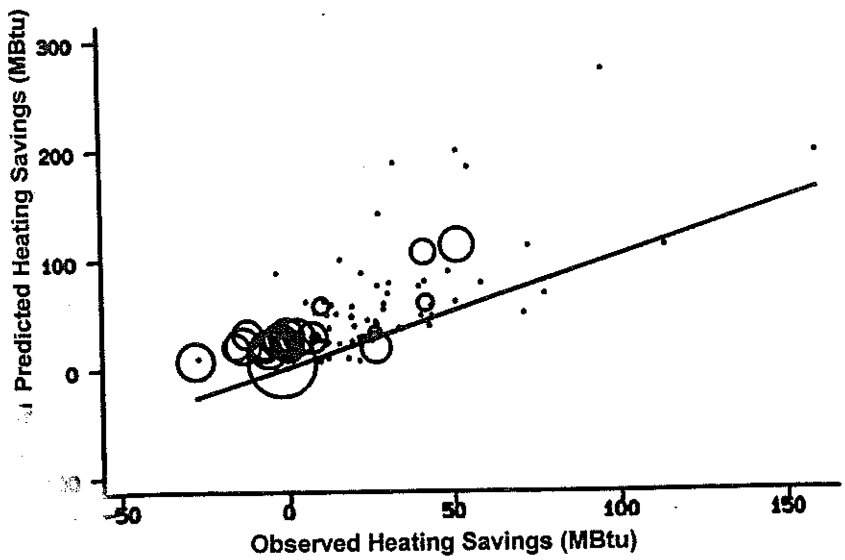

Figure 4.5 NEAT predicted heating savings weighted by the absolute differences between the tracking system and NEAT values of pre-retrofit air leakage rates

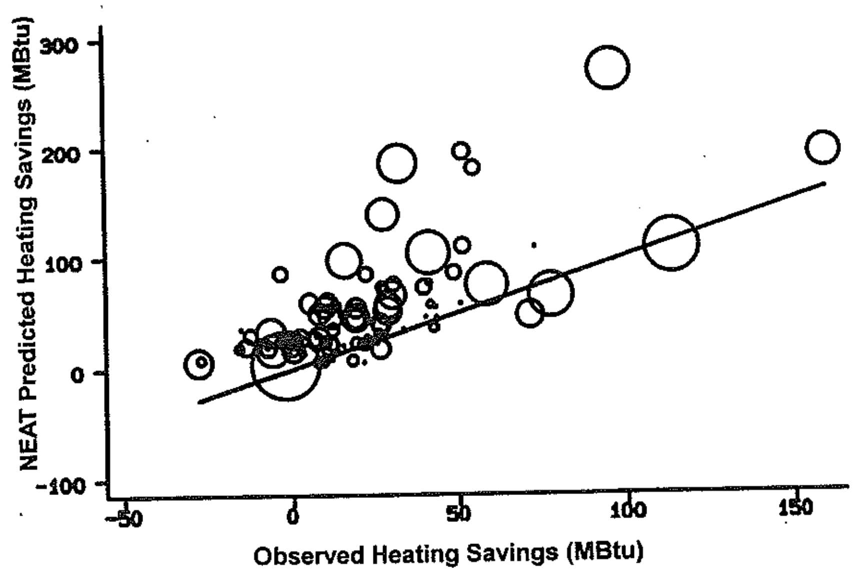

Figure 4.6 NEAT predicted heating savings weighted by the absolute differences between the tracking system and NEAT values of post-retrofit air leakage rates

Analysis of Factors Contributing to Low Realization Rates

Although we could not do an in-depth engineering analysis of reasons behind NEAT's overpredicted savings, we did examine the data for general indications of where the source of error may originate. Our initial examination focussed on NEAT's calculations of annual heating consumption.

NEAT calculates savings as the change between the pre-retrofit and post-retrofit annual heating consumption: if these are not accurate, then the predicted savings will be likewise be in error. If NEAT tends to overpredict the pre-retrofit consumption and/or underpredict the post-retrofit consumption, then savings will be overestimated.

NEAT provides estimates of pre-retrofit and post-retrofit annual heating consumption in its reports. However, the reported pre-retrofit heating consumption is the predicted consumption after infiltration reduction measures have been installed, but prior to the installation of insulation and furnace measures. We calculated the total pre-retrofit heating consumption by adding the total of NEAT's predicted infiltration reduction savings to the predicted post-retrofit annual heating consumption.

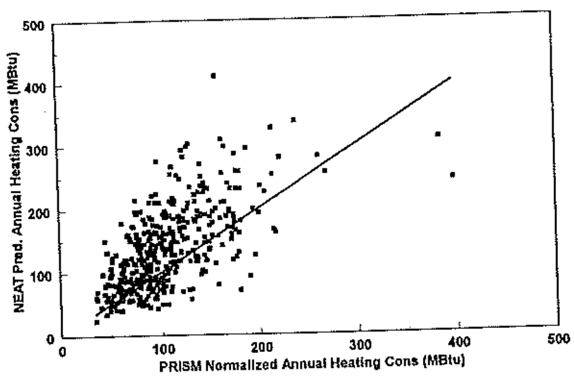

Figure 4.7 Pre-retrofit NEAT predicted annual heating consumption vs. PRISM normalized annual heating consumption for the refined dataset

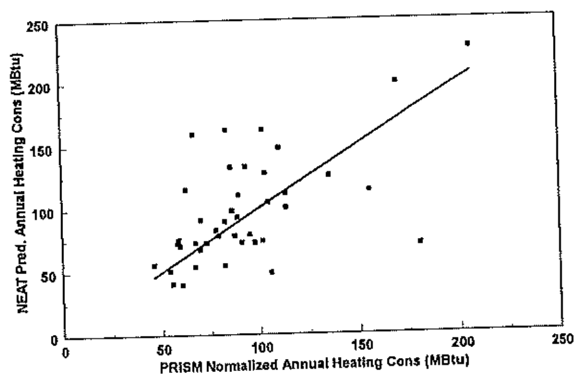

Figure 4.8 Pre-retrofit NEAT predicted annual heating consumption vs. PRISM normalized annual heating consumption for the refined dataset

Figures 4.7 and 4.8 show plots of NEAT's predicted *pre-retrofit* annual consumption compared to the NAHC for the program and refined datasets, respectively. The line indicates a 1 to 1 relationship between predicted and measured annual heating consumption. Figure 4.9 shows a similar plot for NEAT's predicted *post-retrofit* annual heating consumption from the refined dataset (we did not examine the post-retrofit estimates for the full program group because since NEAT's estimates of usage are based upon assumptions of measures that may not have been installed). Figure 4.7, and to a lesser degree, Figure 4.8, show that NEAT's predicted annual heating consumption tends to exceed observed consumption under pre-retrofit conditions; Figure 4.9 shows that NEAT tends to underpredict annual heating consumption in the post-retrofit period.

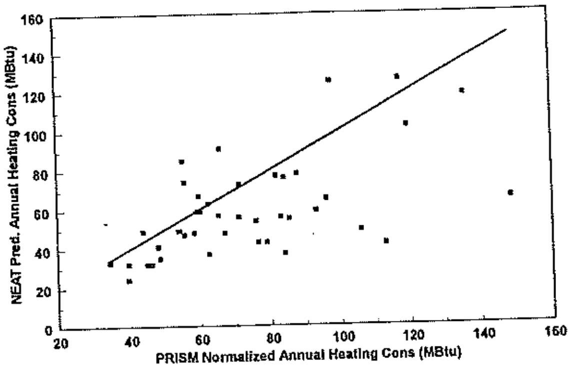

Figure 4.9 Post-retrofit NEAT predicted annual heating consumption vs. PRISM normalized annual heating consumption for the refined dataset

Table 4.5 shows the mean of the ratio of NEAT's predicted annual heating consumption to the NAHC in the pre-retrofit and post-retrofit periods for the refined dataset. The mean ratio was high in the pre-retrofit period, and low in the post-retrofit period indicating that NEAT tended to overpredict annual consumption in the pre-retrofit period, and underpredict it in the post. Since savings are the net of the pre-and post-retrofit annual heating consumption, the savings are overstated.

Table 4.5 Ratio of NEAT Predicted Annual Heating Consumption to Normalized Annual Heating Consumption

	n		Pre-Retrofit	Post-Retrofit
Program Group	408	mean	1.34	NA
		median	1.28	NA
Refined dataset	42	mean	1.08	0.89
		median	1.05	0.89

Noting that the only real difference between the pre-retrofit and post-retrofit condition of these houses was the installation of the weatherization measures, we suspect that NEAT tends to overpredict annual consumption in houses with lower overall thermodynamic efficiency, and underpredict annual consumption in houses that have better thermal performance.

We could find no clear explanation for this behavior. Note that although our refined dataset was designed to control for differences between NEAT data and actual conditions by selecting houses where the insulated area of major insulation, heating system, and air leakage data matched well between the tracking system and the NEAT data, we did not specifically control for cases where high levels of attic insulation were installed or for infiltration reduction that may have resulted from installing high density wall insulation. However we would expect that both of these circumstance would lead to underpredicted savings rather than the generally overpredicted savings which we observed.

Using regression analysis we did examine models that specified the ratio of NEAT's predicted annual heating consumption as the dependent variable, and parameters relating the thermal performance as independent variables. The independent variables included thermal conductance of wall and attic spaces (the inverse of the wall or attic R value), and the difference between the value of steady state efficiency entered in NEAT and the value calculated from the output capacity and input energy. This analysis was restricted to the refined dataset. The results were largely inconclusive, although they did indicate lower R values of walls tended to increase predicted annual heating consumption in the pre-retrofit period.

Analysis of Individual Measure Savings

We also compared NEAT's predicted savings for individual measures with savings estimated using the Statewide Low-Income Collaborative Evaluation (SLICE) algorithms (these are billing analysis adjusted engineering estimates, see the Wisconsin Energy Conservation Corporation reports entitled *An Evaluation of Iowa's Low-Income Weatherization Efforts*, 1994 and *Estimated Low-Income Program Impacts in Iowa*, 1993 for more information.). Note that the SLICE algorithms are not designed to provide precise estimates of savings for specific measures in any given house, but to provide good aggregate estimates of the overall program. Consequently, in this analysis we compare the mean savings by measure rather than compare estimated savings with predicted for specific installations of a measure.

Table 4.6 shows the mean of the house-level savings for the refined dataset.

Table 4.6 Comparison of SLICE and NEAT Mean Estimated Savings for Houses in the Refined Dataset

	Mean Savings (therms)	Realization Rate
SLICE	179	113%
NEAT	373	54%
Observed Savings	203	

Overall the SLICE estimates are much closer to the PRISM mean net savings than NEAT's predicted savings, underestimating savings by 11.8% compared with NEAT's estimates which overpredict savings by 83.7%.

Table 4.7 summarizes a comparison between the measure-level predicted savings for wall and attic insulation, infiltration reduction measures, and furnace replacements[3]. We found that NEAT's mean predicted savings exceeded the SLICE estimates the most for infiltration reduction (141%). A partial explanation for this can be found in the SLICE algorithms, which allocate a portion of infiltration measure savings to wall insulation. This is to account for infiltration reduction from high density wall

[3] We could not compare savings for furnace tuneups--the SLICE algorithms do not predict savings for this measure.

insulation. This practice reduces the SLICE estimates of infiltration reduction relative to other measures, which in turn increases the relative difference between NEAT predicted and SLICE estimated savings for this measure. By the same token, the algorithms increase the SLICE estimates for wall insulation savings, bringing the SLICE estimates more in line with NEAT's predicted savings.

Table 4.7 Comparison of NEAT Predicted Measure Savings with SLICE Estimated Savings

		NEAT Predicted Savings (therms)		SLICE Estimated Savings (therms)		Percentage Exceeding SLICE Estimates	
	n	Mean	Median	Mean	Median	Mean	Median
Attic insulation	30	134	95	61	63	120%	51%
Wall insulation	20	91	160	122	109	57%	47%
Infiltration reduction	41	99	75	41	24	141%	213%
Furnace replacement	9	141	157	120	100	18%	57%

We conducted an analysis of measure-level realization rates using regression analysis. We discuss the procedure that we used is described in Appendix C, however the results were inconclusive.

Cost-effectiveness of Recommended Measures

NEAT calculates the ratio of the life cycle fuel cost savings to the measure costs and reports the results as the Savings-to-Investment Ratio (SIR). NEAT recommends all measures with SIRs above a threshold level--the Iowa weatherization program used a threshold of 1.0. If NEAT's heating fuel savings are overstated, then the cost-effectiveness is likewise overstated and measures which are not cost-effective may be recommended.

Without having values of measure-level realization rates, we could not determine what fraction of the total expenditures were spent on measures that were clearly cost-effective. Instead, we tried to get some idea of cost-effectiveness by examining the fraction of expenditures which would be cost-effective across a range of realization rates[4], from 0.0 to 1.0.

Figure 4.10 shows a plot of those results for wall and attic insulation and infiltration reduction measures. As long as the wall insulation realization rate exceeds 30%, nearly all the expenditures on wall insulation are cost effective. For attic insulation, the fraction of total expenditures that are cost-effective decreases gradually as the realization rates decline; it is approximately 60% at the overall program and 80% for the refined dataset.

The clear cutoff in the cost-effectiveness of wall insulation can be attributed to the range of measures from which NEAT can select. Installations of wall insulation tend to be a single distinct measure

[4] The fuel cost savings consider all fuels affected by the measure, thus insulation measures may also have cooling (electricity) savings. Since we did not allocate costs for heating and cooling portions of savings, our discussion implies that the realization rates for heating and cooling are similar for a given measure.

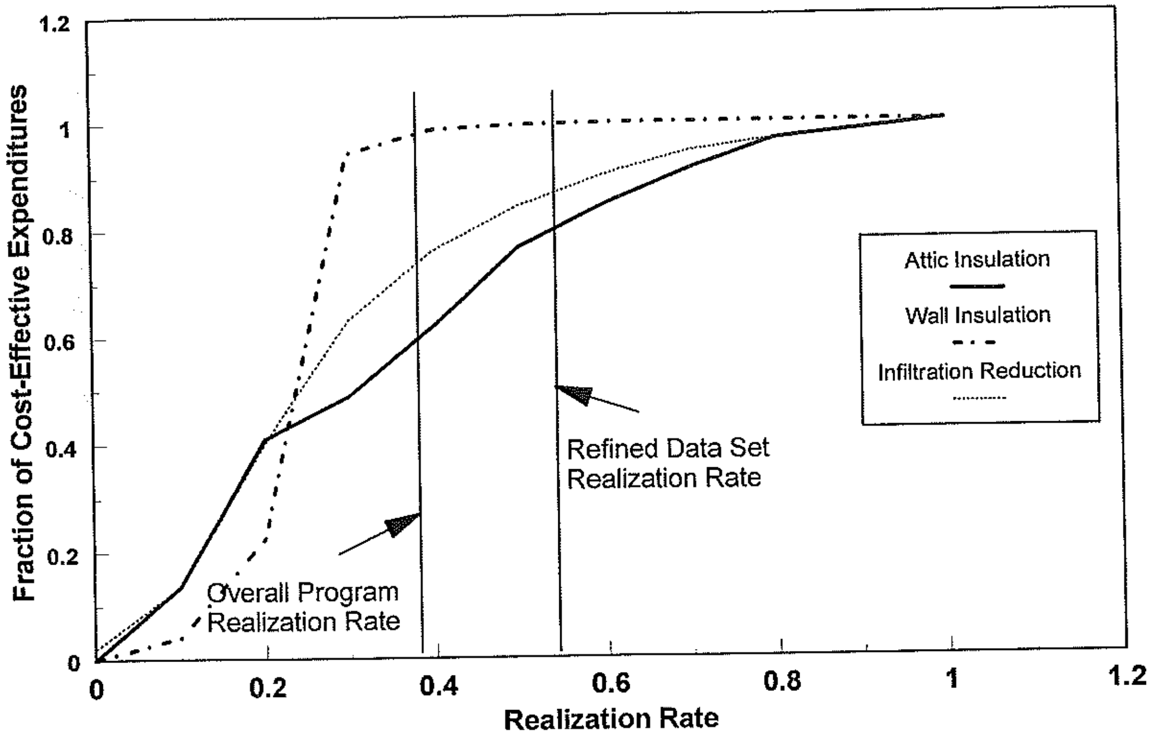

Figure 4.10 Fraction of cost-effective expenditures at varying realization rates

This is in contrast to attic insulation for which NEAT can choose among four levels (R-11, R-19, R-30, R-38) allowing it to more closely approximate an SIR of 1.0. It is important to note that even though the recommended level of attic insulation may not be cost-effective at low realization rates, it is likely that a lesser level of insulation would be cost-effective for many of these installations. For these, only the incremental cost from the lower level of insulation to the level actually recommended by NEAT would be a non-cost-effective expenditure.

The fraction of total expenditures on infiltration reduction that are cost-effective decreases gradually as the realization rates decline; it is approximately 75% for the overall program, and 83% for the refined dataset. However, unlike insulation measures, NEAT does not recommend specific infiltration reduction measures. Instead, NEAT calculates the SIR of all installed infiltration measures after blower door directed air sealing is completed. The SIR is based upon predicted savings (calculated from the values entered for the pre-retrofit and post-retrofit blower door readings) and the actual costs of the infiltration measures which were installed. Consequently, expenditures on infiltration reduction which are not cost-effective are attributable to overly aggressive installation on the agency's part, and not to NEAT's recommendations.

5. CONCLUSIONS

Our analysis shows that natural gas heating measure savings are 39% (±3%) of NEAT's predicted heating fuel savings for the overall program. The greatest factor that contributed to the low realization rate came from NEAT itself--the realization of predicted savings was 54% (±11%) for houses or houses in which the NEAT data matched well with the tracking system data for recommended and installed measures and air leakage rates and which did not use a default value for furnace efficiency.

We found no straight-forward explanation for the low realization rate for NEAT's predicted savings. We did find that NEAT tended to overpredict the annual heating consumption by about 8% in the pre-retrofit period and underestimate it by about 11% in the post-retrofit period for the same houses. This tendency results in overpredicted savings, and suggests that NEAT overpredicts annual heating fuel consumption for house with lower overall thermodynamic efficiency, and underestimates it for houses with better efficiency.

We found that two operational aspects of the program resulted in higher levels of insulation than NEAT modelled: high insulation in attic spaces and the installation of high density insulation (for which NEAT does not allocate infiltration reduction savings). If NEAT had been operated to account for these differences, its predicted annual heating consumption in the post-retrofit period would have been even lower, resulting in greater overpredictions of savings than we observed.

Our examination of operational factors that contributed to the overall low realization rate included the use of a default value of steady state furnace efficiency (56%) and the use of estimated (or otherwise inexact) air leakage rates.

We found that the realization rate dropped from 54% (±11%) to 50% (±7%) after including houses well matched between the tracking system and the NEAT data, but which could also have used of the default value of 56% for the furnace efficiency.

We found a larger drop in the realization of predicted savings (from 54% (±11%) to 44% (±8%)) when we included houses with air leakage rates that differed from tracking system values by more than 300 CFM50, however the drop appeared to be in driven more by the inclusion of houses that had very high over-predicted savings with only a moderate difference in air leakage rates relative to the other houses. This suggests that the air leakage rate was not the only major factor reducing realization rate for this group of houses, but it was unclear what the other factors were.

Overpredicted savings affects the savings to investment ratio so that some measures that were recommended would not have been if the predictions were more accurate. The cost-effectiveness of attic insulation and infiltration reduction measures were more sensitive to changes in predicted savings than wall insulation.

The attic insulation costs in the setup files used by NEAT were scaled at a constant cost per R value. In reality, the cost per installed R value probably decreases as the R value increases. The use of scaled values may have resulted in recommending a lower value of insulation than was what would have been cost-effective.

We found that the SLICE estimates provide a better estimate of overall program savings than total predicted savings from the NEAT reports.

Recommendations for Further Study

We found that although factors related to program implementation did contribute to overpredicted savings, the greatest impact was attributable to error in NEAT's estimates of annual energy consumption. To examine why NEAT tends to overpredict annual heating consumption prior to weatherization and underpredict consumption after, the NEAT results should be compared to results from well-calibrated engineering models that accounts for as much structural detail as possible (e.g. DOE2 models). This could also identify reasons for the large differences in NEAT's predicted annual heating consumption for some houses relative to others.

To further examine operational factors that could result in large errors for individual houses, the study should include a review of the data after the audit but prior to treatment, and a post-retrofit inspection. The data from the tracking system, the NEAT data, the post-audit inspection, and post-weatherization inspection should be reviewed for accuracy and consistency.

Even a detailed comparison of engineering models may not provide the explanation for NEAT's tendency to overpredict savings. Although such a study could help identify the limitations of one model relative to another, it would not identify error introduced by factors foreign to the engineering model inputs, such as the behavior of the occupants. If a detailed engineering analysis does not provide an explanation for NEAT's error in predicted annual consumption, then it may be useful to develop adjustment factors to apply to the estimated savings or to the estimated annual energy consumption. The realization rates determined in this study do provide an overall adjustment for estimated savings, but more refined adjustments based upon the general structural characteristics and occupant data would provide better house-specific estimates.

APPENDIX A

Material Costs

Material	Type	Life (yrs)	Unit	Cost ($/Unit) Matrl	Cost ($/Unit) Labor	Cost/ Item ($)
Ceiling Insulation	Celluls,Blwn - R-11	20	Sqft	.0732	.1540	
Ceiling Insulation	Celluls,Blwn - R-19	20	Sqft	.1264	.2582	
Ceiling Insulation	Celluls,Blwn - R-30	20	Sqft	.1995	.4015	
Ceiling Insulation	Celluls,Blwn - R-38	20	Sqft	.2527	.5057	
Ceiling Insulation	Fbergls,Blwn - R-11	20	Sqft	.17	.15	
Ceiling Insulation	Fbergls,Blwn - R-19	20	Sqft	.22	.20	
Ceiling Insulation	Fbergls,Blwn - R-30	20	Sqft	.25	.23	
Ceiling Insulation	Fbergls,Blwn - R-38	20	Sqft	.28	.26	
Ceiling Insulation	User Type 1 - R-11	20	Sqft	.0732	.1540	
Ceiling Insulation	User Type 1 - R-19	20	Sqft	.1264	.2582	
Ceiling Insulation	User Type 1 - R-30	20	Sqft	.1995	.4015	
Ceiling Insulation	User Type 1 - R-38	20	Sqft	.2527	.5057	
Ceiling Insulation	User Type 2 - R-11	20	Sqft	.17	.15	
Ceiling Insulation	User Type 2 - R-19	20	Sqft	.22	.20	
Ceiling Insulation	User Type 2 - R-30	20	Sqft	.25	.23	
Ceiling Insulation	User Type 2 - R-38	20	Sqft	.28	.26	
Wall Insulation	Blwln Cellulose	20	Sqft	.00	.59	
Wall Insulation	User Type 1 - R-11.0	20	Sqft	.00	.59	
Wall Insulation	User Type 2 - R- 5.0	20	Sqft	.00	.59	
Kneewall Ins.	Faced Batt - R-11	20	Sqft	.14	.15	
Sill Insulation	Faced Batt - R-19	15	Sqft	.24	.24	
Floor Insulation	Faced Batt - R-11	20	Sqft	.14	.24	
Floor Insulation	Faced Batt - R-19	20	Sqft	.24	.24	
Floor Insulation	Faced Batt - R-30	20	Sqft	.38	.24	
Foundation Ins.		20	Sqft	1.21		
Duct Insulation		20	Sqft	.37	1.10	
Vent Damper	Thermal	10	Each	57.11	75.00	
Vent Damper	Electrical	10	Each	135.11	100.00	
IID		10	Each	146.50	75.00	
IID/Elec Vent Dmp		9	Each	281.61	175.00	
Flame Ret Hd Burner		10	Each	540.00		
Furnace Tuneup		2	Each	0.00	45.00	
Replacement Furnace		15	Each	1600.00		
High Eff. Furnace		15	Each	2100.00		
Replacement Boiler		15	Each	2100.00		
Space Heater	Gas - 8 kBtu/h	15	Each	300.00		
Space Heater	Gas - 55 kBtu/h	15	Each	900.00		
Space Heater	Oil - 40 kBtu/h	15	Each	500.00		
Space Heater	Oil - 75 kBtu/h	15	Each	1250.00		
Space Heater	Kerosene - 10 kBtu/h	15	Each	1000.00		
Space Heater	Kerosene - 40 kBtu/h	15	Each	1450.00		
Smart Thermostat		15	Each	35.00	30.00	
Storm Window		15	Each	24.00	27.00	
Air Conditioner	5,000 Btu	15	Each	399.00	100.00	
Air Conditioner	15,000 Btu	15	Each	550.00	200.00	
Air Conditioner	25,000 Btu	15	Each	685.00	225.00	
Evaporative Cooler		15	Each	400.00	400.00	
Awnings		10	Lnft/E	0.00	0.00	55.0
Sun Screen	Fabric Mesh	12	Sqft/E	0.00	3.50	
Sun Screen	Louvered	20	Sqft/E	0.00	5.75	
Window Film		5	Sqft/E	0.00	2.50	
Low-E Window		15	Sqft/E	0.00	0.00	100.0

Fuel Costs

Fuel costs, $/unit

Fuel Unit	gas 1000-cuft	#2-oil gal	electric kwhr	propane gal	wood cord	coal ton	kerosene gal
	5.2635	1.199	.08543	1.079	120.	126.	1.299

Fuel Escalation Rates

- From current year (0)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Electric	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.01	1.02	1.02	1.03	1.03	1.04
Oil	1.01	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.25	1.27	1.29	1.31
Propane	1.00	1.01	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.22	1.24	1.26	1.28
Natl Gas	1.02	1.04	1.05	1.07	1.09	1.12	1.15	1.19	1.22	1.26	1.29	1.32	1.35
Kerosene	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Year	13	14	15	16	17	18	19	20	21	22	23	24	25
Electric	1.04	1.05	1.05	1.06	1.06	1.07	1.08	1.08	1.09	1.10	1.10	1.11	1.12
Oil	1.32	1.34	1.36	1.37	1.39	1.41	1.44	1.46	1.49	1.51	1.54	1.56	1.58
Propane	1.30	1.31	1.33	1.35	1.37	1.39	1.42	1.44	1.46	1.49	1.51	1.53	1.55
Natl Gas	1.38	1.41	1.44	1.49	1.52	1.55	1.58	1.60	1.63	1.66	1.68	1.71	1.73
Kerosene	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Wood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Candidate Measure Selection

Indicate with "y" or "n" whether measure is to be considered

Measure		Measure	
Attic Ins. R-11	_Y_	Attic Ins. R-19	_Y_
Attic Ins. R-30	_Y_	Attic Ins. R-38	_Y_
Wall Ins. 3.5"	_Y_	Sillbox Ins.	_Y_
Foundation Ins.	_N_	Floor Ins. R-11	_Y_
Floor Ins. R-19	_Y_	Floor Ins. R-30	_Y_
Storm Windows	_N_	Wall Ins. R-11 Batt	_Y_
Window Shading	_N_	Sun Screen, Fabric	_N_
Sun Screen, Louvered	_N_	Window Films	_N_
Low-E Windows	_N_	Thermal Vent Damper	_N_
Electric Vent Damper	_N_	IID	_N_
Elect. Vent Dmpr./IID	_N_	Flame Retntn. Burners	_N_
Furnace Tuneup	_Y_	Replace Htg. System	_Y_
High Eff Furnace	_Y_	Smart Thermostat	_N_
Replace Window A/C	_N_	Evaporative Cooler	_N_
Duct Insulation	_Y_		

Miscellaneous Parameters

4.0	Real discount rate (%)
1.0	Minimum acceptable SIR
68.0	Daytime heating setpoint (F)
68.0	Nighttime heating setpoint (F)
78.0	Daytime cooling setpoint (F)
78.0	Nighttime cooling setpoint (F)
6.0	Night setback (F)
4.0	Average annual outside film coefficient (Btu/hr-sqft-F)
2900.	Base value of free heat from internals (Btu/hr)
0.85	Cooling sensible heat ratio
4.42	Uninsulated R-value associated with "Other" wall type
0.6	R-value of "Other" exterior wall type
3.06	R's/inch of "Other" insulation type
12.0	R-value added by foundation wall insulation measure
81.0	Furnace replacement AFUE (%)
80.0	Boiler replacement AFUE (%)
86.0	High efficiency furnace replacement AFUE (%)
9.5	Replacement A/C SEER
1.0	Heat content for natural gas (therms/ccf)
User Type 1	Ceiling Insulation, User defined Type 1
User Type 2	Ceiling Insulation, User defined Type 2
User Type 1	Wall Insulation, User defined Type 1
11.0	R-Value added to wall cavity
User Type 2	Wall Insulation, User defined Type 2
5.0	R-Value added to wall cavity

APPENDIX B

Regression Analysis of the PRISM Dataset

We conducted a regression analysis using the engineering study group (42 houses), to determine a regression-based realization rate on NEAT predicted savings. The regression data also included the comparison group data (549 houses) to account for baseline changes. The model was of the form:

$$save = c_1 * pred + c_2 * slice + cons + e$$

where:

- save is the net savings from the PRISM analysis
- pred is the NEAT predicted savings
- slice is the total of SLICE estimates of water heater and mattress pad savings
- c_x is a coefficient to be determined in the regression
- *cons* is the model constant (denotes baseline change)
- *e* is the error term for house to house variation

The coefficients on the NEAT predicted savings (pred), and SLICE estimated savings for water heater measures and waterbed mattress pads (slice) are the realization rates for those parameters. This means that for every therm of predicted savings, c_x savings are observed. The constant represents the comparison group changes.

The regression results for the engineering group are:

Source	SS	df	MS
Model	25402.7799	2	12701.3899
Residual	136324.415	588	231.844243
Total	161727.195	590	274.113889

Number of obs	=	591
F(2, 588)	=	54.78
Prob > F	=	0.0000
R-squared	=	0.1571
Adj R-squared	=	0.1542
Root MSE	=	15.226

save	Coef.	Std. Err.	t	P>|t|	[90% Conf.	Interval]
pred	.4921834	.0584617	8.419	0.000	.3958707	.588496
slice	1.291568	.7146305	1.807	0.071	.1142508	2.468886
_cons	.7809877	.6421495	1.216	0.224	-.2769209	1.838896

The realization rate on the NEAT predicted savings is 49.2% in the model, which is reasonably close to our PRISM realization rate of 54.4%, and is significant at greater than 99% confidence. The realization rate on the SLICE estimated savings is 130%, and is significant at 93% confidence. The constant value of 0.78 MBtu is not significant, but compares well with the PRISM results of 0.7 MBtu. We examined this model for influential points, and found that the two houses with the highest SLICE savings were leverage points. After removing these two houses we found that the realization rate on NEAT predicted savings increased to 49.7%, and was significant at greater than 99% confidence. We conclude that the regression models provide adequate confirmation of the realization rate from our PRISM analysis.

APPENDIX C

Regression Analysis of Impacts of Specific Measures

We conducted regression analyses to determine how well NEAT predicted savings for specific measures, but were unable to determine the measure-level realization rates.

We used the combined engineering study group and comparison group as in our overall model regression. We used a regression model that was similar in general form to our previous model except the predicted savings were broken-out by individual measures. The realization rate is provided by the coefficients on the predicted savings for each measure:

$$\text{save} = c_1 * \text{pred}_1 + \ldots + c_n * \text{pred}_n + c_{n+1} * \text{slice} + cons + e$$

Our initial model results are:

Source	SS	df	MS
Model	29402.5106	9	3266.94562
Residual	132324.684	581	227.753329
Total	161727.195	590	274.113889

Number of obs	=	591
F(9, 581)	=	14.34
Prob > F	=	0.0000
R-squared	=	0.1818
Adj R-squared	=	0.1691
Root MSE	=	15.091

save	Coef.	Std. E	t	P>|t|	[90% Conf.	Interval]
aint	.2447822	.3356998	0.729	0.466	-.3082766	.797841
cint	.9046119	.2341522	3.863	0.000	.5188507	1.290373
frnt	.7662238	.5073899	1.510	0.132	-.0696911	1.602139
wint	.3812682	.2359693	1.616	0.107	-.0074866	.770023
bint	3.268056	1.976924	1.653	0.099	.0111124	6.525
ftnt	-.41953	.9395203	-0.447	0.655	-1.967371	1.128311
fint	-1.186339	1.089658	-1.089	0.277	-2.981529	.6088517
dint	1.903783	9.595478	0.198	0.843	-13.90458	17.71215
slice	1.308618	.7868737	1.663	0.097	.0122588	2.604977
_cons	.8053978	.6399817	1.258	0.209	-.2489596	1.859755

where the NEAT predicted savings for specific measures are identified as:

aint, infiltration reduction
cint, attic insulation
frnt, furnace replacement
wint, wall insulation
bjnt, bandjoist insulation
ftnt, furnace tuneup
fint, floor insulation
dint, duct insulation

Except for attic insulation, the coefficients on all measures were sigificant at less than 90% confidence (as evidenced by the low *t* statistics). We respecified the model, preserving coefficients for infiltration reduction, wall and ceiling insulation, furnace replacement, furnace tuneup, and SLICE estimated savings for water heater and waterbed mattress pads. We combined savings for bandjoist insulation, floor insulation, and duct insulation into a single parameter (imisc). The results are:

Source	SS	df	MS
Model	28311.4389	7	4044.49128
Residual	133415.756	583	228.843492
Total	161727.195	590	274.113889

Number of obs	=	591
F(7, 583)	=	17.67
Prob > F	=	0.0000
R-squared	=	0.1751
Adj R-squared	=	0.1652
Root MSE	=	15.128

save	Coef.	Std. Err.	t	P>|t|	[90% Conf.	Interval]
aint	.0115277	.3179339	0.036	0.971	-.5122593	.5353148
cint	.9964754	.2307054	4.319	0.000	.6163949	1.376556
frnt	.8273335	.5068229	1.632	0.103	-.0076427	1.66231
wint	.4495384	.234356	1.918	0.056	.0634435	.8356334
ftnt	.364188	.8604438	0.423	0.672	-1.053369	1.781745
imisc	-.2284373	.9985425	-0.229	0.819	-1.873508	1.416633
slice	1.390333	.7878374	1.765	0.078	.0923934	2.688273
_cons	.8368499	.6411318	1.305	0.192	-.2193964	1.893096

The coefficient on attic insulation was again significant at high confidence, but no other measures were significant at 95% confidence.

Wisconsin Energy Conservation Corporation is dedicated to increasing energy efficiency and promoting conservation to benefit all, especially low income families.