ORNL/CON-493

ESTIMATING THE NATIONAL EFFECTS OF THE U.S. DEPARTMENT OF ENERGY'S WEATHERIZATION ASSISTANCE PROGRAM WITH STATE-LEVEL DATA: A METAEVALUATION USING STUDIES FROM 1993 TO 2005

Martin Schweitzer

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ABBREVIATIONS, ACRONYMS, AND INITIALISMS

DOE	Department of Energy
NEAT	National Energy Audit Tool
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
SLICE	Statewide Low-Income Collaborative Evaluation

EXECUTIVE SUMMARY

INTRODUCTION

The U.S. Department of Energy's Weatherization Assistance Program has been funding state and local agencies throughout the United States to weatherize homes for low-income occupants since 1976. A metaevaluation of this program was recently performed by staff at Oak Ridge National Laboratory (ORNL), using data from studies of weatherization efforts in 19 different states that were completed between 1993 and 2005.

This study, like three previous metaevaluations performed between 1996 and 2002, was undertaken to update the findings from the national Weatherization Program evaluation conducted by ORNL in the early 1990s. All of the metaevaluations, including this one, have focused primarily on energy savings in homes heated by natural gas because the large majority of state-level studies have addressed that fuel. In contrast, far fewer studies have addressed energy savings in electrically-heated homes and in dwellings using electricity only for non-heating (baseload) purposes, and the average savings numbers that can be calculated from those few studies are not considered reliable estimates of program-wide savings.

METHODS

The current metaevaluation took data provided by all state-level evaluations completed since 1993 and aggregated them by state rather than treating multiple studies of the same state as separate observations, as had been done in the previous ORNL metaevaluations. We ended up with data on 19 states, compiled from a total of 38 individual state-level evaluations. As shown in Table ES.1, 17 of the state studies addressed energy savings in dwellings heated by natural gas, six covered savings in electrically-heated houses, and four dealt with savings in homes using electricity only for non-heating purposes.

A regression analysis was conducted for gas-heated houses, with each state's data weighted by its share of total national Weatherization Program funding. Under this approach, those states that represent a larger part of the national program contribute more heavily to the analysis, which is appropriate because the purpose of the study is to estimate energy savings nationwide. Energy savings per household was used as the dependent variable and pre-weatherization energy use per household was the sole explanatory variable found to be significantly related to savings. The resulting regression equation, along with available data on average pre-weatherization energy consumption by program participants, was used to estimate average per-household energy savings in gas-heated dwellings nationwide. Although the number of observations used in the analysis (N=17) was relatively small, the fact that each data point represents the average findings from one or more state-level evaluations gives us reason to trust the results.

Table ES.1 Subjects addressed by state-level studies used in 2005 metaevaluation

State	Savings in gas-heated houses	Savings in electrically-heated houses	Savings in houses using electricity only for non-heating purposes
Colorado	■		■
Delaware		■	
District of Columbia	■	■	
Georgia	■		
Illinois	■		
Indiana	■		
Iowa	■		■
Kansas	■		
Minnesota	■		
Nebraska	■		
New York	■		
North Carolina	■		
Ohio	■	■	
Texas	■	■	
Vermont	■		■
Washington	■	■	
West Virginia		■	
Wisconsin	■		■
Wyoming	■		

FINDINGS

Using the regression equation generated by the analysis described above and average pre-weatherization consumption taken from the last national Weatherization Program evaluation, average energy savings per gas-heated household nationwide was estimated to be 30.5 million site BTUs. This latest natural gas savings number is similar to the per-household savings estimates generated by the three previous ORNL metaevaluations (29.1, 26.1, and 31.2 million site BTUs) but is substantially higher than the average savings reported in the national Weatherization Program evaluation (17.3 million site BTUs), which examined performance during the 1989 program year. The similarity among mean savings estimates from the various ORNL metaevaluations is not surprising because those meta analyses used data from many of the same state-level studies. In contrast to the similarity of findings for the four metaevaluations, we found a statistically significant difference between the natural gas savings per household calculated in the current metaevaluation and the savings reported in the national evaluation ($p<0.001$).

The per-household energy savings estimated by the current metaevaluation equals 22.9% of pre-weatherization consumption of natural gas for all end uses. As shown in Figure ES.1, this is similar to the estimates generated by the previous three metaevaluations (21.9%, 19.6%, and 23.4%) but is much higher than the number computed by the national evaluation (13.0%). An examination of the 90% confidence intervals presented in Figure ES.1 shows substantial overlap among the four metaevaluations but no overlap at all between the current metaevaluation and the national evaluation.

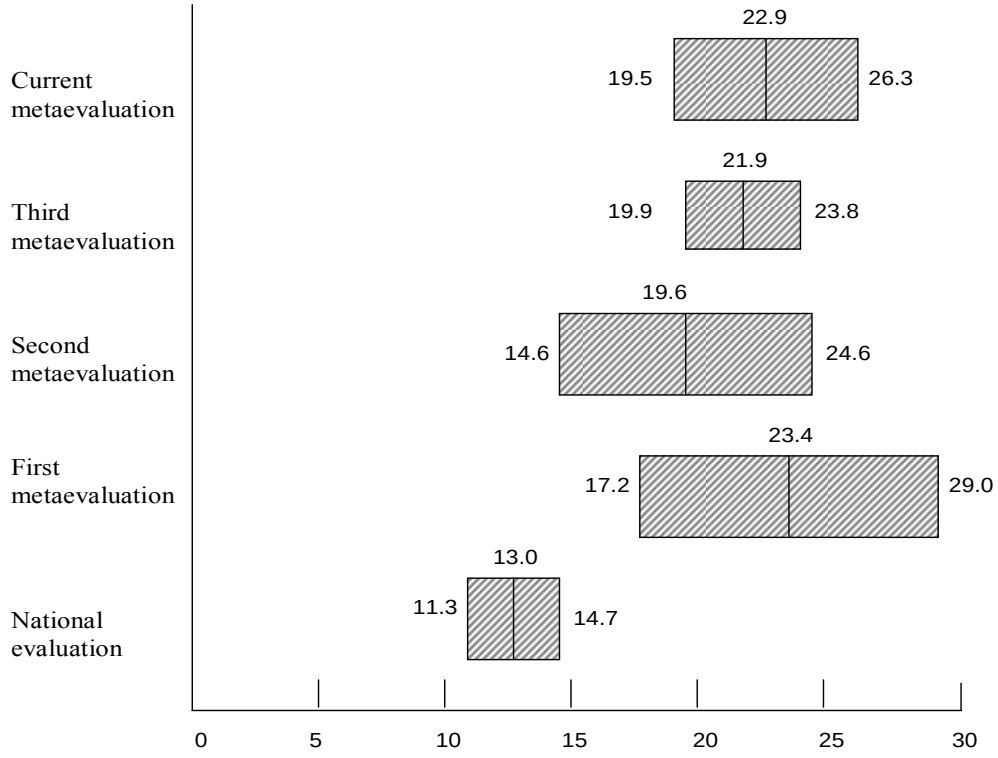

Figure ES1. Estimated average national savings in gas-heated houses as a percentage of pre-weatherization consumption of natural gas for all end uses: means and 90% confidence intervals.

The energy savings per household estimated by the current metaevaluation amounts to 32.3% of the natural gas used during the pre-weatherization period for space heating. This contrasts with the findings of the national evaluation, which reported per-household natural gas savings amounting to 18.3% of space heating consumption.

Benefit-cost ratios for the gas-heated dwellings studied in this metaevaluation were calculated from the program perspective, which compares the value of energy savings to total program costs, and the societal perspective, which uses the same approach to calculating costs but counts both energy *and* non-energy benefits. The

discounted value of natural gas savings, assuming a 20-year lifetime for the installed measures, was calculated to be $3,917, in 2003 dollars. Non-energy benefits were valued at $3,466. On the other side of the equation were weighted program costs, which were calculated to be $2,913, also in 2003 dollars, based on the costs reported by the states. Using the above-reported values, benefit-cost ratios for gas-heated houses served by the Weatherization Assistance Program were computed to be 1.34 from the program perspective and 2.53 using the societal approach. *Actual* benefit-cost rates are likely to be higher than this because reported expenditures included the cost of installing measures to reduce baseload electricity consumption but only natural gas savings were used in the calculations.

It is not surprising that per-household energy savings in gas-heated dwellings was found to be significantly higher by the current ORNL metaevaluation (which is based on state-level studies completed after 1992) than by the national Weatherization Program evaluation (which focused on houses weatherized in 1989). Starting in the early 1990s, advanced audits became increasingly common, as did the use of blower-door directed air sealing and high density wall insulation. Since that time, however, there have been no equally dramatic or widespread changes in Weatherization Program practices affecting heating energy consumption.

While the metaevaluations performed over the last decade have consistently shown higher natural gas savings per household than those reported in the national evaluation, there is a need to corroborate those findings through a rigorous examination of Weatherization Program efforts nationwide. Even the current metaevaluation is based on studies performed in only a third of the states, and those may not be fully representative of the entire Weatherization Program. Also, the value for pre-weatherization energy consumption, which is a major input for the calculation of national savings, is based on 1989 data. In addition, while state-level evaluations have put a strong emphasis on gas-heated houses, few studies have been conducted on electrically-heated dwellings. And it is important to note that the biggest recent change to the Weatherization Program – the addition of baseload measures such as highly efficient refrigerators, water heaters, and light bulbs – has barely been addressed by state-level studies. For all these reasons, there is a strong need for a new national evaluation to thoroughly explore the current operations and achievements of the Weatherization Program across the entire nation.

1. INTRODUCTION

1.1. BACKGROUND

The national Weatherization Assistance Program, sponsored by the U.S. Department of Energy (DOE) and implemented by state and local agencies throughout the United States, weatherizes large numbers of dwelling units every year for low-income occupants. The primary purposes of the program are to increase the energy efficiency of the treated structures, lower the occupants' utility bills, and increase the health, safety, and comfort of the low-income households that are served. Since its inception in 1976, this program has weatherized over 5.3 million low-income residences nationwide.

This report documents the findings of a recent metaevaluation of the Weatherization Assistance Program conducted by staff at Oak Ridge National Laboratory (ORNL). A metaevaluation is a study that uses as its data points the findings from a number of different studies on the topic of interest. In this case, the performance of the national Weatherization Assistance Program is the focus, and the data points are the findings from evaluations of weatherization efforts in 19 states[1] that were completed between 1993 and 2005. The states whose studies were used in this metaevaluation and the number of studies performed for each state are shown in Figure 1.

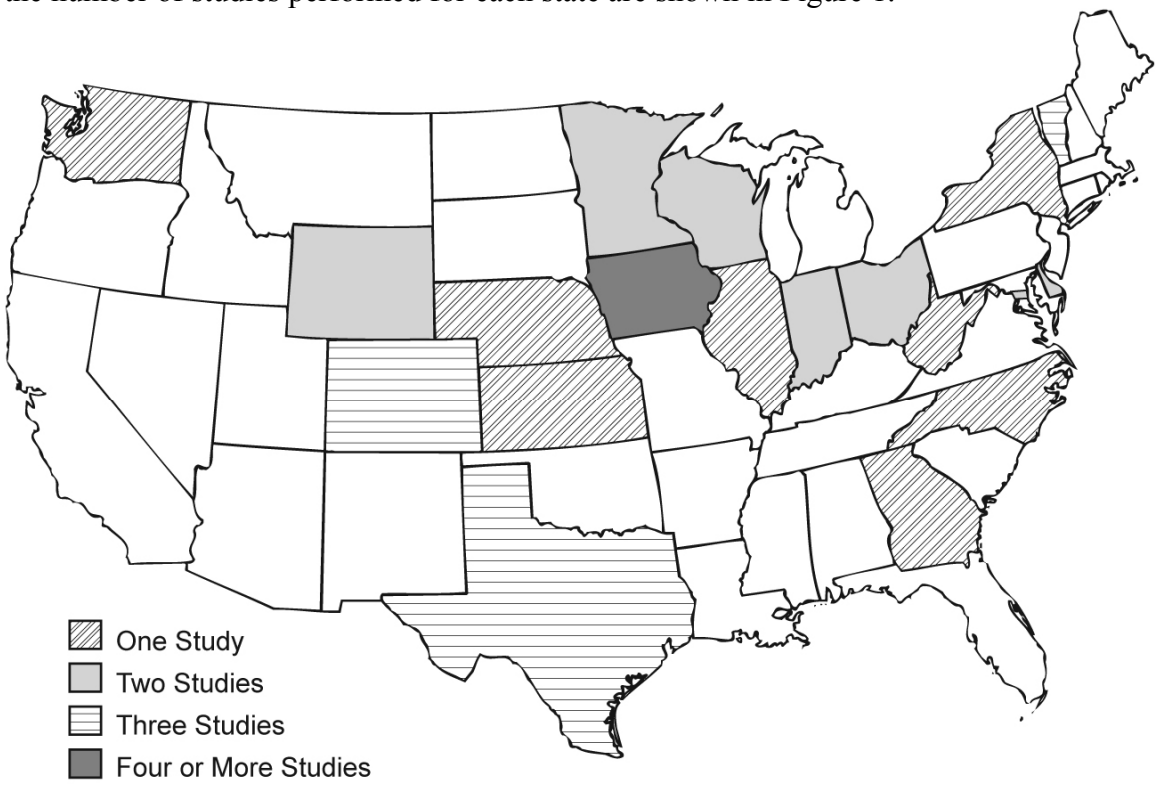

Figure 1. States with studies used in the current metaevaluation

[1] Because the District of Columbia operates its own Weatherization Program, just like the 50 states do, it is treated in this study as the equivalent of the states and the generic term "state" is applied to it.

The current metaevaluation is a follow-up to three earlier metaevaluations of the Weatherization Assistance Program performed by ORNL in 1996 (Berry 1997), 1998 (Schweitzer and Berry 1999), and 2002 (Berry and Schweitzer 2003). Each of those metaevaluations used regression analysis to estimate average per-household energy savings nationwide in dwellings heated with natural gas. The objective of all the studies, including the current one, is to update the findings from a national evaluation of the Weatherization Assistance Program that ORNL conducted in the early 1990s (Brown, Berry, Balzer, and Faby 1993). That study examined Program performance during the 1989 program year.

The previous metaevaluations focused primarily on energy savings in homes heated by natural gas because nearly all of the available state-level studies have examined gas-heated homes. Similarly, the new studies identified during the current metaevaluation primarily address performance in dwelling units using natural gas as their primary heating source. In contrast, savings in electrically-heated homes were addressed for slightly less than one-third of the states with weatherization studies, and savings of electricity for non-heating (baseload) purposes were examined for even fewer states.

1.2. SCOPE OF REPORT

The subsequent chapters of this report describe the approach used in this metaevaluation and discuss the key findings. Chapter 2 describes the methods employed to locate, select, and analyze data for this study. Chapter 3 presents estimates of average nationwide energy and dollar savings and benefit/cost ratios for a typical Program house heated with natural gas. Chapter 4 summarizes the study findings and discusses the observed similarities and differences between findings from this metaevaluation and previous studies of the Weatherization Assistance Program.

Detailed information on the individual evaluations used in this study is presented in Appendix A.

Findings for homes that heat with electricity are not presented in the main body of the report because the number of states that studied energy savings in electrically-heated dwellings is too small to permit reliable estimates of program-wide savings to be made. However, a discussion of electricity savings in homes that heat with electricity is presented in Appendix B. Measurements of electricity savings for non-heating (baseload) end-uses from studies in four states are briefly discussed in Appendix C.

2. METHODS

2.1. LOCATING RECENT STATE-LEVEL EVALUATIONS

This metaevaluation, like the three that preceded it, utilizes data taken from a number of different evaluations of weatherization efforts in individual states. Our first task, therefore, was to identify any new state-level evaluations that could be used in the current study. Accordingly, we contacted Weatherization staff in each state in the spring of 2005 and asked if they had completed an evaluation of their program since June, 2002, when the data collection effort for the previous metaevaluation had been performed. If state weatherization staff reported that an evaluation had been completed during the specified time period, they were asked to send us a copy of the report documenting their study.

In response to the data collection effort described above, we received written reports that presented data on measured energy savings from Weatherization Program efforts in six states: Delaware, the District of Columbia, Iowa, Illinois, Texas, and Wisconsin. Although we requested information only on evaluations that had been completed since June, 2002, some of the studies covered program years prior to 2002 because of the substantial amount of time required to collect and analyze energy use data and prepare reports on the findings. All of the relevant data provided to ORNL by the states were entered into a SAS[2] data set for subsequent analysis, along with existing data used in previous metaevaluations.

2.2. SELECTING STATE-LEVEL EVALUATIONS TO INCLUDE IN THE CURRENT METAEVALUATION

The first two metaevaluations performed by ORNL (in 1996 and 1998) each used separate sets of state-level studies to estimate average natural gas savings per household for the entire nation. In other words, the first metaevaluation examined only studies completed after 1992 and before the end of April, 1996, while the second metaevaluation used data exclusively from studies completed after April 1996 and before the end of September, 1998. However, there was a substantial amount of overlap between the first two metaevaluations in the time periods covered by their individual state-level studies.

An examination of results from the first two metaevaluations revealed relatively little difference between their respective savings numbers. Similarly, for the third metaevaluation (conducted in 2002), an initial examination of the set of new state-level evaluations—all of which were completed between September 1998 and June 2002—yielded savings results for gas-heated houses that were largely the same as those from the first two metaevaluations. Because of the overall similarity of results across the

[2] SAS is a powerful software system that is widely used to perform a large variety of statistical analyses.

various sets of studies, we decided to include findings from all post-1992 state-level studies in the third ORNL metaevaluation (Berry and Schweitzer 2003). This approach has the advantage of increasing sample size, improving our ability to cover all major climate regions in the U.S., and adding to the statistical rigor of our results.

The overlapping time periods covered by the fist two metaevaluations and the subsequent decision to include all post-1992 studies in subsequent analyses create a situation where the results of the various metaevaluations cannot be compared with each other to identify trends in program performance *within* the period since the national Weatherization Program evaluation. However, it can be very helpful to compare the metaevaluation findings with those of the national evaluation to search for possible changes that have occurred since 1989 – the year addressed by the national evaluation.

Like the third metaevaluation, the current study uses data provided by all state-level evaluations completed since 1993. However, this metaevaluation differs from the previous ones in that the available data are aggregated by state, rather than treating multiple studies of the same state as separate observations. For each relevant variable (e.g., energy savings per gas-heated household) a single average value is used to represent the entire state, which prevents overall study results from being skewed due to the presence of multiple studies with similar results in a single state. In those cases where there is only one study for a state, the average value for a given variable is calculated from all the houses examined in the study, as was the case in previous metaevaluations for single-study states. Where there are multiple studies, though, a *weighted* average is determined for each variable from the average values computed in each study, with the weighting done by sample size. For example, Ohio was the subject of two studies. The first study (with a sample size of 658) showed average natural gas savings of 29.3 million site BTUs per household, while the second (with a sample size of 2,209) indicated average per-household savings of 32.4 million site BTUs. Weighted average savings for both studies combined are calculated with the following equation: [(658*29.3) + (2,209*32.4)]/ (658+2,209). Doing the math reveals weighted average savings of 31.7 million site BTUs per household, which is reflective of the savings reported in each study and their respective sample sizes.

A total of 38 evaluations measuring Weatherization Program energy savings within individual states were completed between 1993 and mid 2005 and used in this study[3]. As shown in Table 1, those studies cover 19 different states, with many states having multiple evaluations. Dwellings heated by natural gas were studied in 17 states, while electrically-heated houses were studied in only six states. In four states, the use of electricity for non-heating (baseload) purposes was examined. (For additional information on each of the individual evaluations used in this study, along with a brief discussion of the methods used in the state-level studies to measure energy savings, see Appendix A.)

[3] In order to be used in this metaevaluation, a state-level study had to measure energy savings in a manner judged by ORNL staff to be both rigorous and well-executed. Even so, there was substantial variation among the studies utilized in terms of sample size, the amount of uncertainty accompanying the results, and the completeness of the findings reported.

The 17 states providing data on natural gas savings are spread across the entire country, from the east to west coasts and the Mexican to Canadian borders. Climate-wise, the sample includes states from hot, cold, and temperate zones. Still, it must be noted that two-thirds of the states did not provide natural gas data for this study, which raises the possibility that the sample examined may not fully represent the nation as a whole. As explained in the following section, the analytical approach used in this metaevaluation has several elements designed to make the findings as representative as possible of the entire Weatherization Program nationwide even though only some states contributed data for the study.

2.3. ANALYZING THE DATA

Gas-heated Houses

As in all previous ORNL metaevaluations of the Weatherization Assistance Program, a regression analysis was performed to show the relationship between energy-savings in gas-heated houses and one or more explanatory variables. Although the number of observations used in the analysis (N=17) is relatively small, the fact that each data point represents the average findings from one or more state-level evaluations gives us reason to trust the results. The regression analysis performed for the current study differs from those done for past metaevaluations in that this one *weights* the values reported for each state based on the percentage of total national Weatherization Program funding which the state receives. In other words, the results achieved by a large state (e.g., New York) are given substantially more weight in the analysis than the results achieved by a small state (e.g., Vermont). This is appropriate, because the purpose of the analysis is to estimate nationwide energy savings based on the findings observed in the states studied. Those states that represent a larger part of the national program, therefore, should contribute more heavily to the analysis. The percentage of total 2004 Weatherization Program funding received by each state providing data for the current metaevaluation is shown in the last column of Table 1.

Initially, a funding-weighted regression analysis was run using the SAS system. Natural gas savings per household was the dependent variable and four independent variables were included, all of which could potentially explain observed variations in savings from state to state. The four independent variables were pre-weatherization natural gas consumption per household, square footage per dwelling weatherized, heating degree days, and per-household weatherization expenditures[4]. The only independent variable that proved to be significantly related to savings in the presence of all the other variables was pre-weatherization consumption. Therefore, a subsequent analysis was run

[4] It is important to note that, for each state, the "per-household" data used in this analysis are mean values calculated from all the individual houses studied statewide. In other words, this metaevaluation is based on average findings from each state and not on raw data from individual households.

Table 1. States providing data for 2005 metaevaluation

State	Number of evaluations performed	Fuel Studied: Natural gas	Fuel Studied: Electricity (including space heating)	Fuel Studied: Electricity (non-heating only)	Percent of national Weatherization Program funding
Colorado	3	x		x	2.41
Delaware	2		x		0.25
District of Columbia	2	x	x		0.29
Georgia	1	x			1.29
Illinois	1	x			6.10
Indiana	2	x			2.88
Iowa	7	x		x	2.20
Kansas	1	x			1.11
Minnesota	2	x			4.34
Nebraska	1	x			1.10
New York	1	x			8.88
North Carolina	1	x			1.83
Ohio	2	x	x		6.05
Texas	3	x	x		2.45
Vermont	3	x		x	0.56
Washington	1	x	x		2.00
West Virginia	1			x	1.41
Wisconsin	2	x		x	3.77
Wyoming	2	x			0.52

using per-household energy savings as the dependent variable and pre-weatherization energy use per household as the sole explanatory variable. The regression equation produced by that analysis [energy savings = -10.883 + (pre-weatherization energy use * 0.311)] was used to estimate average nationwide energy savings per gas-heated household for the Weatherization Program. The savings estimate was produced by plugging the average nationwide value for pre-weatherization natural gas consumption per participating household[5] (133 million site BTUs) into the regression equation and calculating the result. In this way, average per-household savings was calculated for the nation as a whole and not just for the states that provided data used in the metaevaluation. The resulting savings number was then used to calculate per-household savings as a

[5] The average value for pre-weatherization natural gas consumption per household was taken from the last national evaluation of the Weatherization Assistance Program (Brown, Berry, Balzer, and Faby 1993). Although the number is relatively old, it still represents the best available estimate of energy use by low-income households that participate in the Program. The 133 million site BTUs reported in that study is very similar to the weighted average for pre-weatherization natural gas consumption per household found in the current metaevaluation (129 million site BTUs).

percentage of pre-weatherization consumption of natural gas for all end uses and as a percentage of pre-weatherization consumption for space heating[6]. Complete findings from the analysis are reported in Chapter 3.

Electrically-heated Houses

Because the number of states reporting findings for electrically-heated houses was quite small (N=6), we considered it inadvisable to use these limited data in a regression analysis for the purpose of estimating nationwide savings. Instead, we calculated *weighted* average electricity savings per household for the six states, using the percentage of total Weatherization Program funding received by each state as the weighting factor. We also calculated weighted average per-household savings as a percentage of pre-weatherization consumption of electricity for all end uses and as a percentage of pre-weatherization space-heating consumption[7]. For comparative purposes, we calculated unweighted means for the same variables as well. Because of the small number of observations, these numbers are not considered reliable estimates of program-wide savings and are therefore reported in Appendix B rather than in the body of the report.

Houses Using Electricity Only for Non-heating Purposes

Weighted and unweighted average per-household savings for houses that used electricity only for non-heating purposes were calculated from data provided by four states. Three states reported both savings *and* pre-weatherization electricity use, and average per-household savings as a percentage of pre-weatherization energy consumption were computed from those data. Because the number of observations for these baseload savings is so small, the averages that we calculated are not considered reliable estimates of program-wide savings. Therefore, they are reported in Appendix C rather than in the body of the report.

[6] While all of the state-level studies provided data on pre-weatherization consumption of natural gas for all end uses, very few of them reported the amount of natural gas used during the pre-weatherization period for space heating. Where that value was missing, we calculated it based on the finding from the last national Weatherization Program evaluation that heating accounted for 71% of total household natural gas usage.

[7] Average percentage savings were calculated from the percentages computed for each individual state rather than by dividing average savings from all studies combined by average pre-weatherization consumption. Where pre-weatherization consumption for space heating was missing, we calculated it based on the finding from the last national evaluation that heating accounted for 34% of total household electricity use.

3. FINDINGS

3.1. ESTIMATED PROGRAM-WIDE NATURAL GAS SAVINGS

A regression analysis was performed using data from 17 states that studied energy savings in dwellings heated with natural gas. To make the available data as representative as possible of the national Weatherization Assistance Program, the values reported for the individual states were weighted based on the percentage of the total Weatherization Program budget which each state receives. The initial analysis used per-household natural gas savings as the dependent variable and included several independent variables that could potentially help explain the magnitude of savings. However, pre-weatherization consumption per household turned out to be the only independent variable that was significantly related to energy savings. The analysis revealed a positive relationship between savings and pre-weatherization energy use (R-Square = 0.419; p = 0.005). The R-Square of 0.419 means that 41.9% of the variance in observed energy savings is explained by pre-weatherization consumption, and the p-value of 0.005 indicates a probability of only five in one thousand that the observed relationship could have occurred by chance. Figure 2 shows where actual state savings fall in relation to the line predicted by the regression analysis.

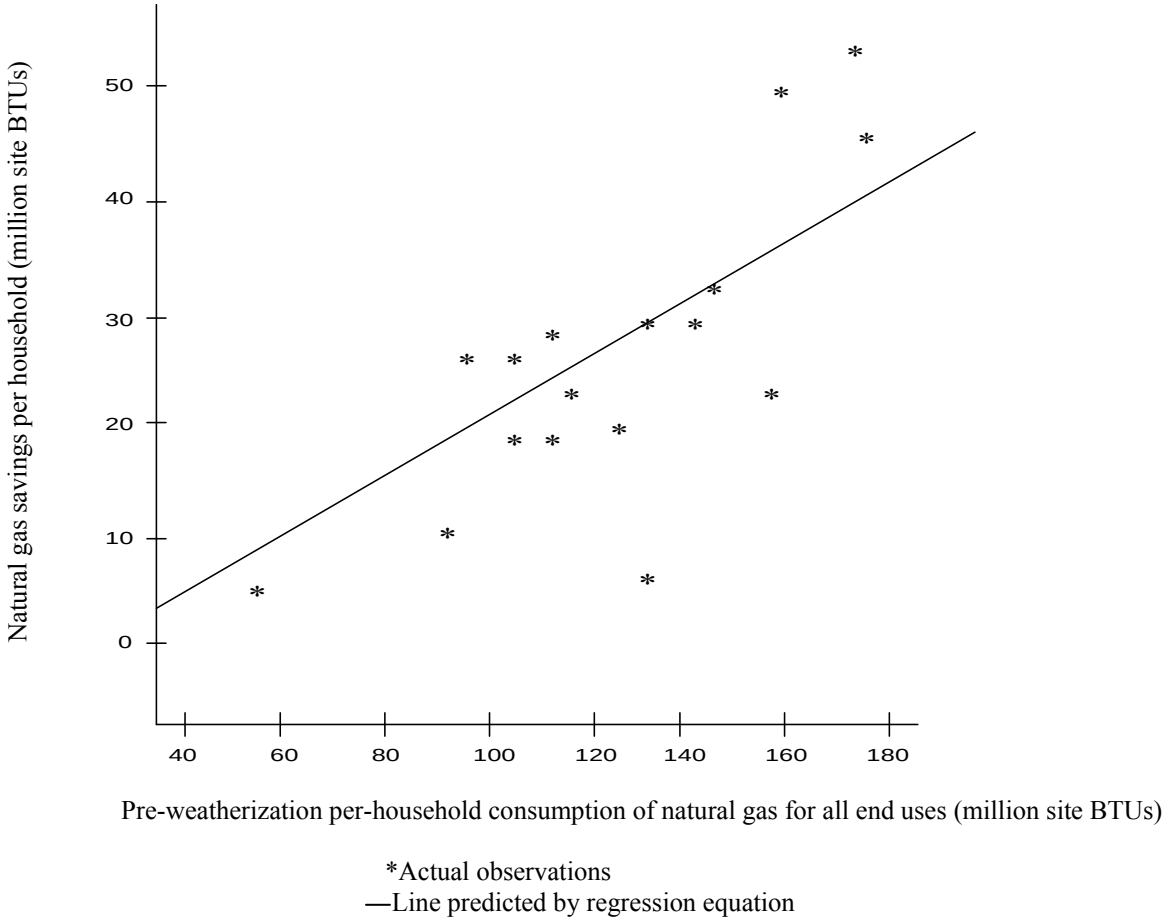

Figure 2. Plot of energy savings by pre-weatherization consumption for natural gas-heated structures

Pre-weatherization energy consumption per household has been shown to have a strong relationship with per-household energy savings in gas-heated dwellings by all three past metaevaluations and the national Weatherization Program evaluation. Although the strength of that relationship (as indicated by the R-Square value) is lower this time than in past metaevaluations[8], the relationship itself is very similar to that revealed in past studies. In fact, the regression equation produced by the current metaevaluation [gas savings = -10.883 + (pre-weatherization natural gas consumption * 0.311)] is nearly identical to the equation generated by the previous metaevaluation [gas savings = -11.29 + (pre-weatherization natural gas consumption * 0.3035)].

The regression equation generated by the current metaevaluation was used to produce an estimate of average per-household energy savings nationwide for Weatherization Program participants heating with natural gas. This was done by taking the average value for pre-weatherization energy consumption per gas-heated household participating in the Weatherization Assistance Program, inserting it into the equation, and calculating the result. The pre-weatherization natural gas consumption number (133 million site BTUs) was taken from the last national Weatherization Program evaluation, which studied participating households throughout the nation.

The average energy savings per gas-heated household calculated using the above approach is 30.5 million site BTUs [-10.883 + (133 * 0.311)]. This is very similar to the funding-weighted mean value for the 17 states studied in this metaevaluation (29.2 million site BTUs). It is also close to the natural gas savings numbers generated by the regression analyses performed in the previous metaevaluation (29.1 million site BTUs), the second metaevaluation (26.1 million site BTUs), and the first metaevaluation (31.2 million site BTUs). However, it is substantially higher than the average per-household savings reported in the national Weatherization Program evaluation (17.3 million site BTUs), which was based on an extensive study of dwellings weatherized in 1989.

Table 2 shows estimated average savings per gas-heated household nationwide from the current metaevaluation, the three previous metaevaluations, and the national Weatherization Program evaluation. In addition to presenting point estimates of the mean values generated by each study, the table also gives 90% confidence intervals for them. This means that we can be 90% certain that the actual mean value for the population of interest (in this case, houses treated by the Weatherization Assistance Program during the relevant time period) falls somewhere between the low and high ends

[8] The drop in the R-Square value (from 0.671 in the previous metaevaluation to 0.419 in this one) can be explained to a large extent by the addition of a new, heavily-weighted state for which the observed relationship between pre-weatherization energy use and savings is substantially different than for most of the other states that contributed data. Removing this state from the sample and running the weighted regression analysis with the remaining 16 states would increase the R-Square to 0.708.

Table 2. Estimated average national savings in gas-heated houses

Study	Average natural gas savings per household (million site BTUs)	Average savings per household as percentage of pre-weatherization consumption of natural gas for all end uses (%)	Average savings per household as percentage of pre-weatherization consumption of natural gas for space heating (%)
Current Metaevaluation	.		
Point estimate	30.5	22.9	32.3
90% confidence interval	26.0 – 35.0	19.5 – 26.3	27.5 – 37.1
Third metaevaluation			
Point estimate	29.1	21.9	30.8
90% confidence interval	26.6 – 31.6	19.9 – 23.8	28.1 – 33.5
Second metaevaluation			
Point estimate	26.1	19.6	27.6
90% confidence interval	19.4 – 32.8	14.6 – 24.6	20.5 – 34.7
First metaevaluation			
Point estimate	31.2	23.4	33.5
90% confidence interval	22.9 – 38.6	17.2 – 29.0	24.6 – 41.4
National evaluation			
Point estimate	17.3	13.0	18.3
90% confidence interval	15.1 – 19.5	11.3 – 14.7	16.0 – 20.6

of the confidence interval[9]. As shown, there is substantial overlap among the confidence intervals for average household savings generated by all four metaevaluations. This indicates that actual mean savings for the dwellings examined in those four studies are likely to fall within comparable ranges. This is not at all surprising, because the various metaevaluations used data from many of the same state-level studies.

In contrast to the similarity of findings for the four metaevaluations, there is no overlap at all between the 90% confidence interval for the current metaevaluation and the

[9] It should be noted that the breadth of the confidence interval varies among the different evaluations. A broader confidence interval is reflective of higher variability in the data and greater uncertainty of results. Generally, a broader confidence interval is associated with lower R-Square values and smaller sample sizes. For example, the confidence interval for average savings per household is considerably broader for the current metaevaluation than for the previous one, and the current metaevaluation has a smaller sample size (17 compared to 28) and R-Square (0.419 compared 0.671) than the previous metaevaluation.

confidence interval for the national evaluation. In fact, there is a substantial gap between the low end of the former and the high end of the latter. To test this apparent difference, mean per-household energy savings from the two studies were compared using a two-sample t-test. Not surprisingly, the results show that the magnitude of natural gas savings per household calculated in the current metaevaluation is significantly greater than the amount of savings reported in the national evaluation ($p<0.001$).

Table 2 also presents findings from all the previously-mentioned studies on per-household savings as a percentage of pre-weatherization consumption of natural gas for all end uses *and* as a percentage of pre-weatherization consumption for space heating. Once again, there is substantial overlap among the findings from the four metaevaluations and a substantial difference between those results and the findings from the national Weatherization Program evaluation. It is interesting to note that the current metaevaluation shows that average energy savings per household amount to 22.9% of pre-weatherization consumption of natural gas for all end uses and 32.3% of the natural gas used for space heating. In contrast, the national evaluation found savings equal to 13.0% of natural gas usage for all household purposes and 18.3% of space heating consumption.

3.2. COST-EFFECTIVENESS RESULTS FOR GAS-HEATED DWELLINGS

Benefit-cost ratios for the gas-heated dwellings studied in this metaevaluation were calculated from two different perspectives. The *program perspective* compares the time-discounted value of energy savings to total program costs (including labor, materials, overhead, administrative expenses, and all other categories of fixed or variable costs). The *societal perspective* uses the same approach to calculating costs, but it factors in the value of both energy *and* non-energy benefits.

The discounted value of natural gas savings was calculated from the estimated average national energy savings determined by this metaevaluation (30.5 million site BTUs per household per year). These energy savings were converted into 2003 dollars based on the commonly-used assumption that the average useful life of the installed measures is 20 years. Actual energy prices and forecasts for the period 2003-2022 were obtained from the Energy Information Administration's *Annual Energy Outlook 2005* report and these were used to calculate the cost of 30.5 million site BTUs of natural gas over a 20 year period. A discount rate of 2.9% was used, which is the rate suggested in OMB Circular No. A-94 for 2003 (U.S. Office of Management and Budget 2003). Following this approach, a discounted energy savings value of $3,917 was calculated.

The discounted value of non-energy benefits was taken from a recent ORNL study of this subject (Schweitzer and Tonn 2002). Adjusting the lifetime value of the

benefits reported in that study to 2003 dollars yields a benefit of $3,466[10].

To calculate average program costs, we began by compiling the total costs of weatherizing gas-heated houses reported for each state studied in this metaevaluation. Then, each state's costs were converted to 2003 dollars, to correspond with the energy savings numbers described above. Finally, a weighted average of program costs was calculated from all the costs reported by the states, weighting each state's share by the proportion of the total national Weatherization Program budget allocated to that state. The resulting cost number, which is used to represent the average cost nationwide of weatherizing a gas-heated house, is $2,913. This number is substantially higher than that used in the previous metaevaluation, and the increase is mainly due to the addition of new data from a heavily-weighted state with relatively high program expenditures. Removing that state from the sample would result in a weighted mean expenditure of $2,568, which is almost identical to the inflation-adjusted expenditure number ($2,558 in 2003 dollars) used to calculate the benefit-cost ratio in the previous metaevaluation.

Using the program perspective, we compute a benefit-cost ratio of 1.34 ($3,917/ $2,913). This means that every dollar spent on weatherizing gas-heated homes results in $1.34 in lifetime energy savings. Under the societal perspective, the benefit-cost ratio is 2.53 [($3,917 + $3,466)/$2,913], which is almost twice that computed from the program perspective. In other words, every weatherization dollar spent results in $2.53 in energy and non-energy benefits combined. *Actual* benefit-cost ratios are likely to be higher than those shown here, because the expenditures reported in the state-level studies often included the cost of installing measures designed to reduce baseload electricity consumption while the savings numbers were for natural gas only. If the cost of baseload electric measures could be identified and removed from the equation, the benefit-cost ratios for gas-heated dwellings would almost certainly be greater than those reported here.

[10] In that study, non-energy benefits were divided into three major categories: ratepayer benefits; household benefits; and societal benefits. In 2003 dollars, ratepayer benefits were $343, household benefits amounted to $938, and societal benefits equaled $2,185. Altogether, benefits in those three broad areas totaled $3,466, as reported above.

4. SUMMARY AND CONCLUSIONS

4.1. SUMMARY

This study, like the three previous metaevaluations, was undertaken to update the findings from the national Weatherization Program evaluation conducted by ORNL in the early 1990s. All of the metaevaluations, including this one, have focused primarily on energy savings in homes heated by natural gas because the large majority of state-level studies have addressed that fuel. In contrast, far fewer studies have addressed energy savings in electrically-heated homes and in dwellings using electricity only for baseload purposes, and the average savings numbers that can be calculated from those few studies are not considered reliable estimates of program-wide savings.

The current metaevaluation took data provided by all state-level evaluations completed since 1993 and aggregated them by state rather than treating multiple studies of the same state as separate observations, as had been done in the previous ORNL metaevaluations. We ended up with data on 19 states, 17 of which addressed savings in dwellings heated by natural gas. A regression analysis was conducted for gas-heated houses, with each state's data weighted by its share of total national Weatherization Program funding. Energy savings per household was used as the dependent variable and pre-weatherization energy use per household was the sole explanatory variable. The resulting regression equation, along with available data on average pre-weatherization energy consumption by program participants, was used to estimate nationwide energy savings in gas-heated houses.

This study estimated average energy savings per gas-heated household nationwide to be 30.5 million site BTUs. This latest natural gas savings number is similar to the per-household savings estimates generated by the three previous ORNL metaevaluations (29.1, 26.1, and 31.2 million site BTUs) but is substantially higher than the average savings reported in the national Weatherization Program evaluation (17.3 million site BTUs). The similarity among mean savings estimates from the various ORNL metaevaluations is not surprising because those meta analyses used data from many of the same state-level studies. In contrast to the similarity of findings for the four metaevaluations, we found a statistically significant difference between the natural gas savings per household calculated in the current metaevaluation and the savings reported in the national evaluation.

The current metaevaluation found average energy savings per household equal to 22.9% of pre-weatherization consumption of natural gas for all end uses and 32.3% of the natural gas used for space heating. This contrasts with the findings of the national evaluation, which reported per-household savings amounting to 13.0% of natural gas usage for all household purposes and 18.3% of space heating consumption.

Benefit-cost ratios for the gas-heated dwellings studied in this metaevaluation were calculated from the program perspective, which compares the value of energy

savings to total program costs, and the societal perspective, which uses the same approach to calculating costs but counts both energy *and* non-energy benefits. The benefit-cost ratios for gas-heated houses served by the Weatherization Assistance Program were computed to be 1.34 from the program perspective and 2.53 using the societal approach. *Actual* benefit-cost ratios are likely to be higher than this because reported expenditures included the cost of installing measures to reduce baseload electricity consumption but only natural gas savings were used in the calculations.

4.2. CONCLUSIONS

It is not surprising that per-household energy savings in gas-heated dwellings was found to be significantly higher by the current ORNL metaevaluation (which is based on state-level studies completed after 1992) than by the national Weatherization Program evaluation (which focused on houses weatherized in 1989). Starting in the early 1990s, advanced audits became increasingly common and the use of blower-doors as a diagnostic tool also increased dramatically. A good description of these changes is provided in a discussion of the reasons for increased savings in the Iowa Weatherization Assistance Program between 1988 and 1995 (Pigg, Dalhoff, and Gregory 1995). The authors point out that, by 1995, the emphasis of the Iowa program had shifted from measures such as caulking, weather-stripping, and storm windows to blower-door guided air sealing and the installation of high density cellulose in wall cavities.

By 1995, weatherization measure selection was commonly guided by advanced computer audit tools or measure lists based on such tools. These customize recommended measure lists to optimize returns on a house-by-house basis. Advanced audits can be expected to produce higher savings than the simple priority list approach that had dominated measure selection in the 1980s, because priority lists assume that the same measure ranking will be equally suitable for all houses. Advanced audits, with their customized measure selection, were shown to increase average savings by more than 10% in two experimental field tests conducted in the 1990s (Sharp 1993; New York State Energy and Research Development Authority and New York Department of State 1993).

While the widespread adoption of advanced audits and the growing use of blower-door directed air sealing and high density wall insulation contributed to savings increases in gas-heated houses between the 1980s and mid 1990s, there have been no equally dramatic or widespread changes in Weatherization Program practices affecting heating energy consumption since that time.

While metaevaluations performed over the last decade have consistently shown higher per-household natural gas savings than those reported in the national evaluation, there is a need to corroborate those findings through a rigorous examination of Weatherization Program efforts nationwide. Even the current metaevaluation is based on studies performed in only a third of the states, and those may not be fully representative of the entire Weatherization Program. Also, the value for pre-weatherization energy consumption, which is a major input for the calculation of national savings, is based on

1989 data. In addition, while state-level evaluations have put a strong emphasis on gas-heated houses, few studies have been conducted on electrically-heated dwellings. And it is important to note that the biggest recent change to the Weatherization Program – the addition of baseload measures such as highly efficient refrigerators, water heaters, and light bulbs – has barely been addressed by state-level studies. For all these reasons, there is a strong need for a new national evaluation to thoroughly explore the current operations and achievements of the Weatherization Program across the entire nation.

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APPENDIX A

DETAILED INFORMATION ON STATE-LEVEL EVALUATIONS

The following table presents detailed information on the 38 individual state-level studies that provided data for the current metaevaluation. It should be noted that the year(s) in which houses were weatherized often preceded the actual publication of this state-level study by several years because of the time required for post-weatherization data collection and for analysis and report preparation.

Table A.1. Key descriptors of state-level evaluations

State	Years in which houses were weatherized	Number of gas-heated houses studied	Number of electrically-heated houses studied	Number of non-heating (baseload) electric houses studied
Colorado	1993 – 1995	3,431	—	—
Colorado	1995 – 1996	2,442	—	1,937
Colorado	1998 – 1999	1,265	—	—
Delaware	1995	—	25	—
Delaware	2002	—	17	—
District of Columbia	1995	159	10	—
District of Columbia	2001 – 2002	100	—	—
Georgia	1997	60	—	—
Illinois	2002 – 2003	2,056	—	—
Indiana	1991 – 1992	53	—	—
Indiana	1993 – 1994	49	—	—
Iowa	1992 – 1993	637	—	—
Iowa	1996	1,907	—	2,284
Iowa	1997	1,877	—	2,229
Iowa	2000	1,655	—	1,949
Iowa	2001	1,706	—	1,987
Iowa	2002	1,807	—	2,080
Iowa	2003	1,588	—	1,813

Table A.1. (Continued)

State	Year(s) in which houses were weatherized	Number of gas-heated houses studied	Number of electrically-heated houses studied	Number of non-heating (baseload) electric houses studied
Minnesota	1995 – 1996	32	—	—
Minnesota	1996 – 1997	44	—	—
Nebraska	1994	37	—	—
New York	1990	187	—	—
North Carolina	1994	40	—	—
Ohio	1990 – 1991	658	—	—
Ohio	1993 – 1994	2,209	154	—
Texas	1991 – 1992	9	81	—
Texas	1997	130	—	—
Texas	1997 – 2000	317	858	—
Vermont	1992 – 1993	149	—	—
Vermont	1995 – 1996	35	—	82
Vermont	1998 – 2002	25	—	9
Washington	1998	71	114	—
West Virginia	1997 – 1998	—	121	—
Wisconsin	1991 – 1993	675	—	—
Wisconsin	2001 – 2003	7,869	—	11,200
Wyoming	1995	38	—	—
Wyoming	1995 – 1996	82	—	—

The state-level studies used a variety of methods to measure energy savings. In the majority of cases, savings were identified by tracking monthly utility bills for a period of approximately 12 months before and 12 months after weatherization. These billing records were most often analyzed with a software system called PRISM, which stands for PRInceton Scorekeeping Method (Fels, Kissock, Marean, and Reynolds 1995; Fels and Reynolds 1990). Other, less commonly used, methods include: attaching data loggers to heating systems to directly measure run-time; conducting econometric analysis; using

alternatives to PRISM for weather-normalizing energy consumption; and adjusting engineering estimates of savings for all weatherized houses with adjustment factors developed through a PRISM analysis performed on a subset of dwellings.

APPENDIX B

ENERGY SAVINGS IN ELECTRICALLY-HEATED HOUSES

Six states provided data on energy savings in electrically-heated houses for the current metaevaluation. They are Delaware, the District of Columbia, Ohio, Texas, Washington, and West Virginia. Because this is such a small sample, we considered it inadvisable to use the available data in a regression analysis. Instead, we calculated average per-household savings for the states, both weighted (by each state's share of total Weatherization Program funding) and unweighted. Those findings are indicative of the outcomes that some state-level weatherization efforts have achieved but, because of the small number of observations, they are not considered reliable estimates of program-wide savings.

Table B.1 shows that average per-household energy savings were much less for electrically-heated dwellings than for those that heat with natural gas. It also demonstrates that, in this case, weighting the data by the proportion of funding received by each state yields a slightly lower savings number (6.6 million site BTUs) than calculating a simple, unweighted average (7.1 million site BTUs).

Table B.1. Average savings in electrically-heated houses, with comparison to national savings estimate for gas-heated dwellings

Fuel/Analysis	Average savings per household (million site BTUs)	Average savings per household as percentage of pre-weatherization consumption for all end uses(%)	Average savings per household as percentage of pre-weatherization consumption for space heating (%)
Electricity/weighted average			
Point estimate	6.6	9.0	19.8
90% confidence interval	3.7 – 9.4	6.6 – 11.5	12.3 – 27.4
Electricity/unweighted average			
Point estimate	7.1	10.3	25.6
90% confidence interval	4.0 – 10.2	6.9 – 13.7	15.3 – 36.0
Natural gas/weighted regression analysis			
Point estimate	30.5	22.9	32.3
90% confidence interval	26.0 – 35.0	19.5 – 26.3	27.5 – 37.1

Average per-household savings in electrically-heated dwellings equaled 9.0 % of pre-weatherization consumption for all end uses, when weighting by percent of Weatherization Program funding received by each state. The unweighted average savings per household for electrically-heated dwellings amounted to 10.3 % of pre-weatherization energy use. This is in marked contrast to the situation in gas-heated houses, where average savings per household equaled 22.9 % of pre-weatherization consumption for all end uses. An important factor behind the smaller percentage savings in electrically-heated houses is that electricity typically is used in a much broader variety of applications than is natural gas and many of those electricity uses are not addressed by Weatherization Program measures.

When we examine average savings per household as a percentage of the pre-weatherization energy used only for space heating, we observe a much greater similarity in the results for electrically- and gas-heated houses. Average per-household savings in electrically-heated dwellings as a percentage of pre-weatherization space heating consumption was 19.8% when weighting by funding and 25.6% using a simple, unweighted average. For dwellings heated with natural gas, average savings per household was 32.3% of pre-weatherization consumption for space heating.

The fact that data on savings in electrically-heated homes are available for only six states indicates the need for additional study. The considerable size of the confidence intervals relative to average savings (Table B.1) demonstrates the magnitude of uncertainty in the savings estimates made from the state-level information that is currently available; this too is an indication that further study is needed. Data on a representative sample of electrically-heated dwellings nationwide are needed to allow reliable estimates of program-wide savings to be made.

APPENDIX C

ENERGY SAVINGS IN HOUSES USING ELECTRICITY ONLY FOR NON-HEATING PURPOSES

The current metaevaluation examined data from four states on energy savings in houses using electricity only for non-heating (baseload) purposes. The four are Colorado, Iowa, Vermont, and Wisconsin. While all four states reported electricity savings, only three reported pre-weatherization electric use, which is needed to calculate percentage savings. As was done for electrically-heated houses (Appendix B), we calculated average per-household savings, both weighted (by each state's share of total Weatherization Program funding) and unweighted. Those findings provide a partial view of the savings in baseload electricity that can be achieved by weatherization efforts, but the sample is too small to let us make reliable estimates of program-wide savings.

As shown in Table C.1, average savings per household for baseload electricity applications equaled 2.1 million site BTUs when weighting by the proportion of Weatherization Program funding received by each state. Simple, unweighted savings amounted to 1.7 million site BTUs. It is important to note the very large size of the 90% confidence intervals relative to those average savings numbers. This is a clear indicator of major uncertainty in the savings estimates.

Table C.1. Average savings in houses using electricity only for non-heating purposes

Type of Savings	Average savings per household (million site BTUs)	Average savings per household as percentage of pre-weatherization consumption for all end uses (%)
Weighted average		
Point estimate	2.1	7.5
90% confidence interval	0.5 – 3.7	-2.9 – 17.8
Unweighted average		
Point estimate	1.7	5.5
90% confidence interval	0.2 – 3.2	-4.0 – 14.9

Average electric baseload savings per household equaled 7.5 % of pre-weatherization consumption for all end uses, when weighting by each state's share of Weatherization Program funding. Unweighted average per-household savings amounted to 5.5% of pre-weatherization energy use. Once again, the extremely broad confidence bands surrounding those point estimates should be noted.

Data from several studies conducted in Iowa over the last few years show that average electricity savings per household have increased dramatically with the addition of refrigerator and freezer exchanges to the state's weatherization program. And recent findings from Wisconsin show considerable savings from refrigerator replacements, as well as from water heater conversions and, to a lesser extent, lighting measures.

Because only four states provided data on baseload electricity savings, and because the uncertainty associated with the average savings calculated from that small sample is very great, there is a strong need for more study of this topic. Such an undertaking is especially important in light of the fact that the biggest change to the Weatherization Program in recent years has been the addition of measures that target non-heating energy consumption. Data on a representative sample of dwellings nationwide are needed to allow reliable estimates of program-wide savings to be made.

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