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Energy Division

EVALUATION OF THE WASHINGTON STATE WEATHERIZATION ASSISTANCE PROGRAM

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EXECUTIVE SUMMARY

INTRODUCTION

Since 1976, the national Weatherization Assistance Program has been working to improve the energy efficiency of dwelling units occupied by low-income residents. Sponsored by the U.S. Department of Energy and implemented by state and local agencies, the program is active in all 50 states and the District of Columbia. This report focuses on the recent outcomes of Washington State's weatherization efforts. The performance of the Washington Weatherization Program is of interest because few evaluations have been performed in this part of the country *and* because Washington contains a high proportion of electrically-heated houses, which have received relatively little examination in the past. This study, which calculates the magnitude of energy savings for both electrically-heated and gas-heated houses and compares program benefits and costs, was initiated by Oak Ridge National Laboratory (ORNL) in the summer of 1998.

METHODS

Based on a list of recently-weatherized houses provided by staff involved in the Washington Weatherization Program, ORNL randomly selected 500 dwelling units and requested descriptive information and a minimum of 12 months of pre-weatherization billing data for each of them. Later, post-weatherization bills were requested for those households providing good data in response to the first request. Eventually, at least nine months of usable data were received for 312 houses; 221 of them were electrically-heated and 91 used natural gas as their primary heating fuel. After additional screening associated with PRISM, a software system used to analyze the billing data, we ended up with 114 electrically-heated houses and 71 gas-heated houses with highly reliable energy consumption and savings data.

Using the PRISM software and local temperature data, energy consumption was normalized so that usage during the pre-weatherization and post-weatherization periods could be compared to each other without the confounding effects otherwise caused by annual temperature fluctuations. The pre- and post-weatherization consumption numbers for each house were then compared to each other to yield normalized annual savings. In addition to calculating energy savings with PRISM, regression analyses were performed to identify relationships between two important savings measures and several potential explanatory variables. The savings measures were normalized annual savings and savings as a percentage of pre-weatherization whole-house energy use. The potential explanatory variables were: pre-weatherization normalized annual consumption; total weatherization costs; the floor area of the house; and heating degree days for the local area.

The cost effectiveness of the Washington Program was assessed by comparing the cost of the energy saved to the costs of performing the weatherizations. Benefit/cost ratios were calculated for three different perspectives: installation, program, and societal.

KEY FINDINGS

The energy savings experienced by participants in the Washington State Weatherization Assistance Program are summarized in Table ES-1. For electrically heated houses, mean normalized annual savings were 2,991 kWh, which amounted to 12.0 % of pre-weatherization whole-house electricity use and 18.6% of the pre-weatherization electricity used for space heat. For the gas-heated houses, mean normalized annual savings were 230.1 CCF, which was 25.4% of pre-weatherization whole-house gas use and 30.8% of the pre-weatherization gas used for space heat.

Table ES-1. Average Energy Savings

	Mean Normalized Energy Savings	Mean Energy Savings as a Percent of Pre-Weatherization Whole-House Energy Use	Mean Energy Savings as a Percent of Pre-Weatherization Energy Use for Space Heat
Electrically-Heated Houses (N=114)	2,991 kWh	12.0%	18.6%
Gas-Heated Houses (N=71)	230.1 CCF	25.4%	30.8%

As shown above, the savings percentages were substantially larger for the gas-heated households. The difference in savings as a percent of pre-weatherization whole-house energy use can be explained by the fact that there is generally much more household electricity than gas used for applications (e.g., lighting, refrigerators, clothes washers) that are not affected by the energy-efficiency measures installed by the Weatherization Assistance Program. Therefore, when weatherization-induced savings are divided by whole-house energy use, there is more to divide by when the fuel is electricity. As for savings as a percent of pre-weatherization energy used for space heating, there are two plausible explanations of why the numbers for the gas-heated houses were so much higher. First, total expenditures in the typical gas-heated house were larger than for the average electrically-heated dwelling, and higher expenditures tend to be associated with greater savings. Second, it is possible that PRISM overestimated the amount of total energy consumption that was used for space heating in the electrically-heated houses, which would make energy savings as a percentage of space heating energy use appear smaller than it actually was.

For both the electrically-heated and gas-heated houses, greater weatherization expenditures were associated with higher energy savings, both in absolute terms as well as relative to how much energy they used prior to weatherization. Also, those houses that used more energy before being weatherized—regardless of heat source—tended to realize higher absolute savings as a result of the weatherization measures installed. For electrically-heated houses, the units with higher pre-weatherization consumption also tended to have greater savings as a percent of pre-weatherization usage.

While the savings percentages were higher in gas-heated houses, the benefit/cost ratios were greater for the electrically-heated units. This was the case in part because electricity is a more expensive fuel, meaning that the monetary benefit of the energy saved was higher in the electrically-heated houses. In addition, the amount of money spent on weatherizing the gas-heated dwellings tended to be higher. However, in both the gas- and electrically-heated homes, average benefit/cost ratios greater than 1.00 were calculated with one or more sets of inputs and assumptions for the entire data set.

The Washington State Weatherization Assistance Program has achieved substantial energy savings in both electrically-heated and gas-heated houses. Washington is in the top one-third nationwide in terms of program-induced energy savings compared to the savings achieved by other states whose weatherization programs were evaluated in the past 10 years. Also, the relationships between energy savings and both pre-weatherization consumption and weatherization expenditures identified in this study are consistent with the findings from earlier studies. These findings suggest that households with high energy consumption make effective targets for state weatherization efforts and that increasing the amount spent per household leads to greater energy savings.

1. INTRODUCTION

1.1 BACKGROUND

The national Weatherization Assistance Program has been working since 1976 to improve the energy efficiency of housing units occupied by low-income residents. Under the sponsorship of the U.S. Department of Energy, the program is implemented by state and local agencies and is active in all 50 states and the District of Columbia. Using Weatherization Assistance Program funding—which often is supplemented by contributions from other federal, state, or utility programs—the states work closely with local agencies (known as "subgrantees") to install appropriate weatherization measures in qualifying dwelling units. The Weatherization Program in Washington State is the focus of this report. In Washington State, the main weatherization measures are attic, floor and wall insulation; diagnostically directed air sealing of the heated living area and heating ducts; and furnace efficiency modifications.

With approximately 5.75 million residents (U.S. Bureau of the Census 1999), Washington is the 15th most populace state in the Union. Its land area of 66,582 square miles extends from British Columbia on the north to Oregon on the south and Idaho on the east. It's western boundary is the Pacific Ocean. Because of its size and topographic diversity, Washington experiences substantial climatic variation within its borders. For example, in Seattle, adjacent to Puget Sound, the average annual number of heating degree days is 4,611 (National Climatic Data Center 1997). In contrast, Spokane, which is located on the other side of the Cascade Mountain Range in close proximity to the Idaho state line, has 6,842 heating degree days in a typical year—almost 50% more than Seattle.

The Washington State weatherization program is implemented by 26 subgrantees located throughout the state. Most of these agencies are Community Action Programs, but other types of organizations are represented as well, such as housing authorities and human services departments. Not surprisingly, a number of the agencies are located in the vicinity of the Seattle-Tacoma area, because of the concentration of population there. A few more are located in or near Spokane and there are a couple of agencies in the Yakima area. A couple of subgrantees also serve the Olympic Peninsula, while the other agencies are spread through the remaining areas of the state.

In recent years, both the Washington Department of Community, Trade and Economic Development, which administers the state's weatherization program, and the U.S. Department of Energy, which provides substantial funding for it, have been very interested in evaluating the performance of the Washington Weatherization Assistance Program. The state has an obvious interest in understanding how well its efforts to save energy in low-income households are succeeding and how cost-effective those efforts are. The performance of the Washington weatherization program is of interest to the *national* program managers because few evaluations have been performed in this part of the country and also because Washington contains a high proportion of electrically-heated houses and this type of unit has been studied relatively little in the past. Oak Ridge National Laboratory, which has examined the performance of the

Weatherization Assistance Program around the country for a number of years, was engaged to perform the Washington State evaluation and began its study in the summer of 1998.

1.2 SCOPE OF REPORT

The subsequent chapters of this report describe the research methods used in this study and discuss key findings. Chapter 2 describes how houses were selected for the study, the kinds of data that were collected, and how these data were analyzed. In Chapter 3, the magnitude of energy savings is presented separately for electrically-heated and gas-heated houses, and the major explanatory factors associated with these savings are discussed. Chapter 4 contains a benefit/cost analysis, comparing the amount of money saved by the weatherized houses over time with the costs of weatherizing them. Finally, Chapter 5 concludes by summarizing the findings of this study and what they tell us about the Washington State Weatherization Assistance Program.

2. METHODS

2.1 SAMPLING

In mid 1998, 22 of the 26 subgrantees involved in the Washington State weatherization program responded to a request to compile and submit lists of the houses that they had weatherized in the recent past. The subgrantees were asked to list only single family houses or multi-family dwellings containing less than five dwelling units; mobile homes were not to be included. Each house was to have a metered energy source (i.e., electricity or natural gas) so that energy consumption could be easily tracked. In total, the 22 participating agencies generated a list of nearly 1,000 houses, most of which had weatherization completion dates between late 1996 and early 1998. From the combined list, ORNL randomly selected 500 houses and requested descriptive information on the weatherized units (State of Washington 1997) and a minimum of 12 months of pre-weatherization billing data for each of them. Because nearly all of the subgrantees operating in the state submitted lists of weatherized units, and because the sample of 500 houses to study was selected at random from those lists, it is very likely that the units contained in the sample are representative of all houses weatherized in Washington State during the study period.

Originally, ORNL staff planned to collect billing data from a group of non-weatherized low-income households as well, to use as a control group. However, most of the subgrantees did not have adequate data to allow them to assemble lists of non-weatherized units that were occupied by low-income residents, that were similar to the weatherized units in terms of housing type and fuel source, and that had not had a change in occupants during the period in question. Since the data that *could* be gathered on non-participants was not at all representative of Washington's different climatic zones or the urban/rural mix of the state, the decision was made to conduct the study without the benefit of a control group.

Data compiled by ORNL from secondary sources (EIA 1999a; EIA 1999b; EIA 1997) as well as from the billing data gathered for weatherization program participants indicate that the price of electricity and natural gas to residential customers in Washington State remained virtually unchanged—except for minor fluctuations—between 1995 and 1999[1]. The fact that fuel prices remained constant throughout the study period means that there was no significant economic incentive for customers to reduce energy consumption on their own. Therefore, it seems safe to assume that, on average, energy use by households that did *not* participate in the Weatherization Assistance Program probably remained largely unchanged during the study period. Under these circumstances, it is unlikely that the addition of a control group would have significantly changed

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[1]The average residential price for electricity in Washington increased from 4.97 cents per kWh in 1995 to 5.03 cents in 1996. It then went down to 4.95 cents in 1997 and back up to 5.03 cents in 1998. Between early 1998 and early 1999, billing data from the study houses show that prices remained constant for most of the state. For natural gas, the average residential price went from $5.89 per 1,000 CCF in 1995 to $5.65 in 1996, $5.64 in 1997, and $5.84 in 1998. Billing data for the study houses indicate no consistent statewide change in price between early 1998 and early 1999.

the findings on energy savings by program participants reported in subsequent chapters of this report.

2.2 SCREENING HOUSES

During the process of collecting data from the sample of weatherized houses and applying certain critical tests to the information that was provided, the number of units involved in the study gradually decreased (Figure 1). Of the 500 dwellings from 22 agencies for which descriptive information and pre-weatherization billing data were originally requested, we received information on 407 units. The data that were provided contained weatherization start- and completion-dates, had at least nine months of pre-weatherization billing information, and were completed during the appropriate time period for 365 of these houses, representing 20 subgrantees. Post-weatherization data were requested for those 365 units, and at least nine months of usable data were received for 312 of them, again from 20 agencies. Two hundred twenty-one of these houses were electrically-heated and ninety-one of them used natural gas as their primary heating fuel. These 312 houses were subjected to screening criteria associated with PRISM[2], a software system used to normalize energy consumption data to neutralize the effects of weather variations from one year to another. After this final step was completed, we ended up with 185 houses with highly reliable energy consumption and savings data. Of these dwelling units, 114 were electrically-heated and came from 20 agencies; the other 71 were heated with natural gas and represented 11 of the subgrantees.

2.3 USING WEATHER DATA

The PRISM software system uses local temperature data to normalize energy consumption so that usage during the pre-weatherization and post-weatherization periods can be compared to each other without the confounding effects otherwise caused by ordinary temperature fluctuations from year to year. The normalized annual consumption numbers generated by PRISM represent adjustments of actual pre- and post-weatherization energy use to reflect average long-term weather conditions in the study area. In order to perform the necessary normalization calculations, PRISM requires daily temperature data for the pre- and post-weatherization periods as well as for a period of at least 12 years prior to weatherization. The latter, more extensive, temperature data are required to calculate average annual degree days to use in the normalization process.

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[2]PRISM, which was developed by researchers at Princeton University, is an acronym for PRInceton Scorekeeping Method. The two screening criteria used in PRISM are the R-Square test, which indicates the amount of the variance in normalized annual consumption (NAC) that is explained by the regression model developed by PRISM, and the Coefficient of Variance (CV), which expresses the standard error of NAC as a percentage of NAC itself. The PRISM Users' Guide recommends that houses should not be used in the analysis unless they have an R-Square of at least 0.7 and a CV no greater than 0.07 (Fels, Kissock, Marean, and Reynolds 1995).

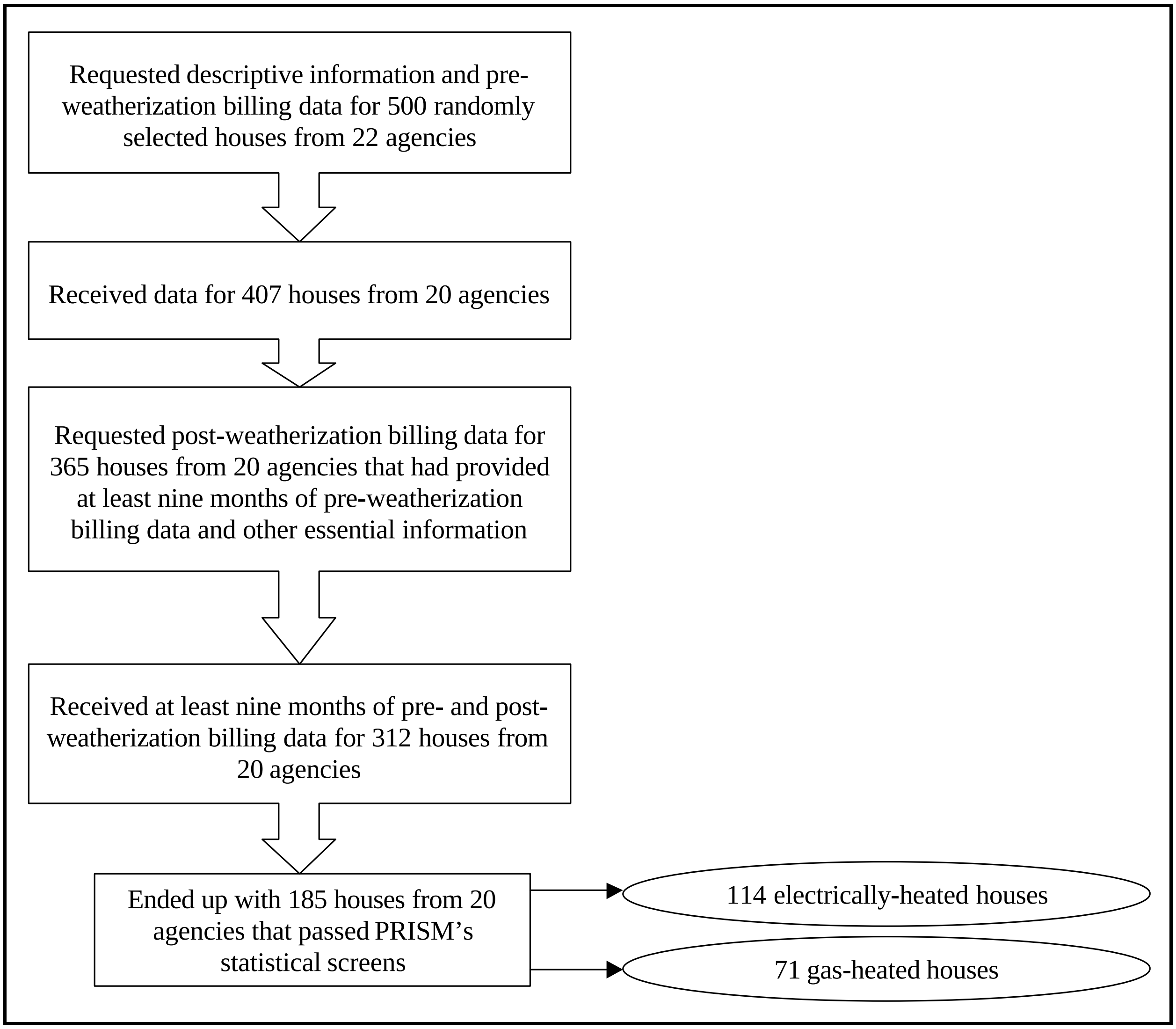

Figure 1. Selection and screening of houses for study.

Because climatic conditions vary substantially among different parts of Washington State, a single weather station would not adequately represent conditions in all areas served by the Washington Weatherization Program. Accordingly, each of the 20 local agencies was matched with the weather station to which it was closest in terms of distance and climate. Weather stations with the necessary temperature data were identified from published (National Climatic Data Center 1997a) and online (National Climatic Data Center 1999) sources. To represent the climatic conditions experienced by the 20 subgrantees in our study, we used data from eight different weather stations[3]. Six of these were located in Washington State and two were in

[3]The Washington weather stations used (and the number of subgrantees matched to them) were Seattle-Tacoma Airport (five agencies), Spokane (four agencies), Yakima (three agencies), Olympia (two agencies), Kennewick (one agency), and Bellingham (one agency). The weather stations in other states were Lewiston, Idaho (two agencies) and Portland, Oregon (two agencies).

neighboring states—Idaho and Oregon—immediately adjacent to the state line. All houses served by a given subgrantee were assigned to the weather station chosen for that local agency.

2.4 DATA ANALYSIS

As mentioned above, PRISM software was used to calculate normalized annual consumption for each house for both the pre-weatherization and post-weatherization periods. The pre- and post-weatherization consumption numbers for each house were then compared to each other to yield normalized annual savings. If post-weatherization normalized consumption was less than pre-weatherization normalized consumption—as was usually the case—savings were expressed as positive numbers. Negative numbers were used to represent "savings" in those cases where post-weatherization energy consumption exceeded pre-weatherization consumption. By dividing normalized annual savings by normalized annual consumption for the pre-weatherization period, we were able to calculate program-induced savings as a percentage of pre-weatherization energy consumption for each house. We also took advantage of PRISM's ability to identify the portion of energy use that is weather-dependent and calculated energy savings as a percentage of the energy used for space heating during the pre-weatherization period. Because we employed the screening criteria suggested by PRISM's designers, we have great confidence in the reliability of the savings numbers calculated for the 114 electrically-heated and 71 gas-heated houses that passed the screens.

In addition to calculating energy savings with PRISM, we also ran regression analyses to identify relationships between two important savings measures and several potential explanatory variables. The savings measures that we used were normalized annual savings and savings as a percentage of pre-weatherization whole-house energy use. The potential explanatory variables that we examined were: pre-weatherization normalized annual consumption; total weatherization costs; the floor area of the house; and heating degree days for the local area. Prior to performing the regression analyses, we developed hypotheses specifying the type of relationship we expected to find between the two savings measures and the various independent variables. We hypothesized that all four of the potential explanatory variables would be positively related to normalized annual savings. In other words, higher values for pre-weatherization energy consumption, total weatherization costs, floor area, and heating degree days would be associated with greater energy savings. For energy savings as a percent of whole-house energy use, we hypothesized a positive relationship with pre-weatherization consumption and total costs only and left the relationship unspecified for the other two explanatory variables.

We assessed the cost effectiveness of the Washington Program by applying the definitions, perspectives, and procedures that ORNL first developed for the National Evaluation of the Weatherization Assistance Program (Brown et al. 1993). This approach to analyzing cost effectiveness relies on several inputs and assumptions. The inputs include the average annual energy savings by fuel type as estimated by PRISM, the current prices of the fuels being considered, and the costs of performing the weatherizations. Key assumptions include the expected lifetime of the retrofit measures, a discount rate that reflects the time value of money, and estimated fuel price escalation rates. To indicate cost effectiveness we calculated benefit/cost ratios for three different perspectives. The definitions of the three perspectives (installation, program and societal) and the types of benefits and costs included in each perspective are explained in Chapter 4. Chapter 4 also presents the results of the cost-effectiveness calculations we prepared with the input data on the energy savings and costs of the weatherizations performed in Washington during the study period.

3. ENERGY SAVINGS

3.1 ELECTRICITY

Table 1 presents key descriptive statistics for three different measures of energy savings: (1) normalized annual savings; (2) energy savings as a percentage of pre-weatherization whole-house electricity use; and (3) energy savings as a percentage of pre-weatherization electricity use for space heating. As you can see, mean normalized savings for electrically-heated houses amounted to nearly 3,000 kWh annually. Energy savings as a percentage of pre-weatherization whole-house electricity use averaged 12.0%, and energy savings as a percentage of the electricity used for space heating during the pre-weatherization period averaged 18.6%. The range of observed values was large for all of the energy savings measures, especially for energy savings as a percentage of electricity used for space heating. However, the confidence intervals for the first two savings measures were relatively compact. For instance, there is a 90% probability that energy savings as a percentage of pre-weatherization whole-house electricity use fell somewhere between 9.2% and 14.8% for the entire population of electrically-heated houses served by the Washington Weatherization Program during the study period. The distribution of values for that important measure of energy savings is illustrated in Figure 2.

Table 1. Descriptive Statistics for Key Energy-Savings Measures for Electrically-Heated Houses

	Normalized Annual Savings (kwh) N=114	Energy Savings as a Percent of Pre-Weatherization Whole-House Electricity Use N=114	Energy Savings as a Percent of Pre-Weatherization Electricity Use for Heating N=114
Mean	2,991	12.0	18.6
Standard Deviation	3,609	18.2	78.4
Minimum	-6,782	-103.8	-711.1
Maximum	12,363	51.2	118.5
90% Confidence Interval	2,430 – 3,552	9.2 – 14.8	6.4 – 30.8
95% Confidence Interval	2,321 – 3,661	8.6 – 15.4	4.0 – 33.1

(Note: Negative savings means that post-weatherization energy use *exceeded* pre-weatherization energy use.)

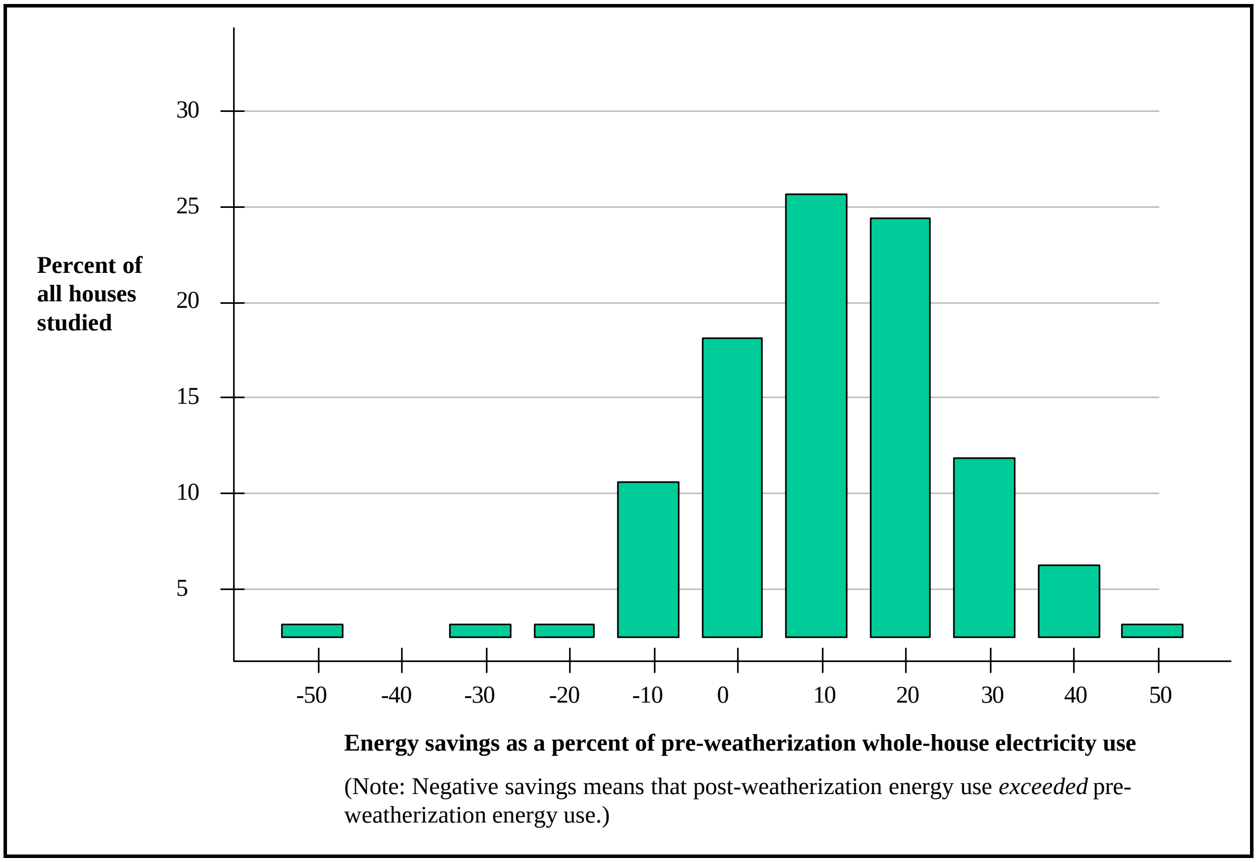

Figure 2. Distribution of energy savings for electrically-heated houses.

A recent metaevaluation of the Weatherization Assistance Program (Schweitzer and Berry 1999) examined 10 studies of state weatherization programs performed between 1996 and 1998. Three of those studies focused on the energy savings achieved in electrically-heated houses[4]. Energy savings as a percentage of pre-weatherization whole-house electricity use *and* energy savings as a percentage of pre-weatherization electricity use for space heating were higher in Washington State than in two of the three states examined in the metaevaluation. We chose not to examine absolute energy savings, because that variable is highly-dependent on climatic conditions in the states under study.

As mentioned in Section 2.4, regression analyses were performed to test possible relationships between two measures of energy savings and four possible explanatory variables. The two measures of energy savings were normalized annual savings and energy savings as a percentage of pre-weatherization whole-house energy use. The four independent variables were: (1) pre-weatherization normalized annual consumption; (2) total weatherization costs; (3) the floor area of the house; and (4) heating degree days for the local area. Table 2 shows the minimum, maximum, and mean values for the four independent variables from our study of 114 electrically-

[4]The states reporting savings for electrically-heated houses were Delaware, the District of Columbia, and Ohio.

heated homes. Mean pre-weatherization annual energy consumption was 22,261 kWh, and mean total weatherization expenditures were $2,673. The floor area of the average house weatherized was 1,166 square feet, and the average number of heating degree days in the areas where the study houses were located was 5,334. The range of values for the explanatory variables was considerable, especially for pre-weatherization consumption and total costs.

Table 2. Values of Independent Variables Used in Regression Analysis for Electricity Savings.

	Number of Observations	Minimum	Maximum	Mean
Pre-weatherization Normalized Annual Consumption (kWh)	114	6,535	55,657	22,261
Total Weatherization Expenditures ($)	114	47	11,554	2,673
Square Footage of Structures	111	480	2,480	1,166
Heating Degree Days	114	4,522	6,597	5,334

A multiple regression analysis was performed to test for possible relationships between normalized annual savings and all four potential explanatory variables described above. A separate regression analysis was performed to test for relationships between energy savings as a percentage of pre-weatherization whole-house electricity use and the same four independent variables. The outcomes of these analyses are shown in Table 3. As shown, statistically significant relationships (i.e., p=.05 or less) were found between both of the energy savings measures and two independent variables: pre-weatherization energy consumption and total weatherization expenditures.

Table 3. Relationships Between Possible Explanatory Variables and Electricity Savings[a]

Explanatory Variable	Savings Measures: Normalized Annual Savings (kWh)	Savings Measures: Energy Savings as a Percent of Pre-Weatherization Whole-House Electricity Use
Pre-Weatherization Normalized Annual Consumption	X	X
Total Weatherization Expenditures	X	X
Square Footage of Structures		
Heating Degree Days		
Number of Houses (N)	110	110
R-square[b]	0.252	0.081

[a]Significant relationships (i.e., p-value = .05 or less) are indicated with an X.
[b]The R-square value describes the proportion of the variance in the designated savings measure that is explained by all explanatory variables combined.

A follow-up regression analysis was performed to examine the relationship between normalized annual savings and the two independent variables that emerged as significant in the previous analysis. In addition, a separate analysis was run that focused on the relationship between energy savings as a percentage of pre-weatherization whole-house electricity use and the same two independent variables. These new analyses used only the two statistically significant independent variables and deleted the other explanatory factors that had been used previously. Detailed results of those follow-up analyses are shown in Table 4. The regression model using both pre-weatherization energy consumption and total weatherization expenditures as independent variables and normalized annual savings as the dependent variable had an R-Square of 0.245 and a p-value of .0001. This means that, together, the two independent variables explained 24.5% of the variance in normalized annual savings, and that the relationship was *very* statistically significant. The estimated parameters for both variables were positive, meaning that greater pre-weatherization energy consumption and greater total weatherization expenditures were associated with higher normalized annual savings. When the same two independent variables were used to explain energy savings as a percentage of pre-weatherization whole-house electricity use, the relationships were still positive but the R-Square dropped to 0.079 and the p-value was reduced to .01. This means that the general nature of the relationships described above remained unchanged and the findings were still statistically significant, but that the two

Table 4. Detailed Results of Regression Analysis for Electrically-Heated Houses, Using Only Statistically Significant Explanatory Variables

Savings Measure = Normalized Annual Savings

	Explanatory Variables		
	Pre-Weatherization Normalized Annual Consumption	Total Weatherization Expenditures	Entire Model
F - value	23.67	6.12	18.01
p - value	< .0001	.007	.0001
Estimated parameter	0.18706	0.46732	Intercept = -2422.42
Number of houses (N)			113
R - square			0.245

Savings Measure = Energy Savings as a Percent of Pre-Weatherization Whole-House Electricity Usage

	Explanatory Variables		
	Pre-Weatherization Normalized Annual Consumption	Total Weatherization Expenditures	Entire Model
F - value	4.27	3.36	4.76
p - value	.02	.03	.01
Estimated parameter	0.00044	0.00193	Intercept = -2.99
Number of houses (N)			113
R - square			0.079

independent variables explained much less of the variance in energy savings as a *percentage* of pre-weatherization whole-house energy use than they did for *absolute* energy savings.

Past evaluations of the Weatherization Assistance Program also have examined relationships between energy savings and potential explanatory variables. Two metaevaluations performed by staff at Oak Ridge National Laboratory (Schweitzer and Berry 1999; Berry 1997) ran regression analyses only for gas-heated houses, due to a paucity of data on electrically-heated dwellings. However, an earlier national evaluation of the Weatherization Assistance Program (Brown, Berry, Balzer, and Faby 1993) did examine the relationships between electricity savings and a variety of potential explanatory factors. That evaluation found that pre-weatherization consumption and weatherization expenditures were positively related to electricity savings, just as this study found. Unlike this study, the national evaluation also found that electricity savings were positively related to the number of heating degree days.

3.2 NATURAL GAS

Descriptive statistics for three measures of natural gas energy savings are presented in Table 5. The table shows that mean normalized savings for gas-heated houses amounted to just over 230 CCF[5] annually. Energy savings as a percentage of pre-weatherization whole-house natural gas use averaged 25.4%, and energy savings as a percentage of the natural gas used for space heating during the pre-weatherization period averaged 30.8%. These savings percentages were substantially higher than those reported for electrically-heated houses. The range of observed values was substantial for all of the energy savings measures. However, the ranges for the percentage measures were considerably less than for electrically-heated houses. The confidence intervals for all three savings measures were relatively compact. For example, there is a 90% probability that energy savings as a percentage of pre-weatherization whole-house natural gas use was somewhere between 21.0% and 29.8% for the entire population of gas-heated houses served by the Washington Weatherization Program during the study period. Figure 3 displays the distribution of values for that measure of energy savings.

As noted in Section 3.1, a recent metaevaluation of the Weatherization Assistance Program (Schweitzer and Berry 1999) examined 10 studies of state weatherization programs performed between 1996 and 1998. Nine of those studies reported energy savings achieved in gas-heated houses[6]. Energy savings as a percentage of pre-weatherization whole-house natural gas use was higher in Washington State than in seven of the nine studies examined in the metaevaluation. And energy savings as a percentage of pre-weatherization gas use for space heating was higher in Washington State than in six of the nine studies. As with electrically-

[5]CCF is a volumetric measure which equals 100 cubic feet of natural gas.

[6]The states reporting savings for gas-heated houses were Colorado, the District of Columbia, Indiana, Iowa (two studies), Minnesota (two studies), Ohio, and Vermont.

Table 5. Descriptive Statistics for Key Energy-Savings Measures for Gas-Heated Houses

	Normalized Annual Savings (CCF) N=71	Energy Savings as a Percent of Pre-Weatherization Whole-House Natural Gas Use N=71	Energy Savings as a Percent of Pre-Weatherization Natural Gas Use for Heating N=71
Mean	230.1	25.4	30.8
Standard Deviation	230.5	22.3	26.7
Minimum	-381.0	-26.7	-33.6
Maximum	998.5	63.8	76.4
90% Confidence Interval	184.5 – 275.8	21.0 – 29.8	25.6 – 36.1
95% Confidence Interval	175.6 – 284.7	20.1 – 30.6	24.5 – 37.1

(Note: Negative savings means that post-weatherization energy use *exceeded* pre-weatherization energy use.)

heated houses, we chose not to examine absolute energy savings because that variable is highly-dependent on state-specific climatic conditions.

An earlier metaevaluation of the Weatherization Assistance Program (Berry 1997) looked at 19 studies of state weatherization programs completed between 1990 and early 1996. All of these studies reported energy savings for gas-heated houses[7]. In Washington State, energy savings as a percentage of pre-weatherization whole-house natural gas use was higher than in 12 of the 15 state studies that reported this statistic. Energy savings as a percentage of pre-weatherization gas use for space heating was higher in Washington State than in four of the six studies in which this statistic was reported.

[7]The states included in the study were Colorado, Indiana, Iowa, Kansas, Nebraska, New York (two studies), North Carolina (three studies), North Dakota, Ohio (three studies), Texas, Vermont (two studies), Wisconsin, and Wyoming.

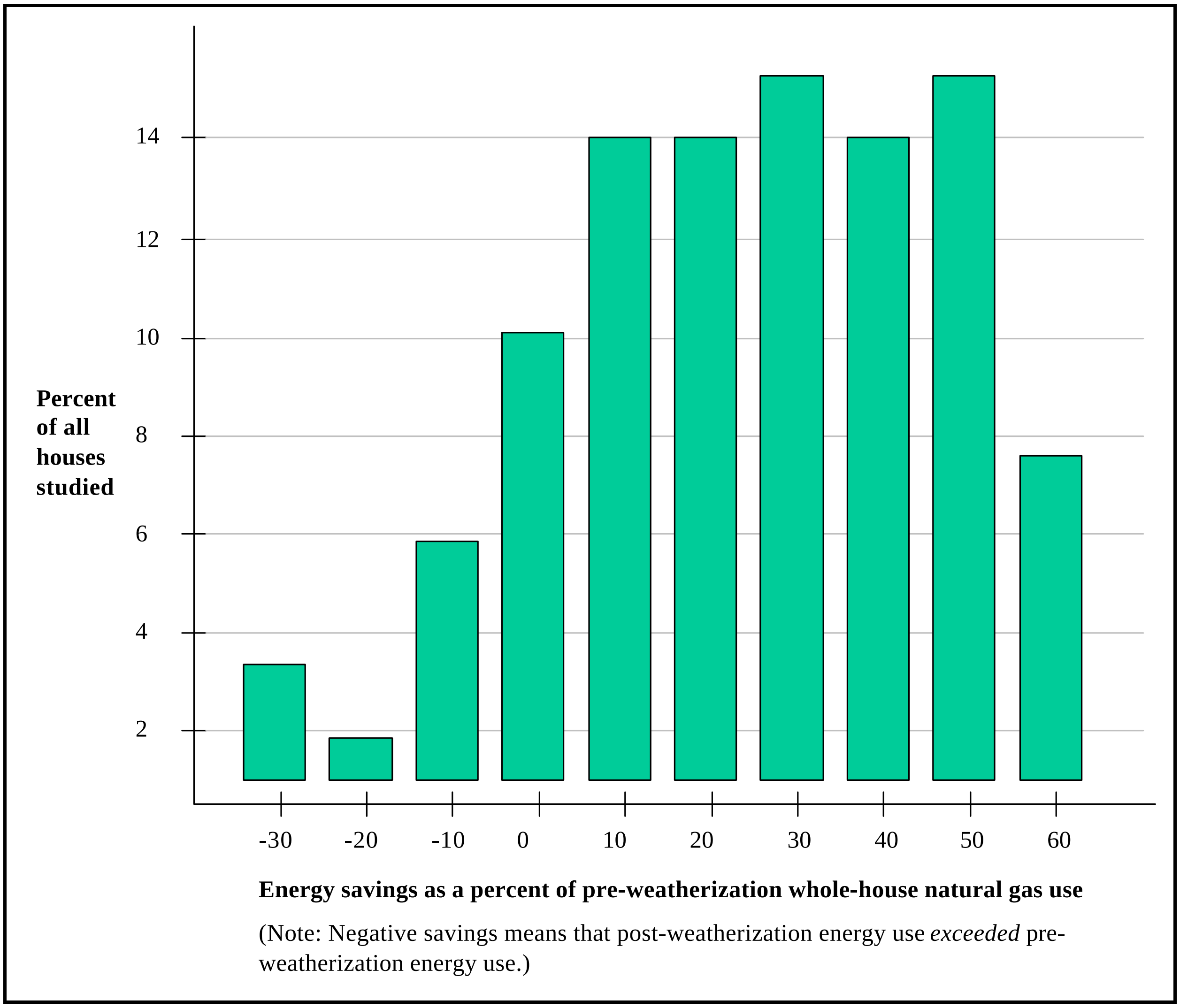

Figure 3. Distribution of energy savings for gas-heated houses.

As with electrically-heated houses, regression analyses were performed to test possible relationships between two measures of energy savings and four possible explanatory variables. Minimum, maximum, and mean values of the four independent variables are shown in Table 6 for the gas-heated houses examined in this study. Mean pre-weatherization annual energy consumption was 852 CCF; mean total weatherization expenditures were $3132 (about 17% more than for electrically-heated houses); average floor area was 1,440 square feet (about 23% greater than for electric homes); and the average number of heating degree days in the areas where the study houses were located was 5,152. As with electrically-heated homes, the range of values for the explanatory variables was considerable.

Table 6. Values of Independent Variables Used in Regression Analysis for Natural Gas Savings.

	Number of Observations	Minimum	Maximum	Mean
Pre-weatherization Normalized Annual Consumption (CCF)	71	160.2	1801.1	852.0
Total Weatherization Expenditures ($)	70	48	7780	3132
Square Footage of Structures	68	625	3180	1440
Heating Degree Days	71	4994	6597	5152

A multiple regression analysis was performed to test for possible relationships between normalized annual savings and all four potential explanatory variables. A separate regression analysis was performed to test for relationships between the same four independent variables and energy savings as a percentage of pre-weatherization whole-house natural gas use. Table 7 shows the outcomes of these analyses. Pre-weatherization energy consumption and total weatherization expenditures were found to have statistically significant relationships (i.e., p=.05 or less) with normalized annual savings, as was the case for electrically-heated houses. Total weatherization expenditures also had a statistically significant relationship with energy savings as a percentage of pre-weatherization whole house natural gas use. Finally, we found that heating degree days were significantly related to energy savings as a percentage of pre-weatherization whole-house natural gas use, even though heating degree days were not associated with either measure of energy savings for the electrically-heated homes.

A follow-up regression analysis was performed that focused on normalized annual savings and the two independent variables that the previous analysis had found to be significantly related to it. In addition, a separate analysis was run that focused on energy savings as a percentage of pre-weatherization whole-house natural gas use and the two independent variables with which it was found to have statistically significant relationships. These new analyses used only the statistically significant independent variables and deleted the other explanatory factors that had been used previously. Table 8 shows the detailed results of those follow-up analyses. The regression model using both pre-weatherization energy consumption and total weatherization expenditures as independent variables and normalized annual savings as the dependent variable had an R-Square of 0.312 and a p-value of .0001. This means that, in

Table 7. Relationships Between Possible Explanatory Variables and Natural Gas Savings[a]

Explanatory Variable	Savings Measures: Normalized Annual Savings (kWh)	Savings Measures: Energy Savings as a Percent of Pre-Weatherization Whole-House Natural Gas Use
Pre-Weatherization Normalized Annual Consumption	X	
Total Weatherization Expenditures	X	X
Square Footage of Structures		
Heating Degree Days		X
Number of Houses (N)	66	66
R-square[b]	0.356	0.248

[a]Significant relationships (i.e., p-value = .05 or less) are indicated with an X.
[b]The R-square value describes the proportion of the variance in the designated savings measure that is explained by all explanatory variables combined.

combination, the two independent variables explained 31.2% of the variance in normalized annual savings, and that the relationship was *highly* statistically significant. The estimated parameters for both variables were positive, meaning that greater pre-weatherization energy consumption and greater total weatherization expenditures were associated with higher normalized annual savings. The regression model using total weatherization expenditures and heating degree days as the only two independent variables and energy savings as a percentage of pre-weatherization natural gas use as the dependent variable had an R-Square of 0.223 and a p-value of .0002. But, with this reduced regression model, heating degree days no longer showed a statistically significant relationship with the savings measure (p=.09). For total weatherization expenditures, the relationship with the savings measure was still positive and highly significant (p=.0002), meaning that higher expenditures were associated with greater savings as a percentage of pre-weatherization natural gas use.

Table 8. Detailed Results of Regression Analysis for Gas-Heated Houses, Using Only Statistically Significant Explanatory Variables

Savings Measure = Normalized Annual Savings

	Explanatory Variables		
	Pre-Weatherization Normalized Annual Consumption	Total Weatherization Expenditures	Entire Model
F - value	12.59	5.35	15.20
p - value	.0004	.01	.0001
Estimated parameter	0.26195	0.03098	Intercept = -93.24
Number of houses (N)			69
R - square			0.312

Savings Measure = Energy Savings as a Percent of Pre-Weatherization Whole-House Natural Gas Usage

	Explanatory Variables		
	Total Weatherization Expenditures	Heating Degree Days	Entire Model
F - value	14.49	3.01	9.62
p - value	.0002	.09	.0002
Estimated parameter	0.00475	-0.01077	Intercept = 65.61
Number of houses (N)			69
R - square			0.223

Both of the metaevaluations mentioned earlier (Schweitzer and Berry 1999; Berry 1997) as well as the national evaluation of the Weatherization Assistance Program (Brown, Berry, Balzer, and Faby 1993) examined relationships between energy savings and potential explanatory variables for gas-heated houses. Like this evaluation, all three of those studies found that pre-weatherization consumption was positively related to gas savings. In addition, the national evaluation found, like this study did, that total weatherization expenditures were positively related to gas savings. Unlike this study, the most recent metaevaluation and the national evaluation also found that heating degree days were positively related to gas savings for certain subsets of their samples[8]. In addition, the national evaluation found that the area of conditioned dwelling space was positively related to gas savings in cold and moderate climate regions.

[8]For the latest metaevaluation, the reduced data set for which the relationship was significant excluded one study focusing on households with abnormally high values for pre-weatherization consumption. For the national evaluation, the relationship in question was significant only in the moderate climate region.

4. BENEFIT/COST ANALYSIS

4.1 DEFINITIONS AND ASSUMPTIONS

We assessed the cost effectiveness of the Washington Program by applying the definitions, perspectives, and procedures that ORNL first developed for the National Evaluation of the Weatherization Assistance Program (Brown et al. 1993). This approach to analyzing cost effectiveness relies on a variety of inputs and assumptions. The inputs include the average annual energy savings by fuel type as estimated by PRISM (from Chapter 3), the current prices of the fuels being considered, and the costs of performing the weatherizations. Key assumptions include the expected lifetime of the retrofit measures, a discount rate that reflects the time value of money, and estimated fuel price escalation rates.

The indicators of cost effectiveness that we calculated were benefit/cost ratios, which were developed for three different perspectives:

- the program perspective,
- the installation perspective, and
- the societal perspective.

The **program perspective** is the most conservative analysis because it includes all classes of costs (i.e., both measure installation costs and program overhead and management) while counting only the avoided costs of purchasing the annual fuel savings as a benefit. The **installation perspective** is the traditional approach used to evaluate weatherization programs. This perspective includes only the on-site measure installation costs (materials and labor) and counts only the avoided costs of purchasing the annual fuel savings as a benefit. The **societal perspective** is the most comprehensive accounting of benefits and costs because it includes all classes of costs (i.e., both measure installation costs and program overhead and management costs) and counts both energy and nonenergy benefits (Figure 4).

The formula we used for calculating the Net Present Value (NPV) of the energy savings benefits is shown in Equation 1. This formula for the NPV of the annual energy savings was applied separately to the electrically-heated homes (4.2) and the gas-heated homes (4.3) weatherized by the Program. Information on the costs of performing the weatherizations also was developed

$$NPV_{savings} = \sum_{j=1}^{n} \frac{S \cdot P_j}{(1+d)^j} \qquad (1)$$

separately, from agency records, for the two subsets of electrically-heated and gas-heated homes.

Where,
n = lifetime of the weatherization measures
S = annual energy savings

Perspective	Benefits Included	Costs Included
Program	Energy Savings Only	All Costs
Installation	Energy Savings Only	On-Site Installation Costs
Societal	Both Energy and Nonenergy Benefits	All Costs

Figure 4. Benefits and costs included in each perspective.

P = energy price in year j, and
d= real discount rate.

4.2 ELECTRICITY

This section addresses the cost effectiveness of the weatherizations of low-income, electrically-heated homes in the state of Washington. The inputs and assumptions used for this analysis are shown in Table 9 and Figures 5, 6 and 7. Figure 7 also shows the benefit/cost ratios calculated with these sets of inputs and assumptions. Two of the three perspectives (installation and societal) produced benefit/cost ratios greater than 1.00. Even with the most conservative perspective (program), a large majority of the weatherization jobs would be cost effective. As Figure 6 shows, nearly 80% of the homes had total costs of less than $4000. If only the homes with costs of less than $4,000 are examined, their benefit/cost ratio would be greater than 1.00 for all three perspectives.

Table 9. Input Variables, Values and Sources for the Benefit/Cost Calculations for Electrically-Heated Homes

Variable	Value	Source
Measure Life	20 years	Brown et al. 1993.
Discount Rate[a]	0.028	OMB Circular No. A-94. An interpolated real discount rate for 20-year period to use for cost-effectiveness analysis.
Fuel Price Escalation Rate[b]	0.002	Developed from residential end-use electricity price forecast, high economic growth scenario, produced by EIA. See Annual Energy Outlook 1999, Table 21.
Average Savings per Weatherization in Electrically-heated homes	2,991 kWh	See Chapter 3.
First year non-energy benefits in Electrically-heated homes	$1040	Brown et al. 1993 (adjusted to 1998 $ using the Consumers Price Index).
Out-year non-energy benefits	$16.63/year	Brown et al. 1993 (adjusted to 1998 $ using the Consumers Price Index).
Fuel cost	$0.05/kWh	1998 average price for residential, electricity in Washington as reported by EIA.
Average Cost of Measures per Weatherization	$2204	See Figure 5
Average Total Costs per Weatherization	$2408	See Figure 6

[a]Discount Rate — OMB Circular No. A-94 contains recommended discount rates to use for cost-effectiveness analyses. Real discount rates are suggested to be used for this purpose. This circular presents discount rates that can be used to analyze projects with 3-year, 5-year, 7-year, 10-year, and 30-year time periods. To determine the discount rate for a 20-year time period, an interpolation of the 10-year and 30-year rate, which are 2.7% and 2.9% respectively, was made and calculated to be 2.8%. The circular recommends interpolation in these cases.

[b]Electricity Price Escalation — The Annual Energy outlook for 1999 is published by the Energy Information Administration (EIA). Table 21, page 98, contains electricity price forecasts for the residential sector for the year 2020. The EIA presents two forecasts, one under a low economic growth scenario and one under a high economic growth scenario. Forecasts are also presented that were produced by other organizations, such as DRI/McGraw-Hill. It was decided that for this DOE-funded study it was most appropriate to use one of the EIA-produced forecasts. The high economic growth scenario forecast was chosen because it was more consistent with the forecasts produced by other organizations.

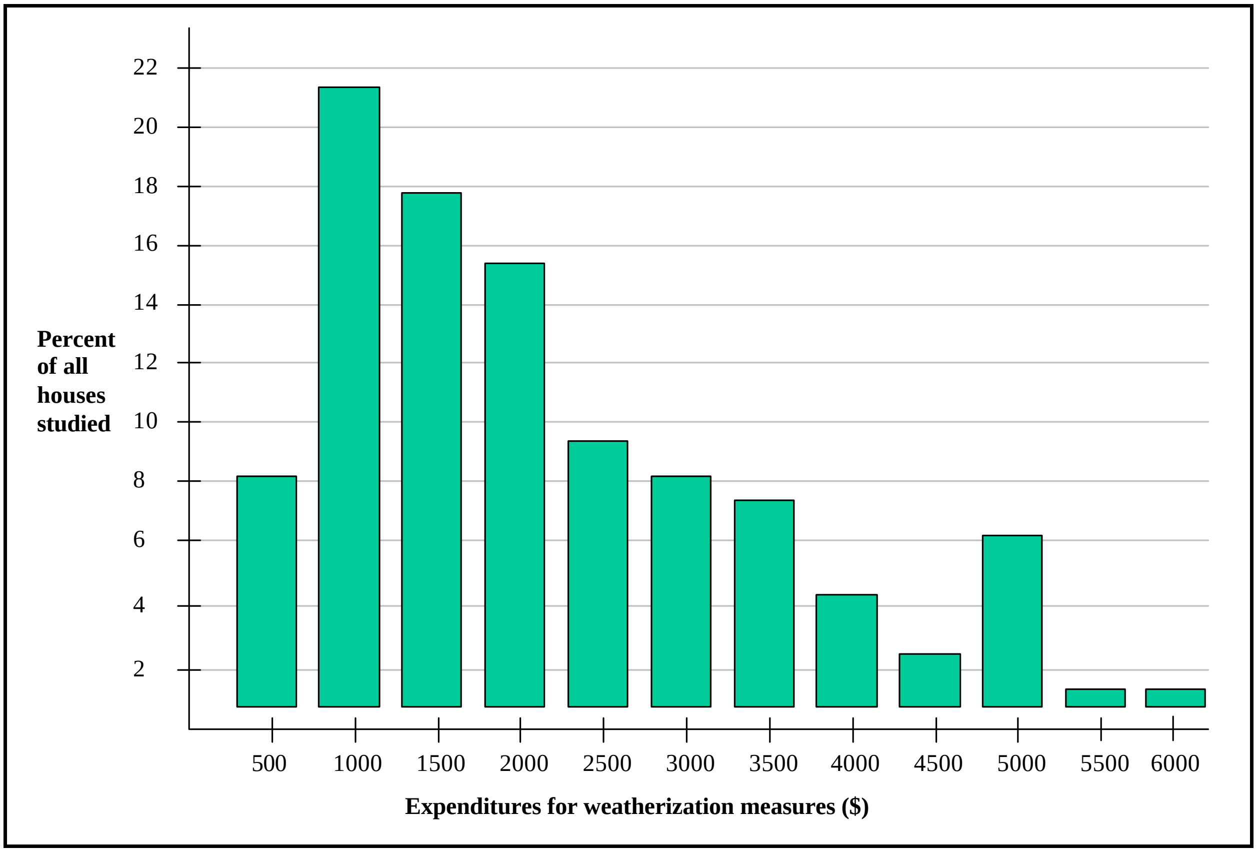

Figure 5. Distribution of weatherization measure costs for electrically-heated houses.

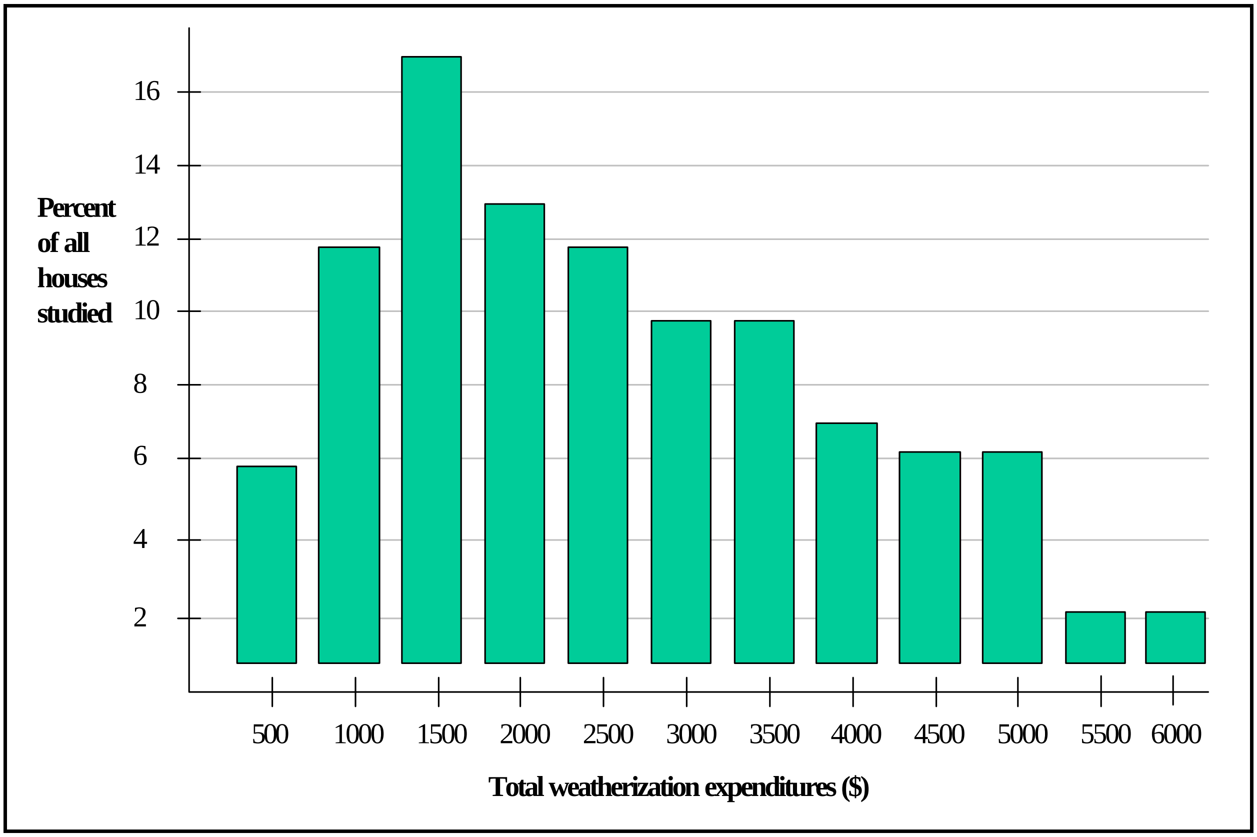

Figure 6. Distribution of total weatherization expenditures for electrically-heated houses.

Perspective	Benefits Included	Costs Included
Program	Energy Savings Only	All Costs
	Benefit/Cost Ratio = 0.91	
Installation	Energy Savings Only	On-Site Installation Costs
	Benefit/Cost Ratio = 1.08	
Societal	Both Energy and Nonenergy Benefits	All Costs
	Benefit/Cost Ratio = 1.38	

Figure 7. Benefit/Cost ratios for electrically-heated houses.

4.3 NATURAL GAS

This section addresses the cost effectiveness of the weatherizations of low-income, natural gas-heated homes in the state of Washington. The inputs and assumptions used for this analysis are shown in Table 10 and Figures 8, 9 and 10. Figure 10 also shows the benefit/cost ratios calculated with these sets of inputs and assumptions. Only the societal perspective produced a benefit/costs ratio greater than 1.00. Thus, the investments in the gas-heated homes were less cost effective than those in electrically-heated homes. This occurred for two reasons. First, gas is a less expensive fuel than electricity – although the percentage of savings was higher in the gas-heated homes, the avoided fuel costs were lower. Secondly, a higher percentage of the gas-heated homes received investments of $4,000 or more (Figure 9). Nevertheless, more than half of the gas-heated homes had investments of less than $4,000 and, for this group, the benefit/cost ratio would be greater than 1.00 for all three perspectives.

Table 10. Input Variables, Values and Sources for the Benefit/Cost Calculations for Gas-heated Houses

Variable	Value	Source
Measure Life	20 years	Brown et al. 1993.
Discount Rate[a]	0.028	OMB Circular No. A-94. An interpolated real discount rate for 20-year period to use for cost-effectiveness analysis.
Fuel Price Escalation Rate[b]	0.002	Developed from residential end-use natural gas price forecast, high economic growth scenario, produced by EIA. See Annual Energy Outlook 1999, page 93.
Average Savings per Weatherization in Gas-heated homes	23.01 mmbtu	See Chapter 3.
First year non-energy benefits in Gas-heated homes	$1040	Brown et al. 1993 (adjusted to 1998 $ using the Consumers Price Index).
Out-year non-energy benefits	$16.63/year	Brown et al. 1993 (adjusted to 1998 $ using the Consumers Price Index).
Fuel cost	$5.84/mmbtu	1998 average price for residential, end-use natural gas for Washington as reported by EIA.
Average Cost of Measures per Weatherization	$2453	See Figure 7
Average Total Costs per Weatherization	$2657	See Figure 8

[a]Discount Rate — OMB Circular No. A-94 contains recommended discount rates to use for cost-effectiveness analyses. Real discount rates are suggested to be used for this purpose. This circular presents discount rates that can be used to analyze projects with 3-year, 5-year, 7-year, 10-year, and 30-year time periods. To determine the discount rate for a 20-year time period, an interpolation of the 10-year and 30-year rate, which are 2.7% and 2.9% respectively, was made and calculated to be 2.8%. The circular recommends interpolation in these cases.

[b]Electricity Price Escalation — The Annual Energy outlook for 1999 is published by the Energy Information Administration (EIA). Table 21, page 98, contains electricity price forecasts for the residential sector for the year 2020. The EIA presents two forecasts, one under a low economic growth scenario and one under a high economic growth scenario. Forecasts are also presented that were produced by other organizations, such as DRI/McGraw-Hill. It was decided that for this DOE-funded study it was most appropriate to use one of the EIA-produced forecasts. The high economic growth scenario forecast was chosen because it was more consistent with the forecasts produced by other organizations.

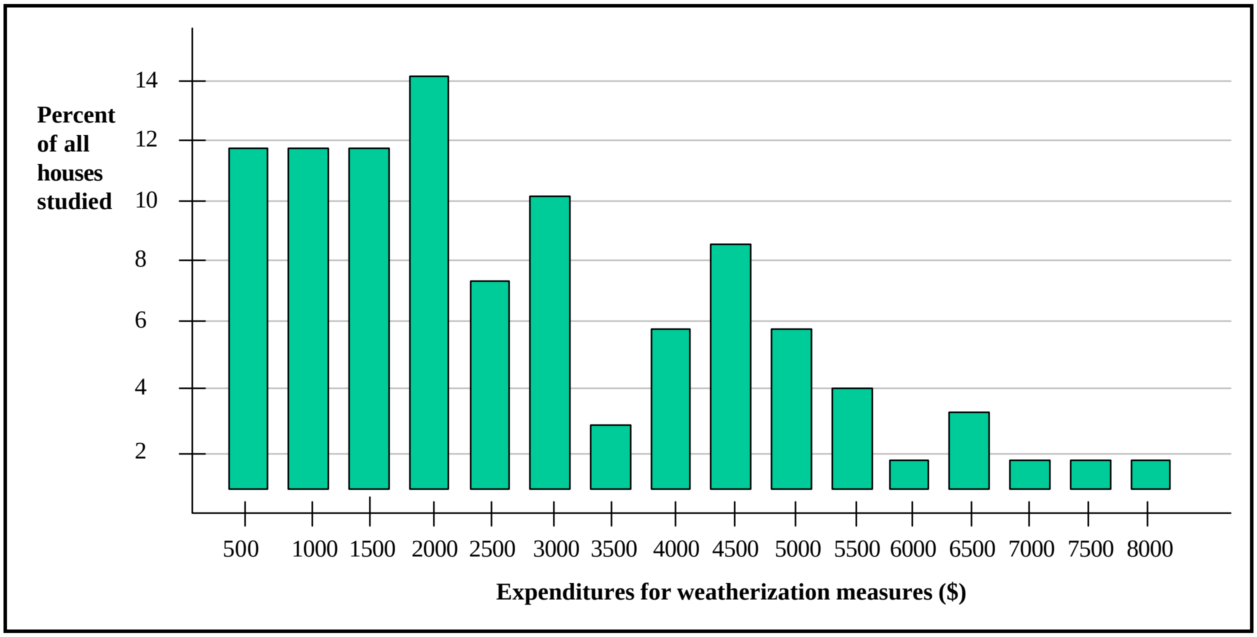

Figure 8. Distribution of weatherization measure costs for gas-heated houses.

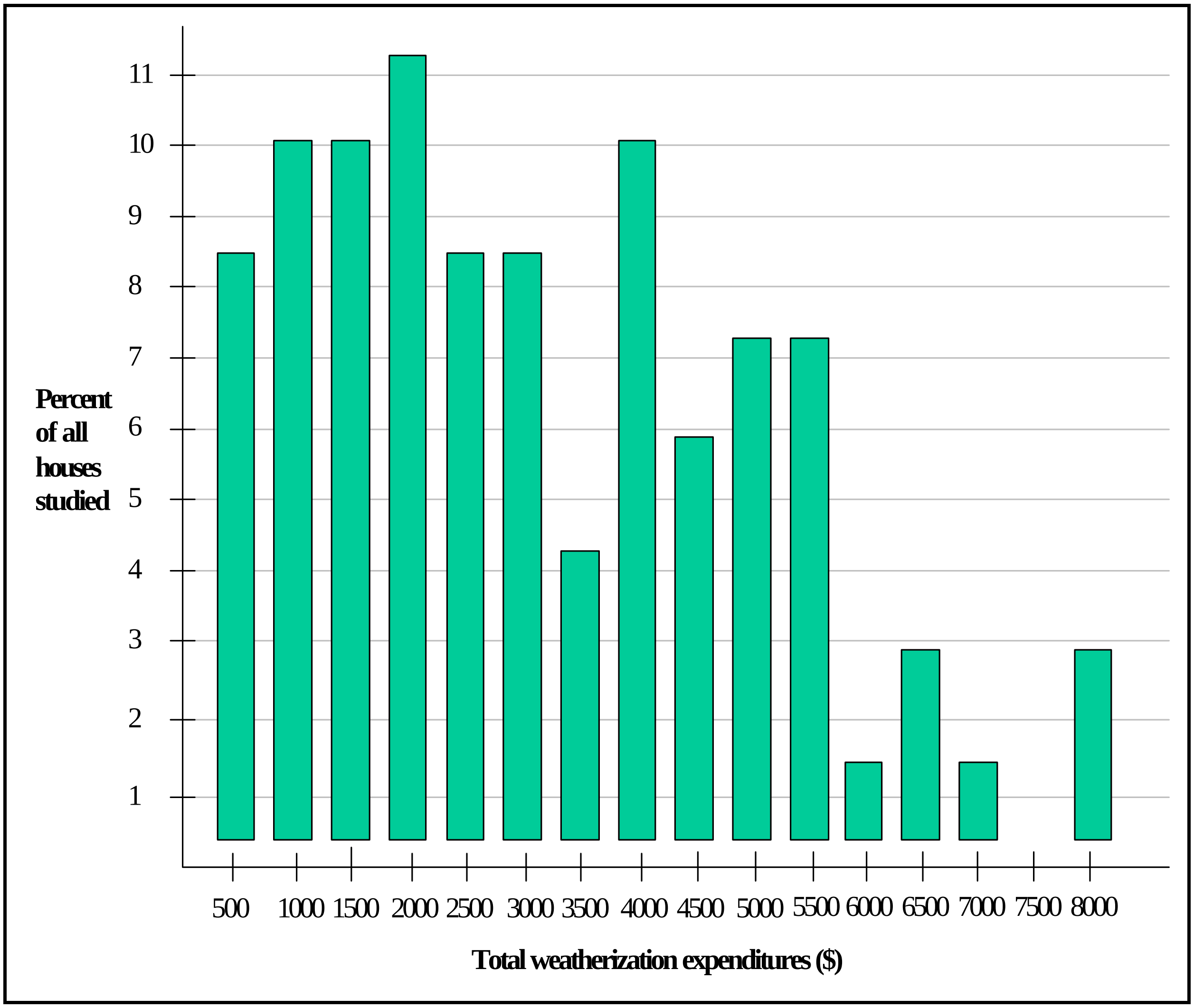

Figure 9. Distribution of total weatherization expenditures for gas-heated houses.

Perspective	Benefits Included	Costs Included
Program	Energy Savings Only	All Costs
	Benefit/Cost Ratio = 0.74	
Installation	Energy Savings Only	On-Site Installation Costs
	Benefit/Cost Ratio = 0.87	
Societal	Both Energy and Nonenergy Benefits	All Costs
	Benefit/Cost Ratio = 1.20	

Figure 10. Benefit/Cost ratios for gas-heated houses.

5. SUMMARY AND CONCLUSIONS

Table 11 summarizes the energy savings experienced by participants in the Washington State Weatherization Assistance Program. As shown, mean normalized annual savings were 2,991 kWh for electrically-heated houses and 230.1 CCF for gas-heated houses. Energy savings as a percentage of pre-weatherization whole-house energy use averaged 12.0% for electrically-heated houses and 25.4% for gas-heated houses. And mean energy savings as a percentage of pre-weatherization energy use for space heating amounted to 18.6% for electrically-heated houses and 30.8% for houses heating with gas.

Table 11. Summary of Energy Savings.

	Electrically-Heated Houses (N=114)	Gas-Heated Houses (N=71)
Mean Normalized Annual Savings	2,991 kWh	230.1 CCF
Mean Energy Savings as a Percent of Pre-Weatherization Whole-House Energy Use	12.0%	25.4%
Mean Energy Savings as a Percent of Pre-Weatherization Energy Use for Space Heating	18.6%	30.8%

Clearly, the savings percentages were substantially larger for the gas-heated households. This is easy to explain for energy savings as a percentage of pre-weatherization whole-house energy use. Generally, there is substantially more household electricity than gas used for applications that are not affected by the energy-efficiency measures installed by the Weatherization Assistance Program (e.g., lighting, refrigerators, clothes washers). Therefore, when weatherization-induced savings are divided by whole-house energy use, there is considerably more to divide by (i.e., the denominator is substantially larger) when the fuel in question is electricity. But why did gas-heated houses do so much better in terms of savings as a percentage of the energy used only for space heating? At least part of the reason probably lies in the fact that total expenditures in the typical gas-heated house were larger than for the average electrically-heated dwelling, and higher expenditures tend to be associated with greater savings. In addition, it is possible that PRISM overestimated the amount of total energy consumption that was used for space heating in the electrically-heated houses, which would make energy savings as a percentage of space heating energy use appear smaller than it actually was. The tendency of PRISM to overestimate the amount of electricity used for space heating is discussed in Fels, Rachlin and Socolow (1986).

In addition to calculating the savings that were achieved as a result of Washington State's weatherization efforts, this study also identified a few key factors that help explain the magnitude of observed savings. Total weatherization expenditures were positively related to normalized annual savings and to savings as a percentage of pre-weatherization energy use in both the gas-heated and electrically-heated dwellings. In other words, houses on which more money was spent tended to achieve greater energy savings, both in absolute terms as well as relative to how much energy they used prior to weatherization. Pre-weatherization energy consumption also was positively related to normalized annual savings for electric- and gas- houses, meaning that houses that used more energy before being weatherized tended to realize higher absolute savings as a result of the weatherization measures installed. For electrically-heated houses, the units with higher pre-weatherization consumption also tended to have greater savings relative to previous usage.

Even though the savings percentages were higher in gas-heated homes, the discounted savings from avoided fuel purchases were greater for the electrically-heated homes. These higher avoided cost values simply reflect the fact that electricity is a more expensive fuel than natural gas. Benefit/cost ratios were higher for electrically-heated homes not only because of larger benefits, but also because of lower weatherization costs. Average investments were lower in electrically-heated dwellings and a smaller proportion of them had investments of more than $4,000. In both the gas- and electrically-heated homes, average benefit/cost ratios greater than 1.00 were calculated with one or more sets of inputs and assumptions for the entire data set.

In conclusion, we find that the Washington State Weatherization Assistance Program has achieved substantial energy savings in both electrically-heated and gas-heated houses. A comparison of the findings from this study with those from many other evaluations of state weatherization efforts conducted over the past 10 years indicates that Washington is in the top one-third nationwide in terms of program-induced energy savings. In addition, the relationships between energy savings and both pre-weatherization consumption and weatherization expenditures reported in this document are consistent with the findings from earlier studies. These findings suggest that households with high energy consumption make effective targets for state weatherization efforts and that increasing the amount spent per household yields tangible returns in terms of energy savings.

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