

Energy Division

Key Findings of the National Weatherization Evaluation

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ABSTRACT

In 1990, the U.S. Department of Energy sponsored a comprehensive evaluation of its Weatherization Assistance Program, the nation's largest residential energy conservation program. The primary goal of the evaluation was to establish whether the Program meets the objectives of its enabling legislation and fulfills its mission statement, to reduce the heating and cooling costs for low-income families—particularly the elderly, persons with disabilities, and children by improving the energy-efficiency of their homes and ensuring their health and safety. Oak Ridge National Laboratory managed a five-part study which produced a series of documents evaluating the Program.

The objective of this document is to summarize the findings of the five-part National Weatherization Evaluation. The five studies were as follows:

- **Network Study**—this study characterized the weatherization network's leveraging, capabilities, procedures, staff, technologies, and innovations.
- **Resources and Population Study**—this study profiled low-income weatherization resources, the weatherized population, and the population remaining to be served.
- **Multifamily Study**—this study described the nature and extent of weatherization activities in larger multifamily buildings.
- **Single-family Study**—this study estimated the national savings and cost-effectiveness of weatherizing single-family and small multifamily dwellings that use natural gas or electricity for space heating.
- **Fuel-Oil Study**—this study estimated the savings and cost-effectiveness of weatherizing single-family homes, located in nine northeastern states, that use fuel oil for space heating.

This paper provides a brief overview of each study's purposes, research methods and most important findings.

KEY FINDINGS OF THE NATIONAL WEATHERIZATION EVALUATION

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INTRODUCTION

Since 1976, the U.S. Department of Energy (DOE) has operated one of the largest energy conservation programs in the nation—the low-income Weatherization Assistance Program. The Program strives to increase the energy efficiency of dwellings occupied by low-income persons in order to reduce their energy consumption, lower their fuel bills, increase the comfort of their homes, and safeguard their health. It targets vulnerable groups including the elderly, people with disabilities, and families with children.

The Weatherization Assistance Program is a formula grant program that operates in a decentralized fashion -- from DOE to State governments to about 1,100 local weatherization agencies. Each local agency weatherizes the dwellings of income-qualified households in its service territory, which is typically composed of several rural counties, a medium to large city, or part of a metropolitan area. The Program weatherizes about 250,000 dwellings per year.

In 1990, DOE initiated a nationwide evaluation of the Weatherization Program, with assistance from Oak Ridge National Laboratory (ORNL) and an advisory group of 35 weatherization professionals, program managers, and researchers. This group provided guidance to the ORNL evaluation team in planning and implementing the five studies that comprised the evaluation. The five studies were as follows:

- **Network Study**—this study characterized the weatherization network's leveraging, capabilities, procedures, staff, technologies, and innovations.
- **Resources and Population Study**—this study profiled low-income weatherization resources, the weatherized population, and the population remaining to be served.
- **Multifamily Study**—this study described the nature and extent of weatherization activities in larger multifamily buildings.
- **Single-family Study**—this study estimated the national savings and cost-effectiveness of weatherizing single-family and small multifamily dwellings that use natural gas or electricity for space heating.
- **Fuel-Oil Study**—this study estimated the savings and cost-effectiveness of weatherizing single-family homes, located in nine northeastern states, that use fuel oil for space heating.

This paper provides a brief overview of each study's purposes, research methods and most important findings. In addition, the links between the studies and their ability to complement and strengthen each other are discussed.

NETWORK STUDY

The purpose of this study (Mihlmester, et al., 1992) was to describe the nature of the state and local agencies that deliver the program's weatherization services to low-income households. To gather this information, questionnaires were mailed to 48 State Weatherization Agencies (Alaska and Hawaii were excluded) and the 1,148 local agencies in these states. Conducting these surveys was the first attempt by DOE in over a decade to inventory and characterize the population of state and local weatherization agencies.

Survey results showed that the Program network weatherized nearly one quarter of a million homes in the 1989 Program Year (PY 1989) with a budget of over \$590 million dollars. The network employed more than 7,000 full-time equivalent staff, the majority of whom received training on a continuing basis and had extensive experience in weatherization. Members of the Program network interact extensively with one another and to a significant degree with external programs and organizations, such as utilities.

The characterization study provided useful information for planning other parts of the evaluation. For example, it made it possible to design a sampling frame for the selection of a representative national sample and to stratify the sample by agency size and geographic location. The study also identified a variety of issues of importance to Program management.

RESOURCES AND POPULATION STUDY

This study had two parts. The first part (Power, et al., 1992) estimated the total number of full-scale low-income weatherizations completed (3.9 million) and the total investment (\$4.4 billion) in these weatherizations for the time period of 1978-1989. Surveys were mailed to state DOE Weatherization Program managers and to utility conservation program managers to obtain these data. Over the time period studied, DOE appropriations became a smaller proportion of total weatherization resources as the relative contributions from the Petroleum Violation Escrow (PVE) Fund and the Low-Income Home Energy Assistance Program (LIHEAP) increased.¹ (Note: PVE funds come from legal penalties assessed against oil companies convicted of violating price controls.)

Regardless of its source, most funding for low-income weatherization (77%) between 1978 and 1989 was spent according to DOE's Weatherization Assistance Program rules. The fact that the vast majority of non-DOE funds have been channeled through the Program underscores DOE's central role in directing weatherization activities nationwide.

About 20% of the weatherizations were completed by utility programs which were concentrated in a few states (mainly in the Northwest, upper Midwest, and in California). Utility

¹In the years of 1978-1989, the proportions of funding for full-scale low-income weatherizations by funding source were: DOE 45%, PVE 14%, LIHEAP 28%, utility 10%, States 2%, Other 1%. By 1994, however, PVE funding has been exhausted in most states.

programs tend to be in states where low-income weatherization programs were mandated by regulatory bodies. Typically, the investment per dwelling by utility programs was about half the average amount invested by the DOE Program.

The 3.9 million dwellings weatherized during 1978-1989 represent a significant, though uncertain, percentage of the low-income housing stock. According to the Residential Energy Consumption Survey, 27.9 million housing units were occupied by program-eligible households in 1989. However, this does not mean that exactly 14% of the eligible households (that is 3.9 million of 27.9 million) received weatherization services during 1978-1989; the percentage may be lower because of the physical and income mobility of the low-income population. Nevertheless, it is clear that the vast majority of households have not received services, and even those that have been weatherized sometimes received only token investments in comparison to their need for efficiency improvements.

The second part of this study (Eisenberg, et al., 1994) described the Program-eligible population in terms of location, housing attributes, energy-use and demographic characteristics. Subsets of the low-income population, such as high energy expenditure households (5.0 million) and high energy burden households (7.2 million), were examined to determine how best to target and allocate limited weatherization resources. It concluded that targeting households with both high burdens and high expenditures (2.1 million) offers the opportunity to reduce utility bills of the neediest households and achieve sizable energy savings (Figure 1).

--FIGURE 1 ABOUT HERE--

The two parts of the resources and population study provided Program managers with information on what has been accomplished and what remains to be accomplished in low-income weatherization. The study identified patterns and trends in low-income weatherization activities and funding. In addition, characteristics and subsets of the eligible population were examined to help guide future Program efforts.

MULTIFAMILY STUDY

The Multifamily Study (Mac Donald 1994) described the nature and extent of weatherization activities in larger multifamily buildings. A multifamily unit was defined as a dwelling that is located in a structure containing more than four residences that are not located in row-housing (or townhouses). Two national surveys were conducted as part of this study: one of the states and one of the local weatherization agencies. These surveys showed that at least 20,000 dwellings (probably more because some states did not respond to the survey) located in larger multifamily buildings (including both public and private housing) were weatherized in PY 1989. This represents about 9%

of the total dwellings (of all types) weatherized by the Program in that year. Since an estimated 15% of the eligible population lives in large multifamily buildings, it is clear that this is an underserved segment of the eligible population.

The Program's multifamily work was centered in a few states, including New York, Massachusetts, Illinois, Minnesota, and Washington (Figure 2). Owner contribution policies and special energy audit procedures for larger multifamily buildings were in place in at least ten states.

--FIGURE 2 ABOUT HERE--

A large variety of measures were installed under the Program in larger multifamily buildings, but the largest investments were made in windows. The Multifamily Study emphasized the need for case studies to document recent innovations and energy savings in multifamily weatherization. These case studies are now underway.

SINGLE-FAMILY STUDY

The Single-Family Study was the largest of the five studies in the National Evaluation. Its first phase was designed to evaluate the national and regional energy savings and cost effectiveness of DOE Weatherization as applied to the largest portion of its client base—low-income households occupying single-family dwellings, mobile homes, and small (2- to 4-unit) multifamily dwellings (Brown, et al., 1993a). The first phase also assessed nonenergy impacts of weatherization, analyzed factors associated with energy savings, and identified promising weatherization opportunities for the future.

The evaluation design for the first phase consisted of a treatment group of dwellings weatherized in PY 1989 and a control group of applicants for weatherization services. Data on dwelling and occupant characteristics, weatherization measures, and costs were collected for 14,971 weatherized dwellings, or 80% of the original sample of 18,748 homes. Gas and electric utilities provided complete consumption data for 4,796 (or 36%) of the weatherized dwellings that heated primarily with gas or electricity, and 3,776 (or 32%) of the control dwellings.

Energy savings were calculated using the Princeton Scorekeeping Method (PRISM), a sophisticated and widely used procedure that normalizes energy use over time by adjusting for outside temperature differences (Fels, 1986). The process is analogous to a procedure to normalize for highway and city driving in a miles-per-gallon analysis of automobile fuel consumption. After normalizing for weather, gross savings were calculated as the difference between energy use before and after weatherization. Finally, consumption of the control homes was analyzed over the same periods. This enabled small (but accurate) adjustments to be made to account for changes in energy use that would have occurred in the absence of weatherization. Net savings of weatherized dwellings

were computed by subtracting the average gross savings for control homes from the average gross savings for weatherized homes.

The second phase of the Single-Family Study built on the first phase, by using its energy-savings estimates to identify local weatherization agencies with a range of savings. The result was a purposive sample selected to allow for comparisons between higher- and lower-saving agencies and dwellings. Phase two was divided into two parts: 1) the first part consisted of ten case studies of higher-saving agencies (Brown, et al., 1993b), and 2) the second part involved on-site inspections of 270 dwellings served by the ten higher-saving agencies and 502 dwellings served by 20 average- or lower-saving agencies (Berry and Brown, 1994).

The data collected for the weatherized and control dwellings in phase two included:

- detailed field data on the building shell and mechanical systems of the dwellings;
- measurements of floor area, window area, volume, and conditioned space;
- air leakage tests performed with blower doors;
- measurements of carbon monoxide (CO) levels and other potential safety problems; and
- occupant perceptions and behavior.

Some of the questions addressed by the phase two study were:

- To what extent does weatherization improve the energy efficiency of low-income housing?
- How do houses with high energy savings differ from houses with low savings?
- How do agencies that achieve high savings differ from those that do not?
- What lessons can be learned about how to produce higher savings?

Energy Savings and Cost-Effectiveness. The first phase of the Single-Family Study concluded that the Program meets the objectives of its enabling legislation and fulfills its mission statement. Specifically, it

- saves energy,
- lowers fuel bills, and
- improves the health and safety of dwellings occupied by low-income people.

In addition, the Program achieves its mission in a cost-effective manner based on each of three perspectives employed by the evaluators.

Measured savings for gas, electricity, and fuel oil (obtained from the fuel-oil study) were combined with estimates of energy savings for dwellings that heat primarily with other fuels such as propane, wood, kerosene, and coal. The average savings for all single-family and small multifamily dwellings weatherized in 1989 was estimated to be 17.6 million Btus per year, 18.2 percent of the energy used for space heating and 13.5 percent of total energy use (Table 1).

--TABLE 1 ABOUT HERE--

The dollar value of the annual net savings was \$116, which with an average installation cost of \$1,050, means that the Program is cost-effective from a variety of perspectives. Further, the investments made in 1989 will, over a 20-year lifetime, save the equivalent of 12 million barrels of oil, roughly the amount of oil added to the Strategic Petroleum Reserve in each of the past several years.

Factors Associated with High Savings. Knowing which measures tend to produce good savings—and which don't—is critical in providing useful feedback to weatherization practitioners. The Single-Family Study found that the following practices were associated with higher-than-average savings:

- **Weatherizing high energy users.** Within each climate region, weatherizing high energy users is associated with high energy savings. High energy use usually points to specific weaknesses in the dwelling's envelope or heating system. Solving such problems usually produces highly cost-effective savings.
- **Using an integrated audit of the heating system and envelope.** Integrated audits help pinpoint problems and guide weatherization work towards what makes a difference—and away from what doesn't. They consider both envelope and heating and cooling system needs, and provide savings-to-investment ratios for individual measures.
- **Curing distribution system problems.** Air leakage from distribution systems can cause serious health and safety problems, as well as affect energy consumption. Curing them is correlated with higher-than-normal savings.
- **Replacing furnaces.** This measure is not only positively correlated with higher-than-average savings, but also frequently solves safety and health problems. Since this is usually a high-cost measure, its cost-effectiveness—considered as only an energy conservation measure—is not always high. On the other hand, removing a furnace with a broken heat exchanger can improve indoor air quality and save lives.
- **Installing attic insulation.** The Single-Family Study clearly showed that the installation of insulation in attics never before insulated is particularly cost-effective.
- **Installing wall insulation.** During the time of the evaluation, only a few agencies had begun using the high-density installation technique (which accomplishes air sealing and insulation with a single operation). However, weatherization jobs that included high-density wall insulation showed even greater savings than those that used older wall insulation techniques.

Remaining Opportunities. The phase two study concluded that nearly every type of measure examined during the on-site inspections of dwellings showed significant opportunities for additional energy-efficiency improvements. This was especially true of the measures that cost the most to install, such as heating system replacements and wall insulation. One clear conclusion, therefore, is that the Program is underfunded relative to the need for efficiency improvements in the low-income housing stock. Without increased average funding per dwelling, all of the available opportunities for efficiency improvements cannot be realized. At present funding levels, Program implementors typically are able to meet only part of the weatherization needs of their clients. While many

important, and cost-effective, energy-efficiency improvements are being implemented by the Program, more funding would make it possible to do much more. In addition, many low-income homes need extensive structural repairs, which must be supported with leveraged funds. Thus, in many homes, leveraging of housing rehabilitation funds to supplement DOE funds is an essential step in achieving minimal structural integrity and energy efficiency.

Figure 3 provides a visual illustration of the relationship between investment and savings. The scatter plot is based on 1,850 gas-heated dwellings grouped into strata of direct costs spanning \$100 ranges. It suggests a close linear relationship between costs and savings, with gas savings increasing by 15 ccf/year for every \$100 increase in direct costs. The increment in savings for every \$100 invested does not appear to diminish as the level of costs rises from \$1,000 to \$2,000 and \$3,000. That is, there is no evidence of a diminishing return in terms of savings resulting from each additional increment of investment.

--FIGURE 3 ABOUT HERE--

Notable Characteristics of the Ten Higher-saving Agencies. The ten higher-saving agencies generated significant gas savings from their weatherization jobs. On average, they reduced consumption by 347 ccf/year, which represents 33% of the gas used for space heating and 24% of the dwelling's whole-house gas consumption. The names and locations of these agencies are shown in Figure 4.

--FIGURE 4 ABOUT HERE--

The most striking finding from the analysis of higher savers was that there were many different formulas for success. Each of the ten successful agencies employed a unique combination of useful and innovative approaches. Nevertheless, common features and trends did emerge when the ten higher savers were compared to average agencies. Table 2 summarizes the most notable characteristics that distinguished the ten higher-saving weatherization programs from less successful programs. These noteworthy features ranged from agency and staff characteristics to client recruitment and selection practices; weatherization measures; resource leveraging; and cost controls. Despite the commonality of the features shown in Table 2, no single higher-saving program had all of these features. The diversity among the higher savers underscored the fact that excellence can be achieved in many different ways.

--TABLE 2 ABOUT HERE--

High- Versus Low-Saving Dwellings. When high-saving dwellings (defined as the 25% of the sample with the highest savings) were compared to low-saving dwellings (defined as the 25% of the sample with the lowest savings), pre-weatherization consumption was the strongest distinguishing factor. In phase one, pre-weatherization consumption was identified as the strongest predictor of savings. In phase two, the same finding was demonstrated again. In particular, the high-saving dwellings used about 70% more energy before weatherization than the low-saving dwellings.

FUEL-OIL STUDY

The goals of the Fuel-Oil Study (Ternes and Levins, 1994) were very similar to those of the Single-Family Study, except that its focus was on the region where the use of fuel oil for home heating is concentrated. The primary goal of the fuel-oil study was to estimate average space-heating savings in weatherized homes located in the Northeast. Other goals were to assess Program cost effectiveness in the fuel-oil submarket, and to assess factors which caused fuel-oil savings to vary.

This study was limited to single-family houses that heated primarily with fuel oil and that were located in nine states in the Northeast. The Fuel-Oil Study employed a split-winter evaluation design involving two heating seasons (1990-91 and 1991-92). Weatherized homes received energy conservation measures in January of each heating season. The three months before and after weatherization comprised the pre- and post-weatherization data collection periods for both weatherized and control groups. A total of 337 houses (222 weatherized and 115 control houses) were monitored from 41 local weatherization agencies.

A data-logger in each house recorded inside and outside temperatures and heating system run-time, and sent averaged hourly data each week via a modem to a central computer. Information about the physical characteristics of each house and its space-heating system was collected at the end of the post-weatherization period. A comprehensive questionnaire was used to obtain occupant characteristics and their perceptions of Program impacts. Local weatherization agencies provided information for each house on service delivery procedures, weatherization dates, installed measures and costs, and household income. Blower-door tests were performed before and after weatherization to determine changes caused by weatherization measures. Steady-state efficiencies of space-heating systems were measured in each house for both pre- and post-weatherization periods. Safety inspections of space- and water-heating systems were performed at the end of the post-weatherization period in all weatherized houses. Control houses were similarly tested.

Findings. The Fuel-Oil Study showed that an average single-family dwelling located in the Northeast and heated primarily by fuel oil saved 160 gallons of fuel oil in the first year following weatherization. This is equivalent to 22.4 million Btus, or 17.7 percent of total fuel-oil use (fuel oil is generally used only for space heating). The dollar value of the net savings was \$162, which with an

average installation cost of \$1,192, means that the Program is cost-effective from a variety of perspectives.

The factors associated with high savings were very similar to those identified in the Single-Family Study. In particular, high pre-weatherization consumption was identified as the best predictor of high savings. Both studies also suggested that high savers were houses that really needed weatherization, while the low savers had less room for improvement. In addition, both studies found that attic insulation, wall insulation (especially high density wall insulation), and heating system replacements stood out as correlates of higher-than-average savings. Houses receiving heating system replacements saved about twice the average of all houses in the Fuel-Oil Study.

THE FUTURE OF WEATHERIZATION: THE NEXT STEPS

The various reports produced by the National Weatherization Evaluation present a comprehensive profile of weatherization procedures and measures that characterize higher-saving agencies and high-saving dwellings. The following recommendations result from these findings and describe a series of next steps to enhance the Weatherization Program beyond its already strong foundation.

- **Enhance the existing high quality of the weatherization work force through increased training and professional development.** Higher-saving agencies are characterized by experienced and well-trained employees. Improving the ability of the weatherization work force to employ diagnostic reasoning and principles from building science will result in even more cost-effective weatherization.
- **Encourage agencies to direct their resources towards clients that have higher-than-average levels of energy burden.** This can be done either through the selection of clients that have a higher-than-average energy burden or the determination of investment levels based on the preweatherization energy burden. Both the Single-Family and the Fuel-Oil Studies found that energy savings are greatest in dwellings that consume large amounts of energy prior to weatherization. These same households also tend to spend a high proportion of their income on energy. By matching levels of investment with potential for savings, overall program cost-effectiveness will improve.
- **Encourage the efforts of states to mobilize other resources to address the rehabilitation needs of low-income housing.** This will enable DOE resources to be focused more on energy-efficiency improvements. Most higher-saving agencies have access to non-DOE funds to help pay for housing repairs. The Program will be stronger as more local agencies have access to non-DOE funds for housing rehabilitation while using DOE funds to improve energy efficiency.
- **Establish technology transfer mechanisms to promote replication of the success of higher-saving agencies.** One striking finding of the Single-Family Study is the tremendous diversity among local agencies. A challenge to DOE's Weatherization Program is to help bring the less innovative and less advanced agencies up to the level of the higher-saving agencies in their region.
- **Continue the Program's strong emphasis on attic, wall, and floor insulation.** High savings in both the Single-Family and Fuel-Oil Studies are associated with greater-than-

average levels of investment in insulation. High-density wall insulation techniques that can achieve air sealing and insulation in the same operation appear to be especially effective.

- **Further analyze the role of replacement windows and storm windows.** The Single-Family and Fuel-Oil Studies have shown that large investments in windows are especially characteristic of dwellings and agencies that achieve lower-than-average energy savings. Yet at least one higher-saving agency specializes in storm windows. Further, owner investments in the weatherization of large multifamily buildings tend to target storm windows. Additional research is needed to assess the conditions under which storm and replacement windows are a cost-effective Program expenditure.
- **Increase the emphasis on replacing inefficient space-heating systems.** Higher-saving agencies identified in the Single-Family Study replace more space-heating systems than other agencies. In addition, they make greater use of instrumented analyses of furnaces and boilers to select measures that promote health, safety, and energy efficiency. System replacements and instrumented analyses are characteristic of high-saving homes in both the Single-Family and Fuel-Oil Studies.
- **Increase attention to heating system distribution systems.** Dwellings that received duct leakage control measures and distribution system diagnostics achieved above-average savings in the Single-Family Study.
- **Increase attention to water-heating measures.** Water-heating conservation measures are characteristic of high-saving homes in the Single-Family and Fuel-Oil Studies. Measures to consider should include domestic hot water tank and pipe insulation, water temperature reduction, low-flow shower heads, and aerators.
- **Select measures based on savings-to-investment ratios produced by audits.** The Program should discourage the use of prescriptive methods such as statewide priority lists for the selection of measures. Audits that rank measures by savings-to-investment ratios, calculated for each individual house, produce more cost-effective weatherization. Evidence supporting this recommendation was produced by analysis of higher-saving agencies in the Single-Family Study.

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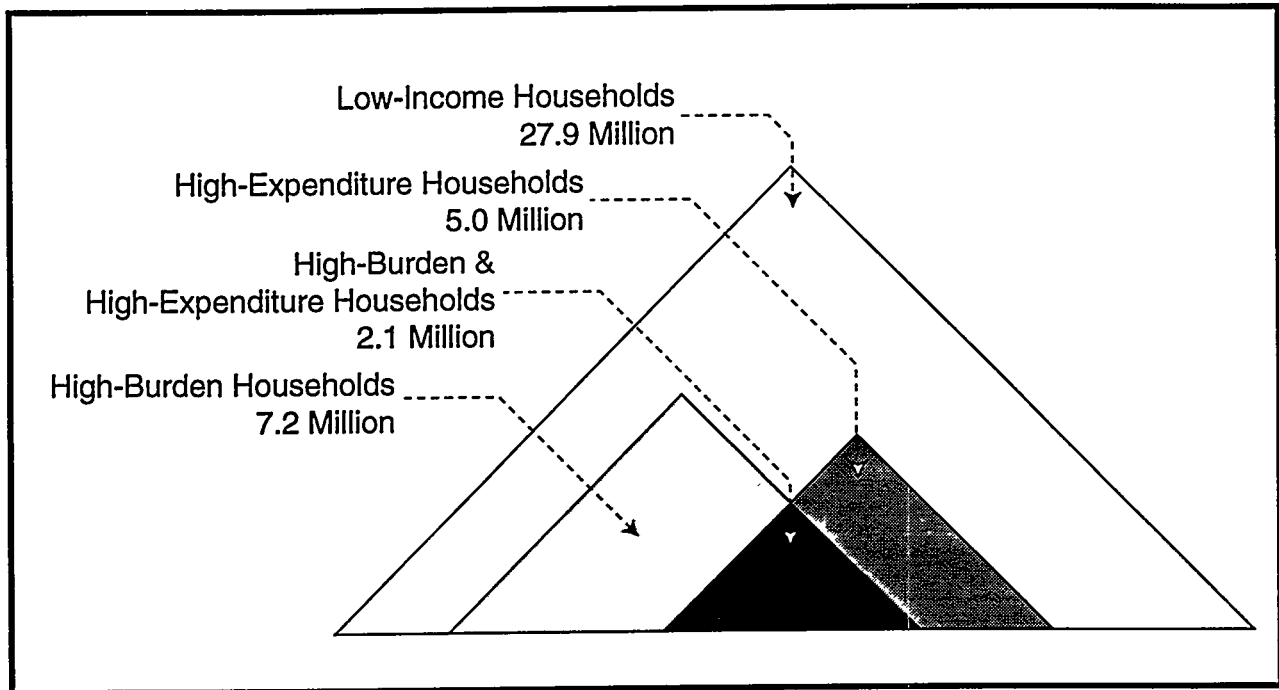


Figure 1. Low-Income Households and Subpopulations in 1990.

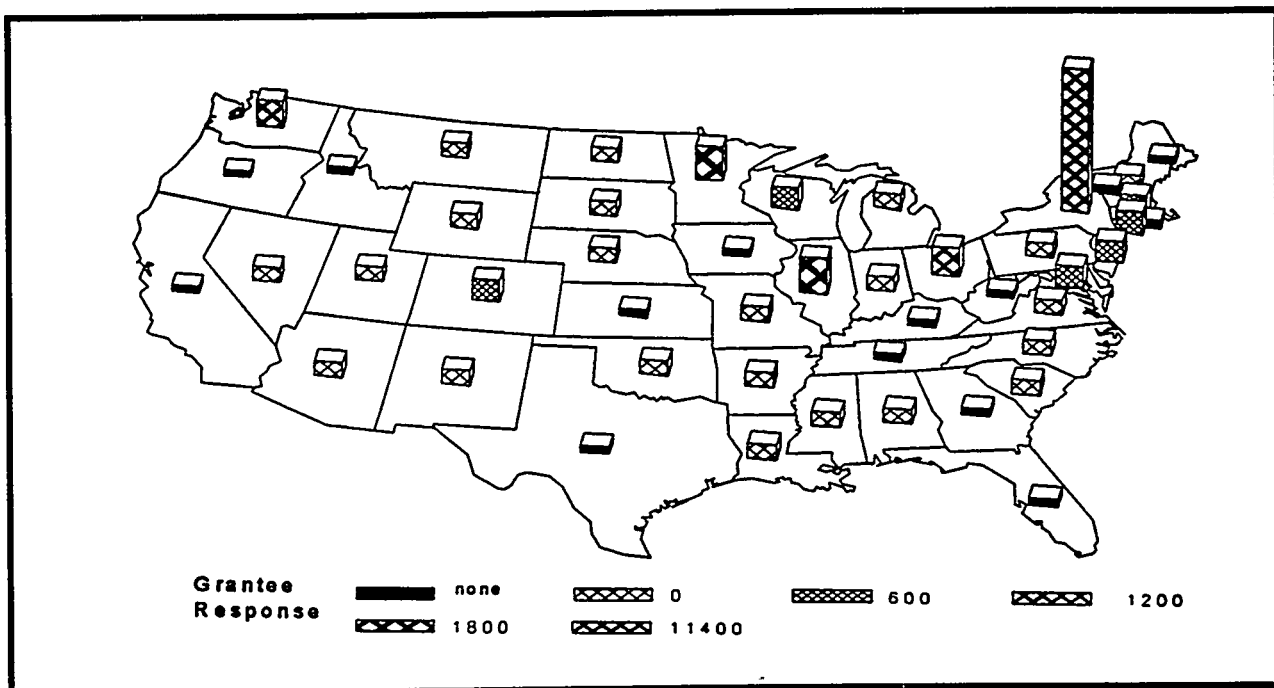


Figure 2. Geographic Distribution of 20,000 Weatherized Large Multifamily Dwellings in FY 1989.

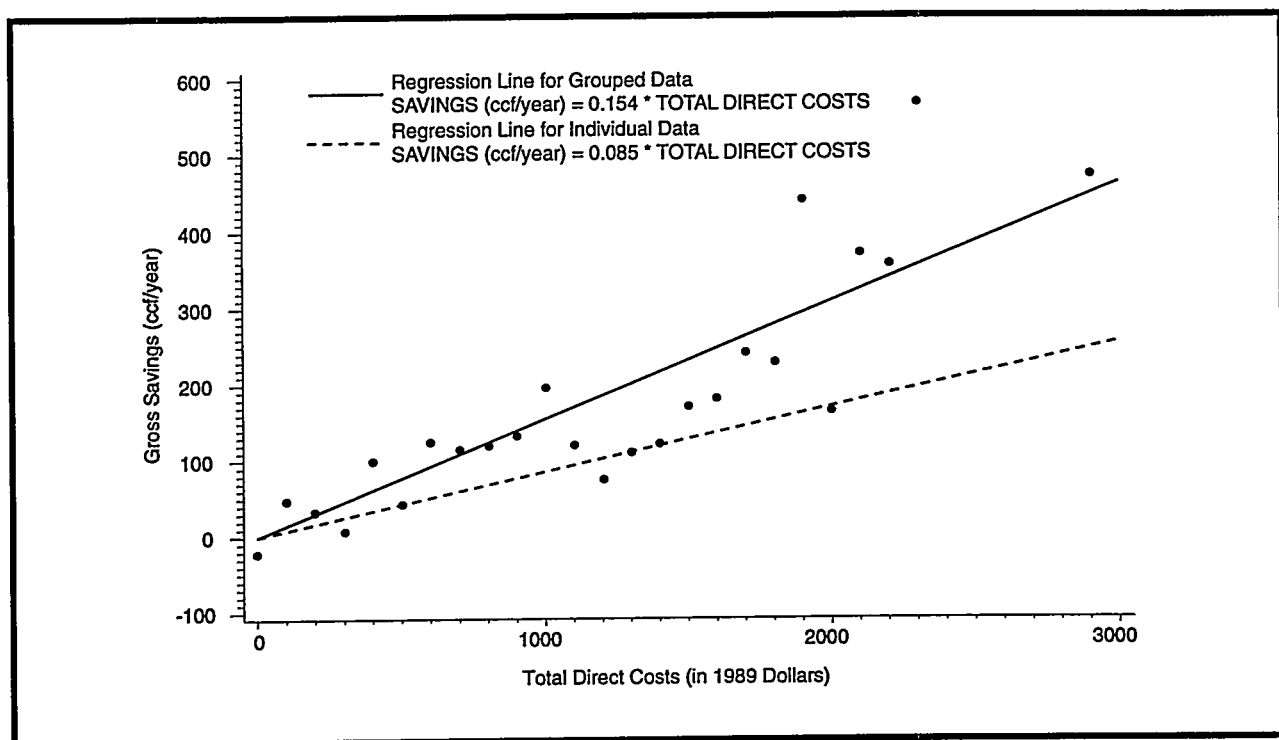


Figure 3. Relationship Between Direct Costs and Energy Savings.

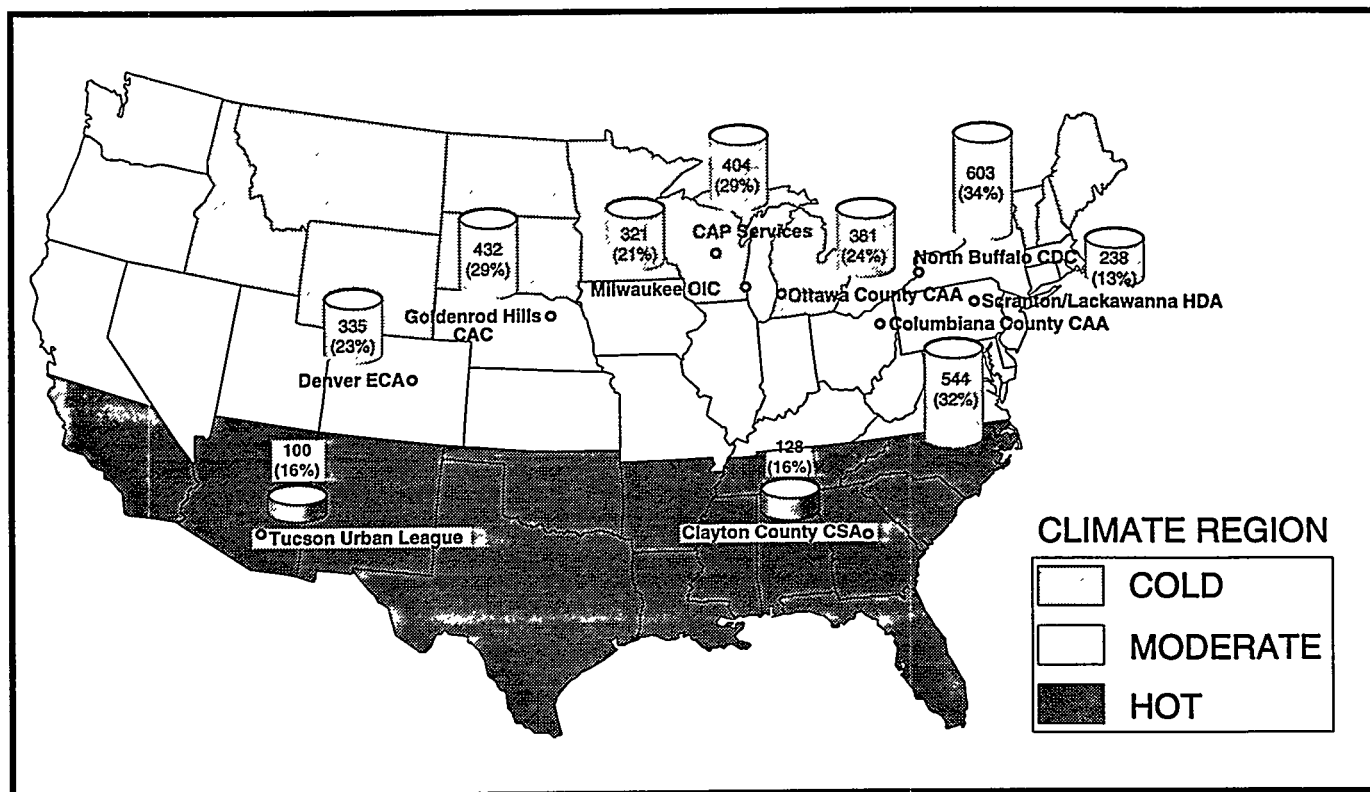


Figure 4. Location of the Ten Higher-Saving Agencies and their Annual Gross Gas Savings (in ccf/dwelling and as a percent of pre-weatherization gas consumption).

Table 1. Net Energy Savings for Single-Family and Small Multifamily Dwellings Weatherized in 1989

Primary heating fuel	Percentage of space heat	Percentage of total fuel use	Net savings (M/Btu/year)
Natural gas	18.3	13.0	17.3 MBtu/year
Electricity	35.9	12.2	18.9 MBtu/year
Fuel oil (Northeast)	17.7	17.7	22.4 MBtu/year
All fuels*	18.2	13.5	17.6 MBtu/year
*Includes estimates for propane, wood, kerosene, coal, and other fuels.			

Table 2. Notable Characteristics of the Ten Higher-Saving Weatherization Programs

Category	Characteristic of a Majority of the Higher Savers
Agency Characteristics	Large, multi-program community action agencies
Weatherization Staff	Limited turnover and substantial weatherization experience
Delivery System	In-house crews supplemented by contractors for furnace work
Client Recruitment	Reliance on LIHEAP rosters for recruiting applicants
Selection of Clients and Investment Levels	Strong and increasing focus on high energy users
Blower Door Use	Limited use in 1989, extensive use in 1992 — during the audit, while air sealing, and as part of the final inspection
Weatherization Measures	More attic and wall insulation and furnace retrofits and replacements
Leveraging Home Repairs	Access to housing rehabilitation funds from non-DOE sources
Cost Controls	Effective cost controls such as bulk purchasing & in-house fabrication of measures
Category	Characteristic of Four of the Higher Savers
Client Education	Ambitious client education programs
Utility Leveraging	Funding and/or in-kind contributions from utilities to expand weatherization efforts