Energy-Efficiency Improvements and Remaining Opportunities in the DOE Low-Income Weatherization Program

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The study discussed in this paper is part of the National Evaluation of DOE's Weatherization Assistance Program. This study conducted on-site inspections of over 700 dwellings and in-person interviews with agency directors and weatherization clients in order to determine the impacts of weatherization, the remaining opportunities for energy-efficiency improvements, and the factors that produce high or low energy savings in individual local agencies and dwellings. The weatherization measures most strongly associated with high savings included attic and wall insulation, and heating system replacements. Nearly every type of weatherization measure examined 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. Thus, the Program is underfunded relative to the need for efficiency improvements in the low-income housing stock. 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, additional funding would make it possible to do much more.

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.

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:

- **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 (Brown et al., 1993a).

- **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 (Ternes and Levins, 1994).

- **Multifamily Study—** this study described the nature and extent of weatherization -activities in larger multifamily buildings (MacDonald, 1994).

- **Network Study—** this study characterized the weatherization network's leveraging, capabilities, procedures, staff, technologies, and innovations (Mihlmester et al., 1992).

- **Resources and Population Study—** this study profiled low-income weatherization resources, the weatherized population, and the population remaining to be served (Power et al., 1992).

The purpose of this paper is to summarize the impacts of weatherization on energy-efficiency features (such as insulation, windows and doors, air leakage, and heating systems and ducts) and to identify remaining opportunities for efficiency improvements. It presents a brief overview of the findings of a recently completed part of the National Weatherization Evaluation: the second phase of the Single-Family Study (Berry and Brown, 1994). The

relation of the first and second phases of the Single-Family Study and the issues addressed in the second phase are explained below.

Single-Family Study: Phase One

Goals

The Single-Family Study, which was the largest of the five studies in the National Evaluation, had two phases. The first phase was designed to evaluate the national and regional energy savings and cost effectiveness of DOE Weatherization as it has been 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).

Methods

The evaluation design for the first phase consisted of a treatment group of dwellings weatherized in Program Year (PY) 1989 and a control group of applicants for weatherization services. Because of the difficulty and expense of obtaining data from large numbers of utilities and local weatherization agencies, a two-stage, cluster sampling technique was used for the representative national sample. The national sample was designed to be large enough to provide estimates of national energy savings that were within 10% of the mean at the 90% confidence level. A sample of 400 local weatherization agencies was selected in the first stage. The second stage produced a sample of 18,748 weatherized dwellings (13,162 that heated primarily with gas or electricity and 5,586 that heated primarily with other fuels), and 11,795 gas- or electrically heated control homes. The sample was restricted to dwellings weatherized entirely, or in part, with DOE funds or with funds from other sources that were used according to DOE Weatherization regulations.

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 consumption was weather normalized by the Princeton Scorekeeping Method (PRISM), and a cross-sectional, time-series approach was used to estimate energy savings.

Findings

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.

For all fuel types, the national estimate of annual savings per dwelling was 17.6 million Btu's per weatherized dwelling resulting in an 18.2% reduction in the energy used for space heating, a 13.5% reduction in total energy use, and an annual decrease of $116 in the average client's energy bills. In addition, the Program achieves its mission in a cost-effective manner with benefit/cost ratios of from 1.09 to 1.72 based on three perspectives employed by the evaluators (Brown et al. 1993a).

Single-Family Study: Phase Two

The second phase of the Single-Family Study built cm the first phase. In particular, the energy-savings estimates from phase one of the Single-Family Study were used to identify local weatherization agencies with a range of performance (based on the average energy savings of their weatherized dwellings). Because phase one documented that the cold and moderate climate regions had higher average savings than the hot region, high and low performance were defined in relation to climate region averages, not in relation to the national average (Figure 1).

After agencies were ranked by average energy savings, the next step was to select 10 higher-saving, 13 average-saving, and 7 lower-saving agencies for the phase two sample. The result was a purposive sample selected to allow for comparisons between higher-and lower-saving agencies and dwellings in several climate regions. Because the phase two sample is not a representative sample, conclusions about the energy savings and cost effectiveness of the national program must be based on phase one.

Phase two was divided into two parts: 1) the first part consisted of ten case studies (Brown et al., 1993b) of the higher-saving agencies (Figure 1), 2) the second part involved on-site inspections of 270 dwellings served by the ten higher-saving agencies and 502 dwellings served by the 13 average and 7 lower-saving agencies (Berry and Brown, 1994).

The questions addressed by the phase two study included:

- To what extent does weatherization improve the energy efficiency of low-income housing?
- How much of the cost-effective potential for energy-efficiency improvements has weatherization captured?

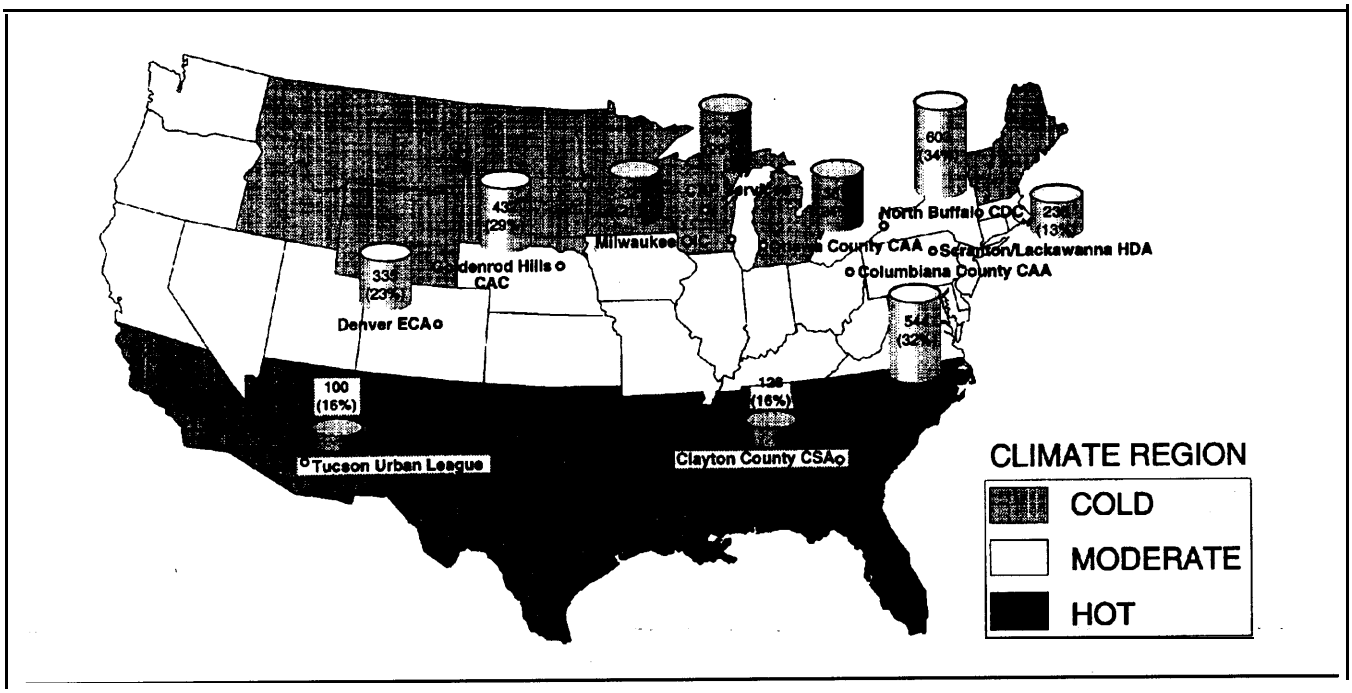

Figure 1. Location of the Ten Higher-Saving Agencies and Their Annual Gross Gas Savings (in ccf/Dwelling and as a Percent of Pre-Weatherization Consumption)

- To what extent does weatherization improve the safety, health, and comfort of low-income clients and their homes?
- How do houses with high energy savings differ from houses with low savings?
- What kinds of houses should be targeted to increase 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?

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.

Study Design

The phase two study involved four types of comparisons (Figure 2). First, all weatherized homes were compared to the control group of homes to quantify the overall energy-efficiency impacts of the Weatherization Program. Second, the treated homes, which are the subset of weatherized homes that received the specific weatherization measure under consideration, were compared to the control homes to quantify the impacts of a measure *when it is peformed.* Third, the characteristics of weatherized dwellings with especially high energy savings were compared with those that had especially low energy savings. The question addressed here was why some homes have greater energy savings than other homes. Fourth, pairs of higher-and lower-saving agencies in each of several climate regions were compared. This analysis helped to identify more and less effective weatherization practices as well as promising future directions for the Program.

Major Findings of Phase Two

Each of the four types of comparisons illustrated in Figure 2 provided insight into the following topics:

- insulation,
- windows and doors,
- air leakage control,
- heating systems and ducts,
- structural problems,
- weatherization expenditures,

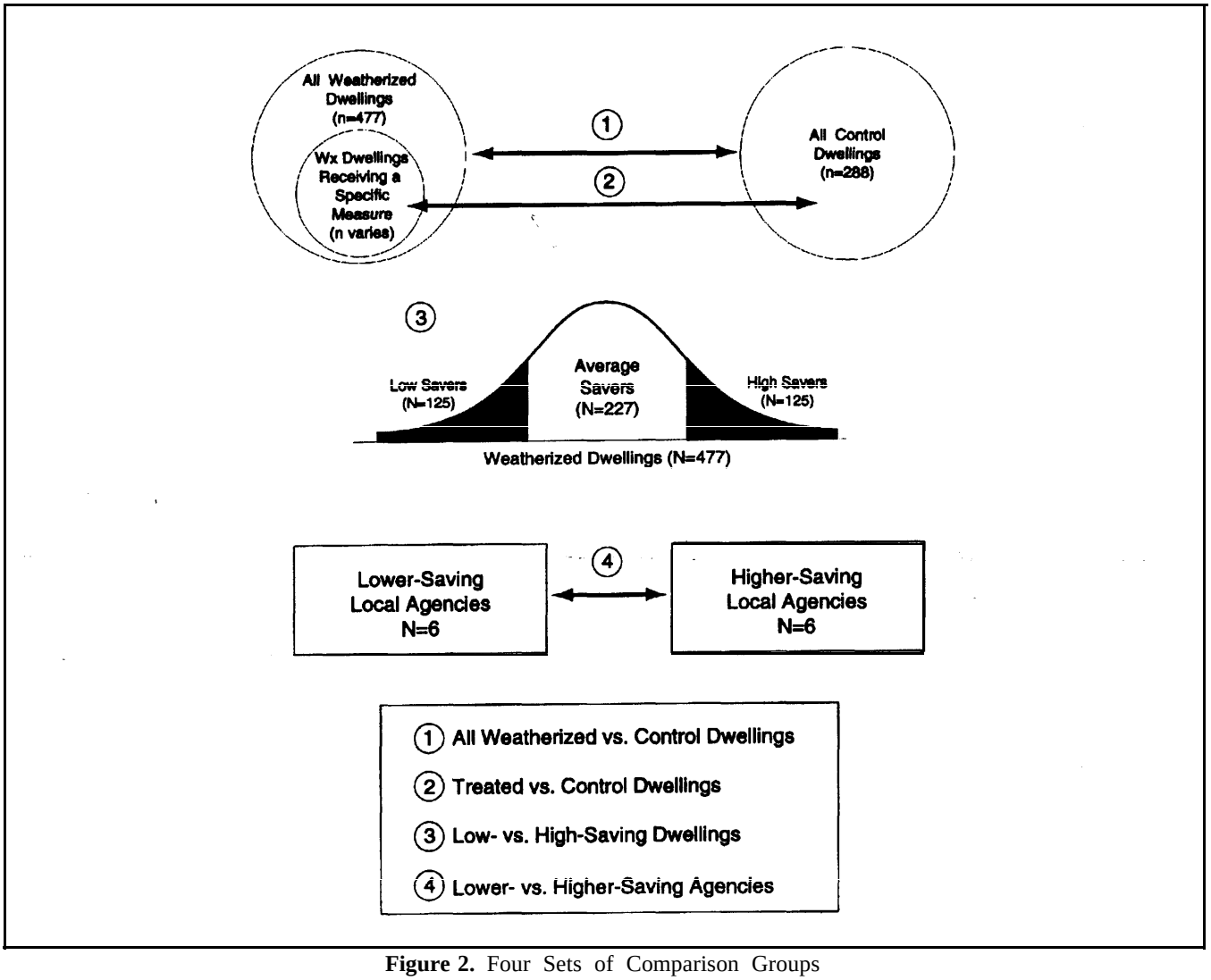

Figure 2. Four Sets of Comparison Groups

- energy consumption, and
- occupant perceptions of nonenergy benefits.

Major findings in each of these topic areas are summarized below.

Insulation

In PY 1989 attic insulation was added in 19.9% of weatherized homes and was installed for the first time in 28.0% of them. The mean R-value of attic insulation was almost twice as high in the phase two weatherized homes (R-26) as in the control homes (R-15) (Figure 3). In treated homes that had attic insulation installed by the Program for the first time, the average R-value was 28. In treated homes where attic insulation was added by the Program to the insulation that was already in place, the average R-value was 31. Market research, conducted by Owens-Corning Fiberglass in 1992, found that in dwellings of all income levels the average R-value was R-21. Thus, the weatherized homes have' R-values above the average for the U.S. housing stock. This indicates that dwellings in higher income groups also need higher levels of insulation, and that the Program is improving insulation in low-income homes to a level that exceeds what is found in the average home.

Although the R-values in weatherized homes are significantly higher than those in control homes (or the average U.S. home), the R-values of the attic insulation in weatherized homes are still often below DOE-recommended levels. For example, about 26% of weatherized homes have R-values of less than R-19, which is below recommended levels in all climate regions in the U.S. R-values of less than R-30 were observed in 63% of weatherized homes. R-30 is the recommended level for the hot region, while the recommended levels for the moderate (R-38), and cold (R-49) regions are higher. Thus, significant proportions of weatherized homes still have attic insulation with R-values below DOE-recommended levels, which

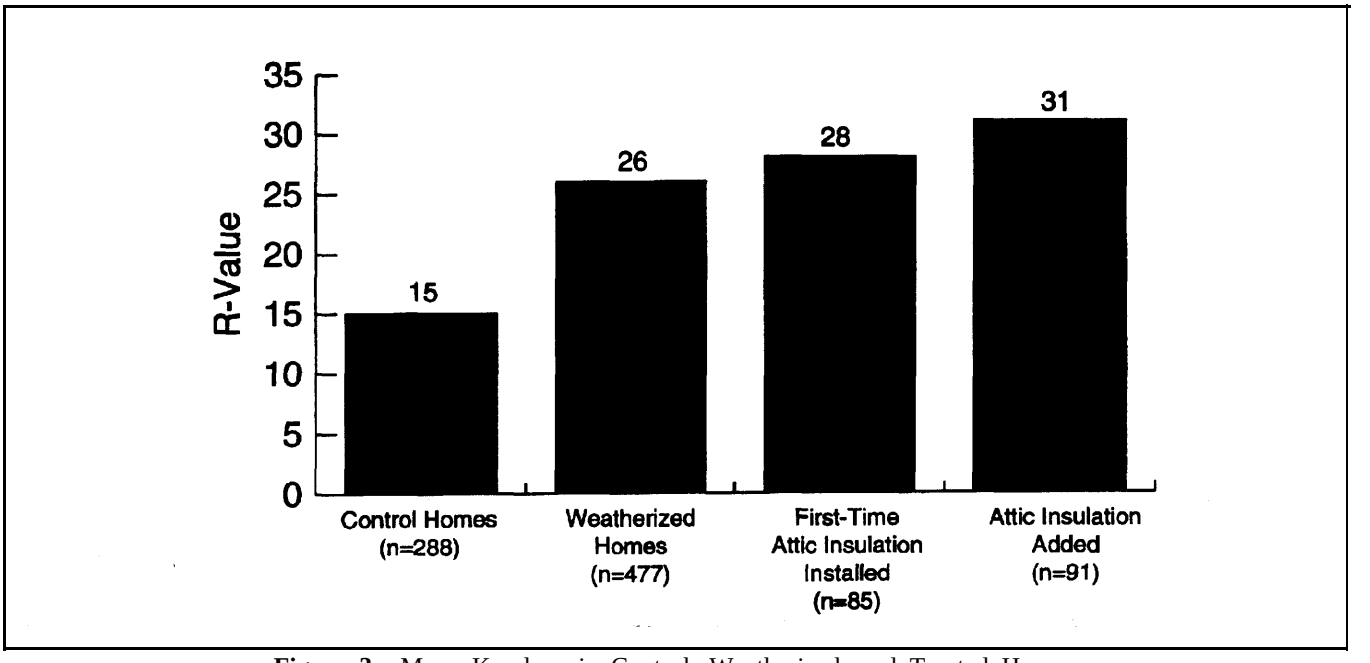

Figure 3. Mean K-values in Control, Weatherized, and Treated Homes

suggests that there is a cost-effective opportunity to install additional insulation in many homes.

Wall insulation, when present, generally was near recommended levels; but, the on-site inspectors noted in their comments that wall insulation was needed in 30% of the total sample of weatherized dwellings and in 35% of the hot region's sample. Nationally, wall insulation was installed in 19.3% of weatherized homes in the 1989 Program Year. In the hot region, however, less than 1% of homes received this measure. Clearly, more installation of wall insulation, especially in the hot region, would be desirable.

These findings suggest that there is a substantial unmet need for additional attic and wall insulation, especially in the hot region. The high energy savings associated with first-time attic insulation and with wall insulation (Brown, et al., 1993a) add support to this conclusion. In addition, higher-saving agencies install much more attic and wall insulation than lower-saving agencies, and high-saving dwellings are much more likely to have received attic and/or wall insulation than low-saving dwellings (Figure 4).

Windows and Doors

The installation of replacement windows and doors along with a variety of repairs to windows and doors were performed in a majority of the homes weatherized in PY 1989. Storm windows were installed in over one-third of the weatherized homes, nationally. Doors also were replaced in over one-third of weatherized homes, nationally. Rates of window and door replacements and repairs were lowest in the cold region and highest in the hot region.

In the phase two sample, the percentage of the total window area that was covered with storm windows was significantly higher for the weatherized homes (64%) and treated homes (73%) than for the control homes (49%). In the hot region, only about 10% of the total window area in control homes had storm windows, as compared to 59% in both the cold and moderate regions. In weatherized homes, 29% of the total window area in the hot region had storms, while 70% in the moderate region and 80% in the cold region had storms.

In general, the higher-saving agencies installed fewer window and door replacements and high-saving dwellings were more likely to receive window repairs than window replacements. Patterns of storm window installation rates, however, showed a weaker, or less consistent, association with lower savings. Although high- and low-saving dwellings had almost identical rates of storm window installation, a smaller proportion of the total money invested was spent on storm windows in the high-saving dwellings. In the cold and the moderate regions, the higher-saving agencies typically installed fewer storm windows. In the two hot regions, however, the higher-saving agencies installed significantly more storm windows, Thus, there appears to be an association between higher rates of storm window installations and lower savings in the climate regions where storm windows are already present in most dwellings. In the hot region, in contrast, where most dwellings have no storm windows, higher installation rates may enhance savings.

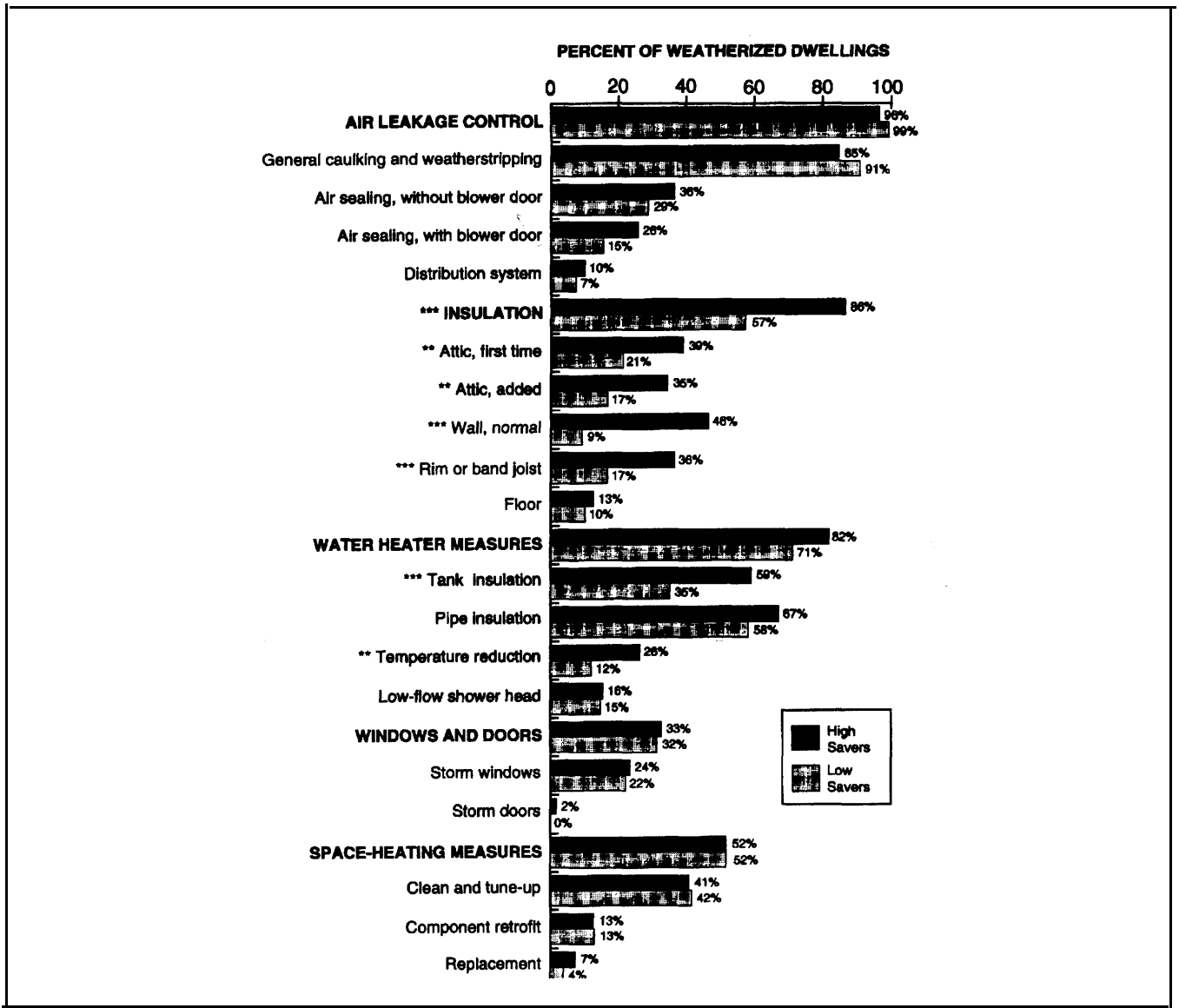

Figure 4. Percentages of High- and Low-saving Dwellings Receiving Various Types of Measures

Air Leakage Control

In PY 1989, over 95% of weatherized homes received one or more air leakage control measures. As expected, therefore, the weatherized homes were significantly tighter than the control homes. Compared to the control homes, the weatherized homes had about 13% less air leakage. Although the weatherized homes were clearly tighter than the control homes, approximately 80% of them had air leakage rates that indicated a need for more air infiltration reduction.

Higher-saving agencies had air leakage rates in their weatherized homes that were about the same as the national average. High-saving dwellings, however, had air leakage rates that were well above the average for all weatherized homes. This result may be due to the fact that high-saving dwellings were older and larger than the average dwelling and so may have been much leakier before weatherization.

Heating Systems and Ducts

Two other areas of opportunity for capturing more of the energy-efficiency potential of Program-eligible homes are the replacement of heating systems and the sealing and repair of distribution systems. Heating systems in both the weatherized and control homes were generally old (nearly half are more than 15 years old) and inefficient (mean steady-state efficiency of 75%). When heating systems were replaced, as they were in 4% of PY 1989 homes, high energy savings typically resulted. Space heating replacements occurred almost twice as often among high-saving dwellings as among low savers, although this

difference was not statistically significant because of the small numbers of homes involved. Replacement of heating systems also is a measure that is heavily emphasized by one of the highest performing agencies (Brown et al., 1993b). These findings suggest that agencies should give higher priority to the replacement of heating systems.

The condition of ducts was poor in more than 50% of the dwellings. In PY 1989, distribution system work was completed on less than 7% of the weatherized homes, far below the proportion that needed duct work. In the phase two inspections, there was little difference between the weatherized and control groups in the incidence of duct problems. There also was no statistically significant difference between high-and low-saving dwellings or high- and low-performing agencies, perhaps because duct work is performed so infrequently. Here again is an unrealized opportunity to cost-effectively improve the energy efficiency of low-income dwellings.

Structural Problems

Structural problems are prevalent in the Program-eligible low-income housing stock, especially in the hot region. Nearly 70% of the control homes and over 65% of the weatherized homes in the hot region had one or more structural problems. Holes in walls and ceilings were the most common problems in both control and weatherized homes, followed by defects in windows and roofs. In every category of structural problem, the hot region had a higher incidence than the total sample average. In several categories dwellings in the hot region were more than twice as likely to have the structural deficiency. The high level of structural problems in the hot region undoubtedly has a negative effect on its ability to achieve comparable energy savings with the same level of investment. When money must first be spent to repair broken windows or holes in the roof or walls, less will be left to invest in attic, wall, and floor insulation, or other energy-efficiency measures. Clearly, the need for structural repairs in low-income dwellings cannot be met with existing funding.

Weatherization Expenditures

In general, the more that is invested in weatherizing a dwelling, the greater the savings (Figure 5). Figure 5 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.

The high-saving dwellings received significantly larger investments than the low savers. The average materials and labor costs for high savers were $1,192, slightly above the national average of $1,050. The low savers, in contrast, received an average investment of $714, or about 68% of the national average. In addition, to the overall difference in investment, the amount invested in specific measures varied. In the average high-saving dwelling, for example, more than $230 was spent on insulation materials, while in the average low-saving dwelling less than $100 was spent on insulation. About twice as much was spent on water-heating measures in high-saving dwellings,

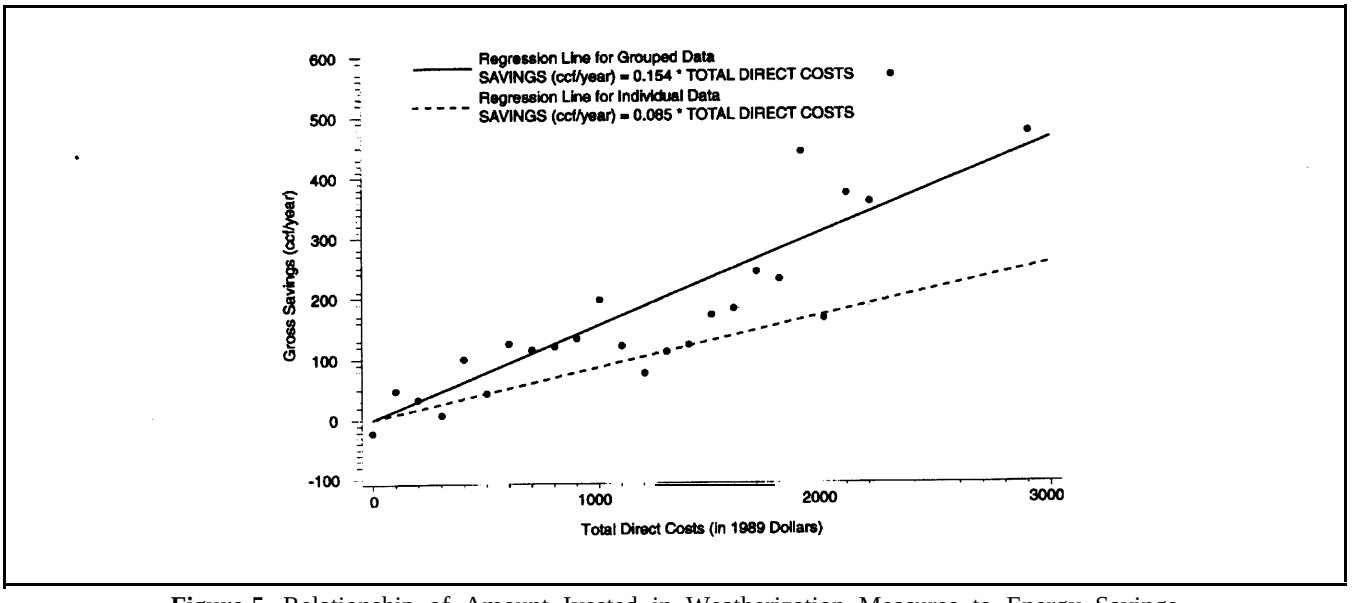

Figure 5. Relationship of Amount Ivested in Weatherization Measures to Energy Savings

and significantly higher amounts were spent on air leakage and space-heating measures. Compared to all single-family and small multifamily dwellings weatherized in PY 1989, the high savers benefited from significantly greater investments in the same four types of measures, and significantly lower investments in structural measures and windows and doors.

The higher-saving agencies invested an average of $727 per house in materials, while the lower-saving agencies invested $535. Higher-savers invested more in the same four measures (air leakage, insulation, space-heating, and water-heating measures) that received the most investment in high-saving dwellings, while the lower-saving agencies invested more in structural repairs and in windows and doors (Figure 6).

Almost all of the higher-saving agencies used leveraged finds to supplement their weatherization jobs. The types of leveraging they used, which are discussed in Brown et al. 1993b, include LIHEAP, utility, and housing rehabilitation grant and loan programs funded by various federal, state and local agencies. Most of the lower-saving agencies did not leverage their resources.

Energy Consumption

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. The high savers also were significantly more energy inefficient prior to weatherization, consuming 25 Btu/square foot/heating degree day (HDD), compared to 20 Btu/square foot/HDD for the low savers.

The average pre-weatherization consumption in homes weatherized by higher-saving agencies also was noticeably higher (1,219 ccf/year versus 932 ccf/year). Homes weatherized by the higher-saving agencies used more energy, in part, because they tended to be larger and older. However, their average usage measured in Btu/square foot/HDD also was higher, which suggests that the pre-weatherization energy efficiency of the dwellings weatherized by the higher-saving agencies was less, and that they had more room for improvement. High energy use usually points to specific weaknesses in the dwelling's envelope or heating system. Solving such problems is likely to produce highly cost-effective savings. Thus, it is clear that weatherizing dwellings that are using more energy, consistently produces more energy savings.

Occupant Perceptions of Nonenergy Benefits

Occupants of weatherized and control homes were asked to rate their dwellings in terms of comfort, draftiness, safety, and heating expenses. They also were asked to rate their own health (in terms of the incidence of illnesses, such as colds, flu, allergies, headaches, nausea, arthritis, which may be affected by the temperature, CO levels, or drafts).

On every rating scale the weatherized group reported a highly significant and positive change between the before and after weatherization time periods (Figure 7). The control group, on the other hand, reported no change in any of the ratings. Thus, the weatherization clients experienced improvements in the comfort and safety of their homes, while the control group did not. The weatherized group also believed their homes became less

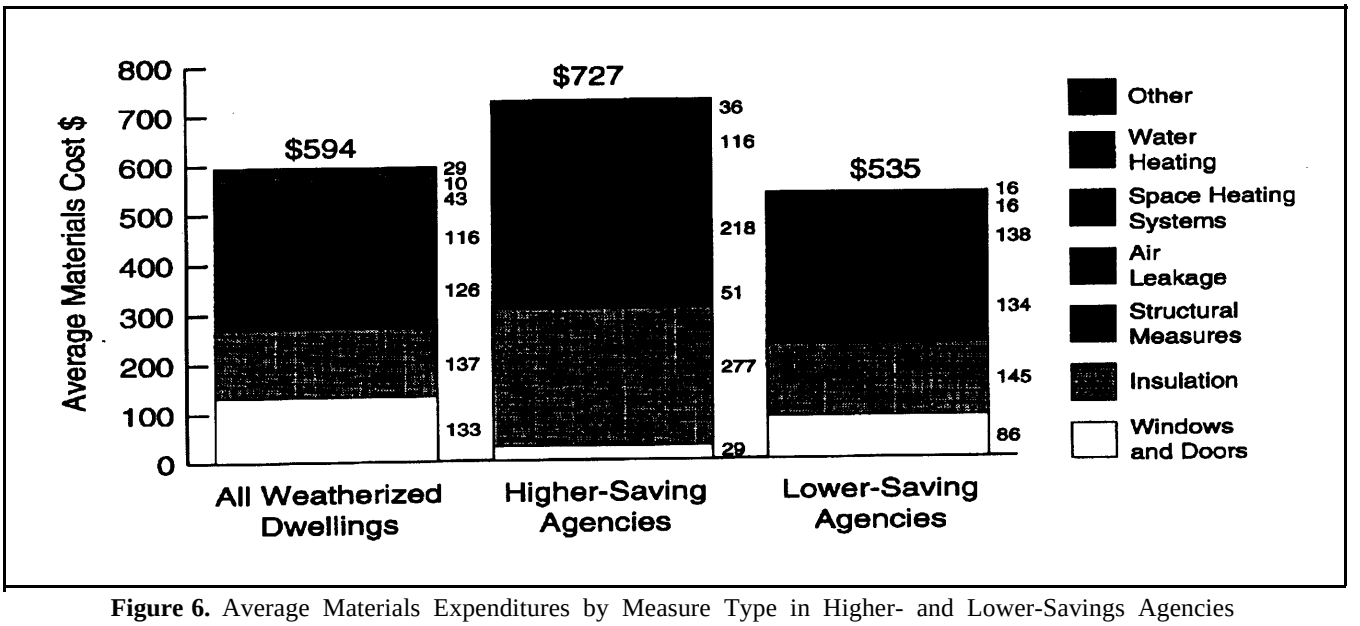

Figure 6. Average Materials Expenditures by Measure Type in Higher- and Lower-Savings Agencies

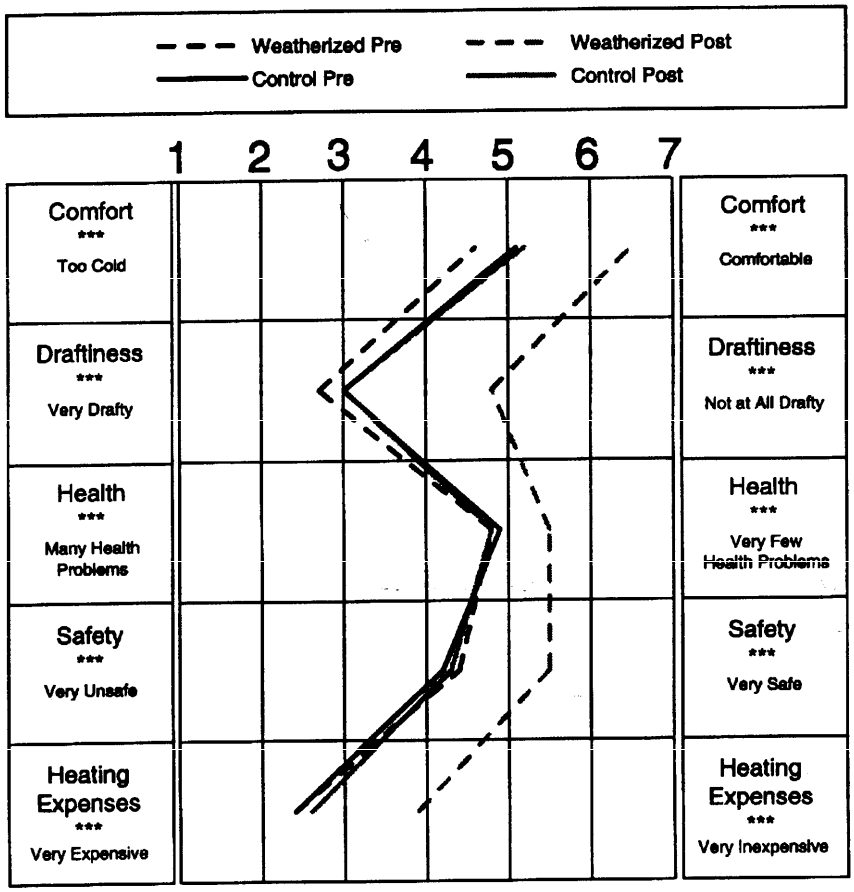

Figure 7. Occupant Perceptions of Nonenergy Benefits in Weathered and Control Dwellings

drafty, and their heating bills more affordable after weatherization. The control group said there was no change during the same time periods. Finally, the weatherized group felt that there had been an improvement in their own health, while the control group did not. Both the high- and low-saving dwellings reported a significant and positive change on each of the rating scales. Thus, both high and low savers experienced improvements in the comfort, draftiness, and safety of their homes, and believed their heating bills were more affordable after weatherization. Both groups also reported an improvement in their own health. However, the occupants of high-saving dwellings not only experienced more energy savings but also perceived greater nonenergy benefits in terms of improved comfort and safety, and reduced draftiness and heating expenses.

On every rating scale the occupants of dwellings weatherized by both the higher-saving and lower-saving agencies reported a positive change between the before and after weatherization time periods. For each of the ratings, the amount of change for the higher-saving agencies was comparable to the amount of change in the lower-saving agencies. Thus, the occupants of dwellings weatherized by the higher-saving agencies and by the lower-saving agencies reported essentially the same levels of nonenergy benefits.

Conclusions

Overall, the findings of the phase two study reinforce the conclusions of the first phase of the Single-Family Study. Both studies showed that attic and wall insulation, water-heater measures, and furnace replacements are the measures that are associated with high levels of savings. These associations are apparent in multivariate models, in comparisons of high- and low-saving dwellings, and in comparisons of higher- and lower-saving agencies.

Nearly every type of measure examined in the on-site inspections of phase two 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 funding 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 also are inadequately funded. In many homes, leveraging of housing rehabilitation funds to supplement DOE funds is an essential step in achieving minimal structural integrity and energy efficiency.

In summary, many additional cost-effective opportunities for improving the energy efficiency of low-income dwellings are not being realized. Some of the most important areas for increased Program emphasis and funding are:

- greater targeting of clients with high levels of energy use;
- more attic and wall insulation, especially in the hot region;
- more heating system replacements; and
- more distribution system sealing and repairs.

Increased average expenditures per dwelling are needed to take full advantage of these opportunities.

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