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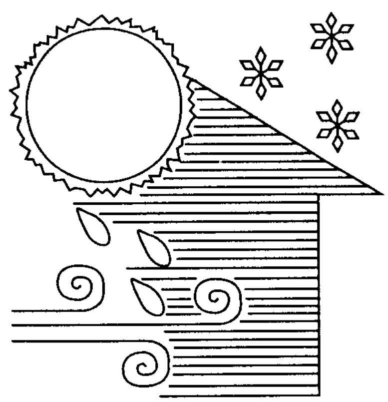
PATTERNS OF IMPACT IN THE WEATHERIZATION ASSISTANCE PROGRAM:

A CLOSER LOOK

Linda G. Berry
Marilyn A. Brown

June 1994



WEATHERIZATION ASSISTANCE PROGRAM

U.S. DEPARTMENT OF ENERGY

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/CON-331

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Prepared by the
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Oak Ridge, Tennessee 37831
Managed by
Martin Marietta Energy Systems, Inc.
for the
U. S. Department of Energy
under Contract DE-AC05-84OR21400

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ACKNOWLEDGMENTS

Members of the National Weatherization Evaluation's working groups helped design this study, guide its implementation, and interpret its findings. The authors are grateful for their contributions and would like to acknowledge them individually:

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Mary Ann Bernald
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Dale Canning
Salt Lake Community Action Agency

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Response Analysis Corporation

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Department of Commerce, Energy Office

Margaret Fels
Princeton University Center for Energy and Environmental Studies

Michael Foley
National Association of Regulatory Utility Commissioners

Michael Ganley
National Rural Electric Cooperative Association

Richard Gerardi
New York State Dept. of State
Division of Economic Opportunity

Sharon Gill
U.S. Department of Energy, Chicago Support Office

Larry Goldberg
Sequoia Technical Services

Miriam Goldberg
U.S. Department of Energy, Energy Information Administration

Judy Gregory
Center for Neighborhood Development

Al Guyant
Public Services Commission of Wisconsin

Martha Hewett
Center for Energy and the Urban Environment

Bion Howard
Alliance to Save Energy

Larry Kinney
Synertech Systems Corporation

Judith Lankau
Orange and Rockland Utilities

Leon Litow
U.S. Department of Health and Human Services

Ron Marabate
Michigan Department of Labor
Bureau of Community Services

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American Gas Association

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Aspen Systems Corporation

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Consolidated Edison Company, Inc.

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The Commonwealth of Massachusetts

Jeffrey Schlegel
Wisconsin Energy Conservation Corporation

Ken Tohinaka
Vermont Energy Investment Corp.

Wendel Thompson
U.S. Department of Energy

Marjorie J. Witherspoon
National Association of State Community Services Programs

We greatly appreciate the high level of cooperation and extensive assistance with data collection that we received from all 30 of the agencies in this study. Without their help the study would not have been possible.

Richard Balzer and Edward Lapsa, of Manhattan Data Systems, provided assistance with data base management, data analysis, and graphics. Michael Bonn and Mark Beyer of Aspen Systems developed the original database and also provided assistance with data analysis. Sherry Surdam and Dan Bell did the formatting and layout of the report.

Tom Wilson and Larry Kinney of Synertech System Corporation helped to design the house characteristics survey form, trained the field contractors, and provided advice on the meaning and interpretation of various measurements. The following companies assisted with the collection of field data:

Energy Resources Center, University of Illinois

GRASP

Planergy, Inc.

Optimal Energy

Stroud, Inc.

Synertech Systems Corporation

Thermo-Scan Energy Management Corporation.

Their assistance is greatly appreciated.

EXECUTIVE SUMMARY

INTRODUCTION

Background

Since 1976, the U.S. Department of Energy (DOE) has operated the largest residential energy conservation program in the nation—the low-income Weatherization Assistance Program. This 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 comprise the evaluation. The five studies are as follows:

- **Single-family Study**—this study estimates 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 estimates the savings and cost-effectiveness of weatherizing single-family homes in nine northeastern states that use fuel oil for space heating.
- **Multifamily Study**—this study describes the measures used, resources employed, and challenges faced in weatherizing large multifamily buildings.
- **Network Study**—this study characterizes the weatherization network's leveraging, capabilities, procedures, staff, technologies, and innovations.
- **Resources and Population Study**—this study profiles low-income weatherization resources, the weatherized population, and the population remaining to be served.

Goals of Phase Two

The second phase of the Single-Family Study, which is the subject of this report, is part of this coordinated evaluation effort. The first phase of the Single-Family Study involved a large-scale statistical analysis designed to produce national and regional energy-savings and cost-effectiveness estimates for the Weatherization Program (Brown, et al., 1993a). The second phase focuses on significantly fewer agencies and dwellings. It is designed to allow for a more complete understanding of the impacts of weatherization and of the factors that produce high or low savings in individual agencies and homes than was possible in phase one. In particular, data from on-site inspections and occupant surveys are used to address the following questions:

- To what extent does weatherization improve the energy efficiency of low-income housing?
- To what extent does weatherization improve the safety, health, and comfort of low-income clients and their homes?
- How much of the potential for energy-efficiency improvements has weatherization captured?
- How do houses with high energy savings differ from houses with low energy savings?
- How do agencies that achieve higher-than-average energy savings differ from those that do not?
- What lessons can be learned about how to produce higher energy savings?

STUDY DESIGN

This report examines four sets of comparison groups (Fig. A.1). First, all weatherized homes are compared to the control group of homes to quantify the overall impacts of the Weatherization Program. Second, the treated homes, which are the subset of weatherized homes that received the specific weatherization measure under consideration, are compared to the control homes to quantify the impacts of a measure *when it is performed.* Third, the characteristics of weatherized dwellings with especially high energy savings are compared with those that had especially low energy savings. The question addressed here is why some homes have greater energy savings than other homes. Fourth, pairs of agencies with higher and lower energy savings in each of several climate regions are compared. This analysis helps to identify more and less effective weatherization practices and potential future directions for the Program.

Sample Selection

Findings from phase one of the Single-Family Study were used to identify gas-heated weatherized dwellings and local weatherization agencies with a range of gas energy savings. The analysis is limited to gas-heated homes because they represent 90% of the homes with complete energy consumption data. Because phase one documented that the cold and moderate regions had higher average gas savings than the hot region, higher and lower agency savings were defined in relation to climate region averages, not in relation to the national average.

After agencies were ranked by their average gas energy savings, the next step was to select agencies with higher-than-average gas savings, and agencies with lower-than-average gas savings for the phase two sample. The result was a purposive sample selected to allow for comparisons between higher- and lower-saving agencies and dwellings. Because the phase two sample is not a representative sample, conclusions about energy savings and cost effectiveness of the national program must be based on phase one. In the phase two study, dwellings with especially high or low

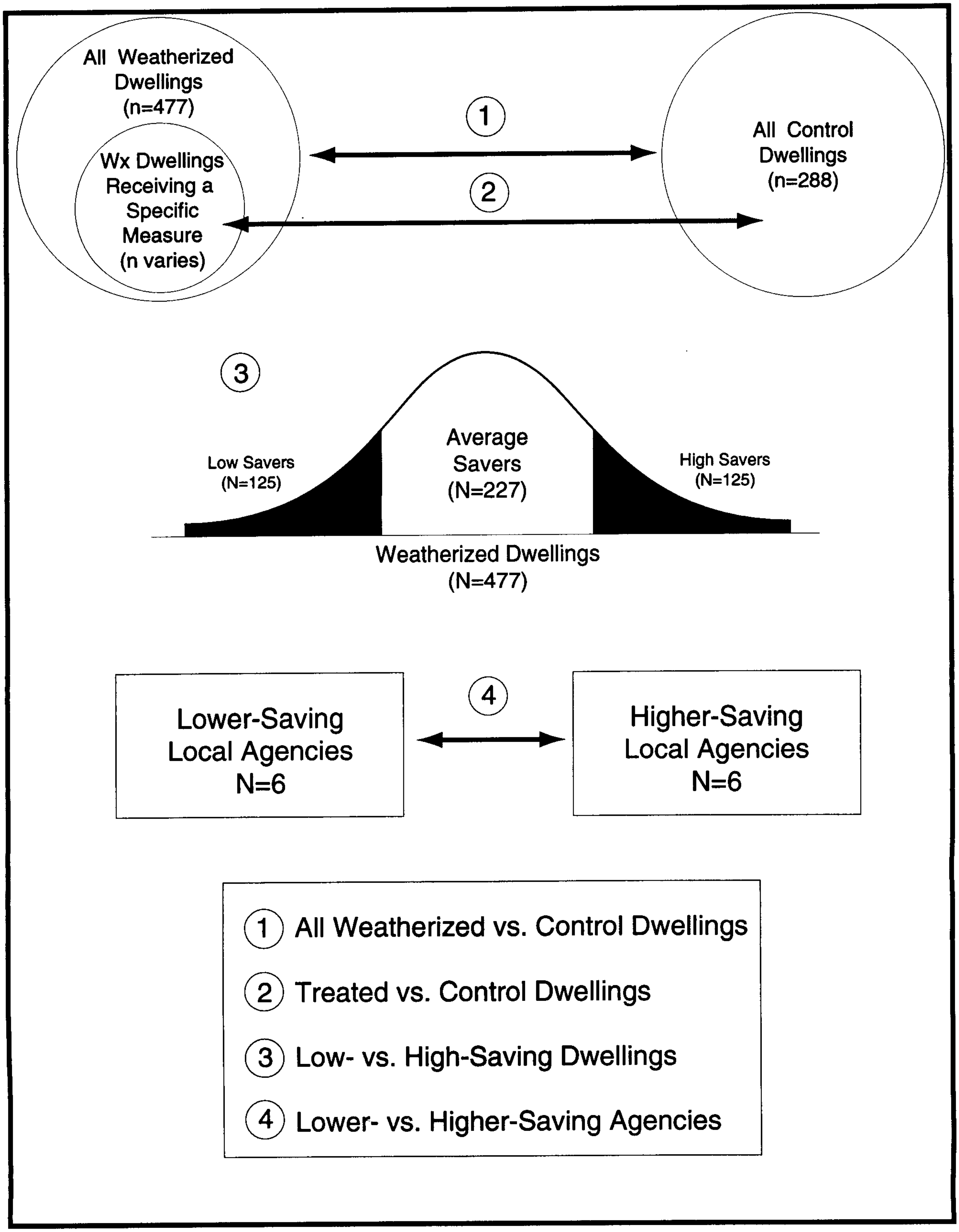


Fig. A.1 Four Sets of Comparison Groups

savings, which were drawn from the purposive sample of 30 agencies, are examined. In addition, the weatherization practices of six matched pairs of higher- and lower-saving agencies from several climate regions are contrasted. The higher- and lower-saving agencies included in phase two are not the only agencies with higher and lower savings, nor do they necessarily have the highest or lowest average gas savings in their region. They are, however, agencies with measured savings that can be compared to one another and to the average for their climate region.

Data Collection

Staff of the participating local weatherization agencies assisted with data collection by contacting their clients to arrange for in-home data collection sessions. They also obtained the cooperation of a control group consisting of clients who had applied for, but as of late 1992 had not yet received, weatherization services.

ORNL hired experienced private contractors to provide two-person teams for conducting the four-hour sessions of in-home measurements and to complete an in-person interview with each client. The contractors began the field work in October 1992 and completed it in March 1993.

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;
- heating system efficiency tests;
- measurements of carbon monoxide (CO) levels and other potential safety problems; and
- survey data on occupant perceptions and behavior.

In addition, data collected in phase one included:

- dwelling and occupant characteristics at the time of weatherization;
- weatherization measures installed;
- material and labor costs;
- utility data on fuel consumption; and
- weather data.

In total, a great deal of information was available for 477 dwellings weatherized during Program Year (PY) 1989 and for 288 control dwellings.

MAJOR FINDINGS

Each of the comparisons illustrated in Fig. A.1 provided insight into the impacts and remaining potential of the following weatherization measures:

- air leakage control,
- health and safety measures,
- insulation,
- heating system and duct measures,
- structural repairs, and
- storm and replacement windows and doors.

In addition, the impacts of variations in weatherization expenditures on the magnitude of energy savings are examined, as are the impacts of variations in the pre-weatherization energy consumption of dwellings. Finally, occupant perceptions of nonenergy benefits are compared for weatherized vs. control groups, high- and low-saving dwellings, and higher- and lower-saving agencies. Major findings in each of these topic areas are summarized below.

Air Leakage Control

In PY 1989, over 95% of weatherized homes received one or more air leakage control measures. Therefore, for these measures there was little difference between the treated and the weatherized homes. Air leakage rates were measured at only one point in time, which was post-treatment for the weatherized homes and pre-treatment for the control homes. As expected, the weatherized homes were significantly tighter than the control homes. As 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 still had air leakage rates that exceeded 1,500 cfm_{50} (a threshold above which more air infiltration reduction is generally recommended).

Higher-saving agencies had post-treatment air leakage rates in their weatherized homes that were about the same as the national average. High-saving dwellings, however, had post-treatment 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.

Health and Safety

Nationwide, in PY 1989, about 18% of agencies routinely provided health and safety-related services. Some of these services, such as CO testing, and replacing broken glass or defective windows, are a standard part of the Program, supported by DOE funding. Other services, including the installation of smoke alarms and radon testing, are not a standard part of the Program and must be supported with funds from other sources.

In the phase two inspections, weatherized homes were more likely than control homes to have smoke alarms. Weatherized homes also were less likely than the control homes to have broken glass, or to have either windows or sashes that needed replacement. The better condition of the windows in the weatherized homes is especially significant because these inspections took place several years after the homes were weatherized.

During the 1992 phase two inspections, carbon monoxide tests were performed in four locations (at the furnace flue, five feet from the heating system, at the nearest register, and in the living space) in each home. The results indicated that CO levels exceeded safe levels in each location in only a few homes, less than 2% of those inspected. The existence of CO problems in a few weatherized homes is not surprising, given that more than two years had passed since weatherization.[1]

Higher-saving agencies did more CO testing (47% of their weatherized dwellings) than lower-saving agencies (17%), and high-saving dwellings received CO tests almost twice as frequently as low savers. Because of the low incidence of CO problems, however, there were no statistically significant differences between these groups. Rates of installing smoke alarms and of repairing broken glass and windows were about the same in the higher- and lower-saving agencies.

Insulation

In PY 1989 attic insulation was added in 19.9% of weatherized homes and was installed for the first time in 28.0%. 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) (Fig. A.2). 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.

Although the R-values in weatherized homes were significantly higher than those in control homes, the R-values of the attic insulation in weatherized homes were still often below DOE-recommended levels. For example, about 26% of weatherized homes had R-values of less than R-19 and 63% had R-values of less than R-30. R-19 or less is below recommended levels in all climate regions in the U.S and R-30 is below the recommended level for all except the hottest regions. Thus, significant proportions of weatherized homes still had attic insulation with R-values below DOE recommended levels. This suggests there is an unrealized opportunity to install additional cost-effective insulation in many homes.

To put the R-values of weatherized homes into context, it is useful to compare them to the average for all income groups. Market research by Owens-Corning Fiberglass, conducted in 1992, indicated that in dwellings of all income levels, the average level of attic insulation was R-21 (Owens Corning Corporation, Zinn, 1993). Thus, the weatherized homes have R-values above the average for the U. S. housing stock and the Program is improving insulation in low-income homes to a level that exceeds the average for homes of all income levels.

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

[1] Corrective action was taken in all of the homes in which unsafe levels were found.

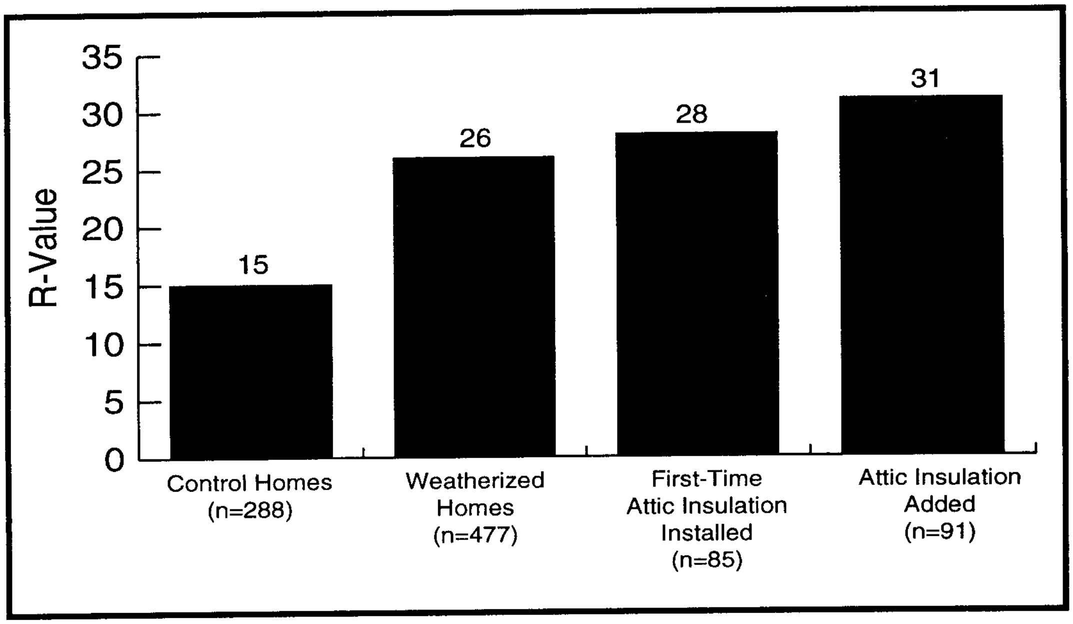


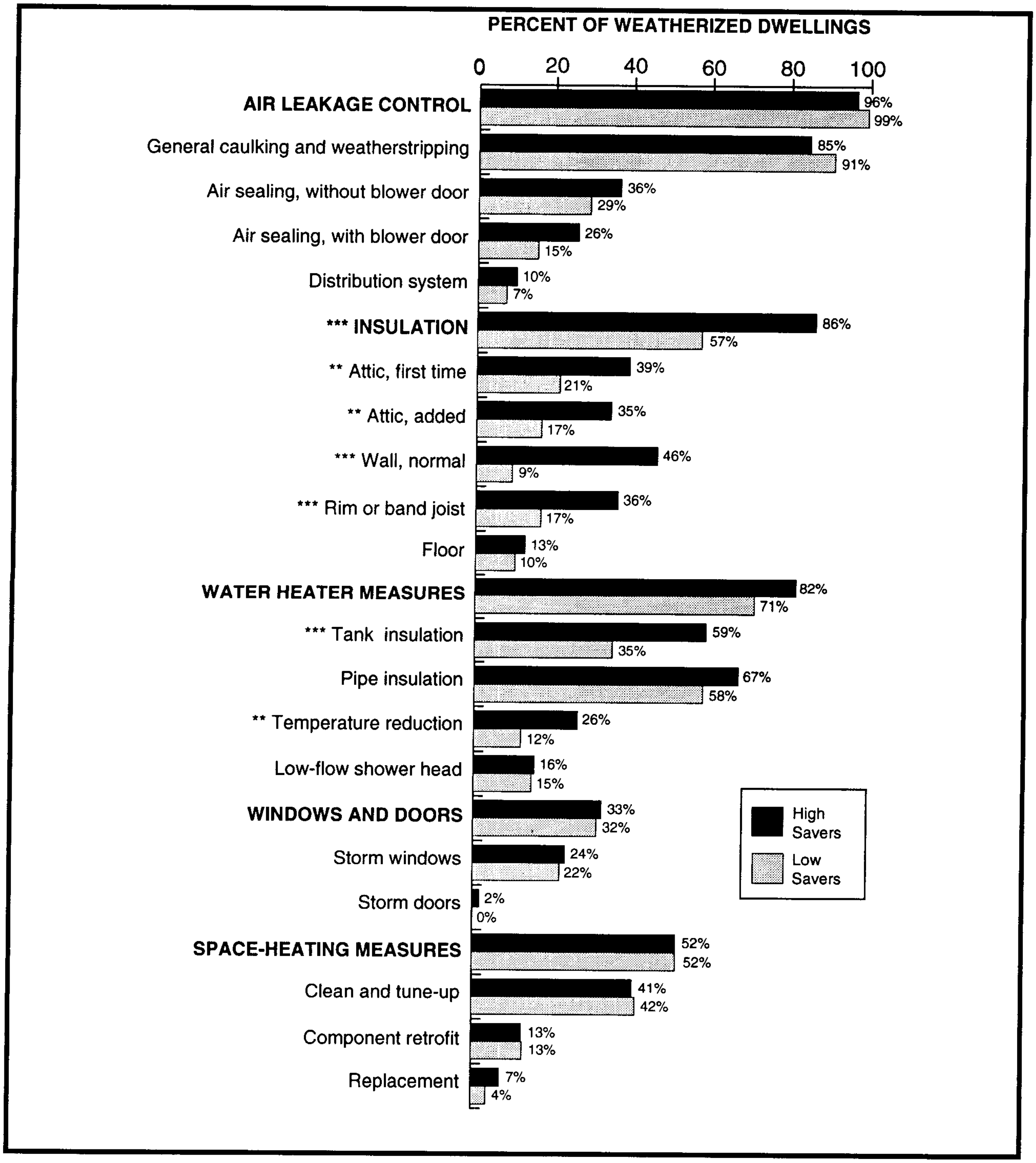
Fig. A.2 Mean R-Values in Control, Weatherized, and Treated Homes

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, installing more 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 (Fig. A.3).

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 (duct) systems. Heating systems in both the weatherized and control homes were generally old and inefficient. When heating systems were replaced, as they were in 4% of PY 1989 homes, high energy savings typically resulted. Space heating system 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 saving agencies (Brown et al., 1993b). These findings suggest that the Program would benefit from access to greater resources to accomplish more heating system replacements.



*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Fig. A.3 Percentages of High- and Low-Saving Dwellings Receiving Various Types of Measures

The condition of ducts was poor in more than 50% of the weatherized dwellings inspected in 1992-1993. In PY 1989, distribution system work was completed on less than 7% of the weatherized homes, far below the proportion that needed duct improvements.[2] In the phase two inspections, the incidence of duct problems was the same in the weatherized and control groups. High- and low-saving dwelling and higher- and lower-saving agencies also had the same incidence, perhaps because duct work was performed so infrequently in PY 1989. Thus, many unrealized opportunities to improve duct systems were present in all the subgroups of dwellings.

Structural Repairs

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 a structural deficiency. The high level of structural problems in the hot region undoubtedly has a negative effect on the ability of agencies there to achieve energy savings that are comparable to those in other regions 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. In order to meet the need for structural repairs in low-income dwellings, substantial funding for housing rehabilitation must be obtained from leveraged sources. The DOE funds are not meant to be spent on major housing rehabilitation.

Windows and Doors

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. Rates of window and door replacements and repairs were lowest in the cold region and highest in the hot region. Storm windows were installed in over one-third of the weatherized homes nationally, and over one-third of the homes received replacement doors.

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%) than for the control homes (49%). In treated homes, namely in those weatherized homes in which the Program installed storm windows in PY 1989, 73% of their window area was covered with storms. 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

2 This rate is much higher today, as many agencies are giving increased attention to duct problems.

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 were covered.

In general, the higher-saving agencies install fewer window and door replacements and high-saving dwellings are more likely to receive window repairs than window replacements. Patterns of storm window installation rates show that high- and low-saving dwellings had almost identical rates of storm window installation. However, a smaller proportion of the total money invested was spent on storm windows in the high-saving dwellings. Thus, investments in high-saving dwellings are relatively lower for windows and higher for other measures.

Weatherization Expenditures

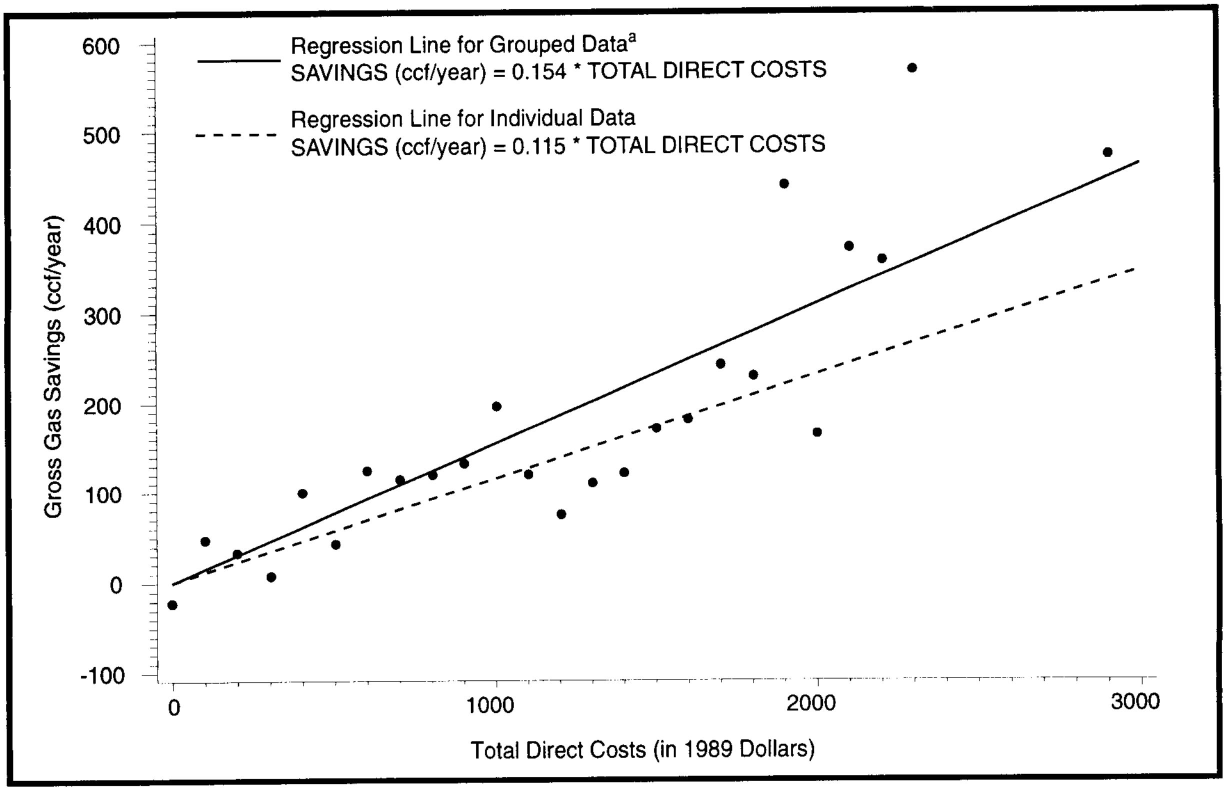
In general, the more that is invested in weatherizing a dwelling, the greater the savings. Among the 1,850 gas-heated dwellings weatherized in PY 1989, gas savings were found to increase by 11 to 15 ccf/year for every $100 increase in direct costs (Fig. A.4). In addition, the scatter diagram shown in Fig. A.4 suggests a linear relationship between savings and costs, with no diminishing return of savings to investment up to $3,000 in direct costs.

Consistent with this linear trend, the high-saving dwellings received significantly larger investments than the low savers. High savers had direct costs of $1,192 (slightly above the national average of $1,050) and materials costs of $602 (approximately equal to the national average of $594). The low savers, in contrast, received an average investment of $714, or about 68% of the national average, and materials costs of only $427 (Fig. A.5). A similar pattern was found for higher- and lower-saving agencies. In addition, both high-saving dwellings and higher-saving agencies invested more in air leakage, insulation, space-heating, and water-heating measures, and relatively less in structural repairs and in windows and doors.

Almost all of the higher-saving agencies used leveraged funds from non-DOE sources 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, and relied exclusively on DOE funding.

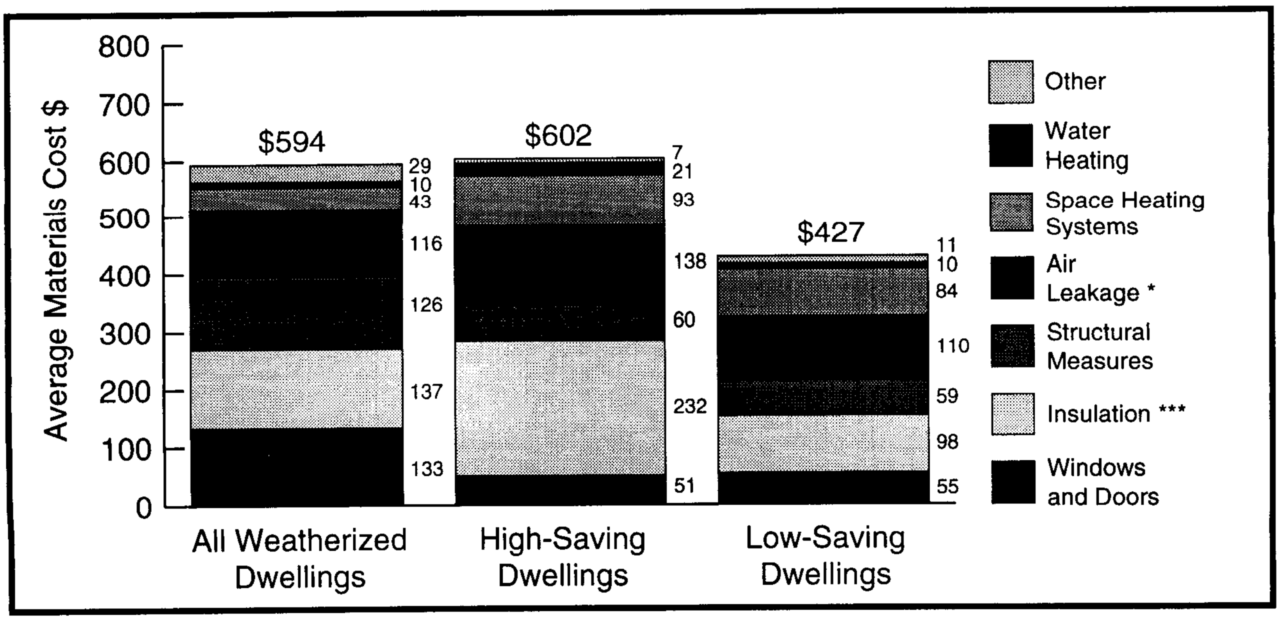
Energy Consumption

In phase one of the Single-Family Study, pre-weatherization consumption was identified as the strongest predictor of gas savings in gas-heated homes. In this study, the same finding was demonstrated again. In particular, the high-saving dwellings used about 70% more gas before weatherization than the low-saving dwellings. Before weatherization, the high savers also were significantly more energy inefficient, consuming 25 Btu/square foot/heating degree day (HDD),



[a] The points plotted in this figure are grouped data that illustrate the gas saved by $100 intervals of total direct costs.

Fig. A.4 Relationship of Amount Invested in Weatherization Measures to Energy Savings



*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Fig. A.5 Average Materials Costs (in 1989 dollars): All Weatherized Dwellings vs. High- and Low-Saving Dwelling

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). The higher-saving agencies' homes 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 lower, and that they had more room for improvement. Thus, weatherizing dwellings that use 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 indoor temperatures, CO levels, or drafts).

On every rating scale the weatherized group reported a highly significant and positive change between the pre- and post-weatherization time periods (Fig. A.6). 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 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 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, health, 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.

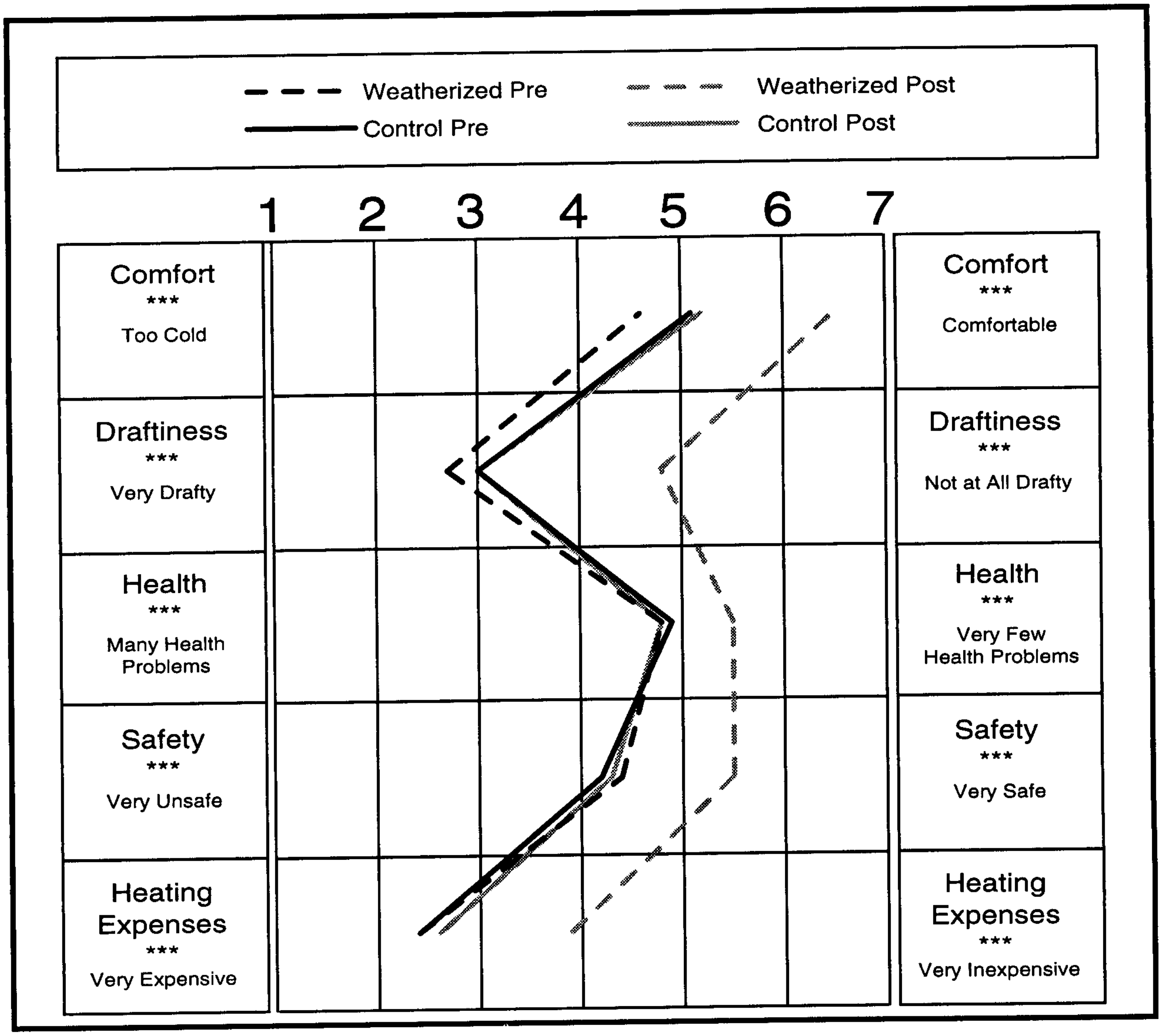


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Fig. A.6 Occupant Perceptions of Nonenergy Benefits of Weatherization

CONCLUSIONS AND RECOMMENDATIONS

Overall, this study's findings reinforce the conclusions of the first phase of the Single-Family Study, that attic and wall insulation, water-heater measures, and heating system replacements are the measures most closely associated with high levels of energy savings (Brown et al. 1993a). The Fuel-Oil Study also identified the same measures as correlates of high savings (Ternes and Levins, 1993). In addition, all of these studies pointed to the strong association between high levels of pre-weatherization energy consumption and high savings. Greater efforts to target homes with the highest saving potentials, and to invest more of the available funds in the most effective measures would increase overall program energy savings.

Nearly every type of measure examined in this report showed significant opportunities for additional energy-efficiency improvements. Opportunities for additional air sealing were present in 80% of client homes. The need for more frequent installations of attic and wall insulation was widespread and especially important in the hot region. The poor condition of heating systems and ducts in many homes also pointed to opportunities for additional savings. Measures that cost the most to install, such as heating system replacements and wall insulation, are performed more infrequently than less expensive measures. The many unrealized opportunities for efficiency improvements suggest the Program is underfunded relative to the need for efficiency improvements in the low-income housing stock. In addition, regulations that limit the amount spent per dwelling do not allow agencies to achieve the maximum savings in many homes. Clearly, without increased funding, all of the available opportunities for energy-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. Although many important, and cost-effective, energy-efficiency improvements are being implemented by the Program, more funding would make it possible to do much more. Because of the overhead costs involved in setting up work in each home, it would be most cost efficient to capture as many opportunities as possible at the time of the DOE-sponsored installations. In addition, because a home will rarely be revisited at a later date, cost-effective measures which are not installed are likely to be long-term "lost opportunities." Leveraged funds from utilities are an important vehicle for providing more complete and comprehensive weatherization and for minimizing lost opportunities.

Many low-income homes need extensive structural repairs, which must be paid for with leveraged funds. Federal and state housing rehabilitation funds should be accessed to finance repairs whenever possible. In many homes, leveraging of housing rehabilitation funds to supplement DOE funds is an essential step in achieving minimal structural integrity and energy efficiency.

This study indicates that present levels of investment do not capture all of the opportunities for energy-efficiency improvements. Further research is needed to quantify the energy-savings potential of additional investments. For instance, the results of an advanced home energy audit could be used to identify the cost-effective investments that practitioners currently are unable to install. Alternatively, a demonstration project could compare measured savings in a group of homes that received standard investment levels to a group of homes that received all the investments recommended as cost-effective by an advanced audit. More definitive documentation of this remaining potential would help utilities make more informed decisions about the cost effectiveness of forming partnerships with the DOE Program.

PATTERNS OF IMPACT IN THE WEATHERIZATION ASSISTANCE PROGRAM: A CLOSER LOOK

1. 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.

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1.1 GOALS OF PHASE TWO

The Single-Family Study, the second phase of which is the subject of this report, is part of this coordinated evaluation effort. The first phase of the Single-Family Study involved a large-scale statistical analysis designed to produce national and regional energy-saving and cost-effectiveness estimates for the Weatherization Program (Brown, et al., 1993a).

Phase two of the Single-Family Study focuses on a much smaller number of agencies and dwellings. It is designed to allow for a more complete understanding of the impacts of weatherization and of the factors that produce high or low savings in individual agencies and homes than was possible in phase one. In the second phase, detailed on-site data are used to assess energy-efficiency, health, safety, and comfort improvements and to highlight differences between higher- and lower-saving agencies and high- and low-saving dwellings. This report uses detailed on-site data to address the following questions:

- To what extent does weatherization improve the energy efficiency of low-income housing?
- To what extent does weatherization improve the safety, health, and comfort of low-income clients and their homes?
- How much of the potential for energy-efficiency improvements has weatherization captured?
- 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 large-scale statistical analysis of phase one produced solid estimates of energy savings and cost effectiveness by using secondary data to produce a broad-brush characterization of the Program's accomplishments. This study, in contrast, characterizes program efforts by using detailed on-site measurements of dwelling characteristics, in-home occupant interviews, and process evaluations developed through site visits and in-person interviews with local agency staff. The detailed data collected in this phase are used to describe the eligible housing stock in great detail, and to quantify the effect of weatherization on the energy-efficiency, comfort, health, and safety conditions of dwellings. The occupant interview is used to assess client perceptions of the benefits of weatherization, and to develop an analysis of how occupant behavior affects energy savings. Information on dwelling characteristics and weatherization measures is supplemented by interview data on occupant turnover, fuel switching, changes in heated areas, and thermostat management to explain variations in the energy savings of individual dwellings more completely.

1.2 STUDY DESIGN

This report involves the examination of four sets of comparison groups (Fig. 1.1). For each set the focus is on identifying differences between the groups. Each set of comparison groups is used to address a unique set of issues.

First, all weatherized homes are compared to the control group of homes (comparison one in Fig. 1.1) to quantify the overall impacts of the Weatherization Program. Secondly, the treated homes, which are the subset of weatherized homes that received the specific weatherization measure under consideration, are compared to the control homes (comparison two in Fig. 1.1) to quantify the impacts of a measure *when it is performed*. When a measure is installed in a large majority of homes, average results

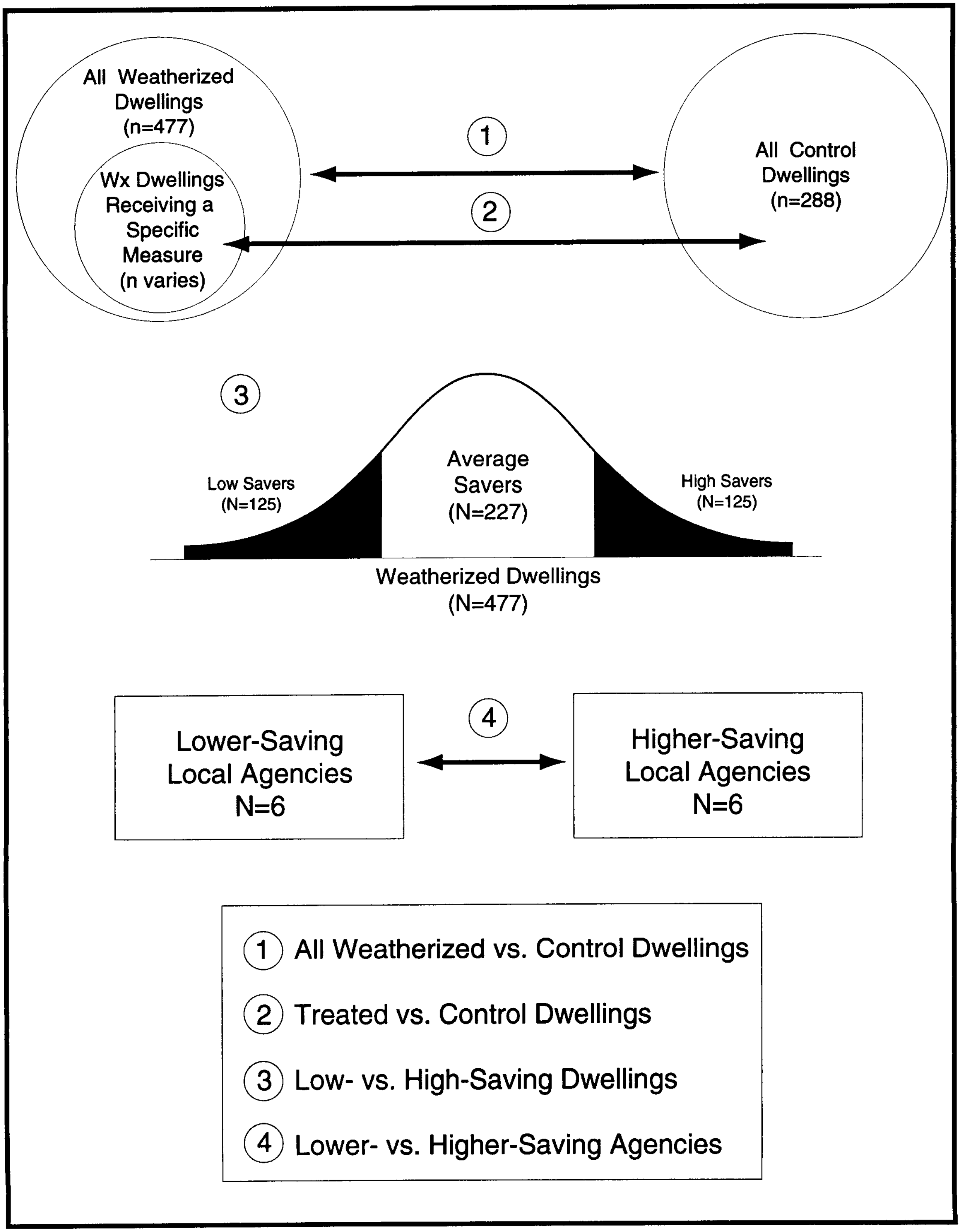

Fig. 1.1 Four Sets of Comparison Groups

for all weatherized homes and for treated homes will be similar. On the other hand, when only a small percentage of homes receive a measure, the impacts on the subset of treated homes will typically be much greater than the impacts on all weatherized homes.[1]

Comparison three in Fig. 1.1 focuses on the characteristics of weatherized dwellings with especially high versus those with especially low energy savings. The question addressed here is why some homes have greater energy savings than other homes.

Comparison four, which examines pairs of higher- versus lower-saving agencies in each of several climate regions, focuses on the identification of more and less effective weatherization practices and of promising future directions for the Program.

1.3 REPORT OVERVIEW

In this first chapter the goals and overall design of the study are presented. Chapter 2 discusses methodology, the sample selection process, and data collection procedures. The following chapters (3, 4, and 5) compare the four sets of comparison groups as explained in the previous section.

In Chapter 3, the results of extensive descriptions and measurements of dwelling characteristics, and of blower door, heating system efficiency, and carbon monoxide (CO) tests are compared for control, weatherized, and treated dwellings. By comparing these measurements and test results, we assess the degree of improvement in energy efficiency, structural soundness, comfort, health and safety conditions produced by the Program as a whole and by specific measures.

In Chapter 4, characteristics of weatherized dwellings with especially high versus those with especially low energy savings are examined. Dwelling characteristics, the presence and amounts of specific weatherization measures, and occupant characteristics and behaviors are examined as factors that may explain variations in energy savings.

Chapter 5 presents comparisons of pairs of higher- versus lower-saving agencies in each of several climate regions. These comparisons examine differences in housing stock, service delivery procedures, weatherization measures installed, and allocation of agency funds. The focus here is on the identification of more and less effective weatherization practices and of promising future directions for the Program. These issues also were addressed in an earlier report that presented case studies of ten higher-saving agencies (Brown, et al., 1993b). This report adds to the earlier one by comparing the practices of lower-saving agencies with those of the higher-saving ones.

Chapter 6 compares occupant perceptions of comfort, health, safety, and energy affordability for the weatherized versus control group clients, for the high- versus low-saving dwellings, and the higher-

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1 Some weatherization measures, such as air leakage control, are installed in almost all weatherized homes. In this case, the mean air leakage rates are nearly the same for all weatherized homes and for treated homes. Other measures, such as heating system replacements or distribution system repairs, are installed in less than 10% of homes. In these cases, the measurements of heating system efficiency in the treated homes may be very different from the results for the entire population of weatherized homes.

versus lower-saving agencies. These comparisons of client perceptions offer an additional way of assessing the impacts of weatherization. Chapter 7 summarizes this study's findings and presents recommendations.

2. METHODOLOGY

The second phase of the Single-Family Study builds on the first phase. In particular, the energy-savings estimates of phase one were used to identify local weatherization agencies with a range of performance (based on the average energy savings of their weatherized dwellings). Only agencies with complete fuel consumption records for at least 17 houses were included in the phase two sampling frame to help increase confidence in the agency-level estimates of energy savings. Out of the 400 agencies in the original representative national sample of the first phase, 82 agencies had 17 or more homes with complete gas or electric fuel records. The 30 agencies included in this study were selected from among these 82 agencies. *Thus, it is important to emphasize that the phase two sample is not a representative sample and conclusions about the energy savings and cost effectiveness of the national program must be based on phase one. In addition, the higher- and lower-saving agencies included in phase two are not the only higher and lower savers, nor are they necessarily the highest or lowest savers in their region. They are, however, agencies with measured savings that can be compared to one another and to the average for their climate region.*

The higher-saving agencies, which were the subject of a separate report (Brown, et al., 1993b), were (with their permission) identified by name and location. These ten agencies also received awards from the DOE to recognize their accomplishments. The remaining 20 agencies, however, were promised anonymity as a condition of their participation.

2.1 SAMPLE SELECTION

The phase two sample is a purposive sample of 30 agencies designed to allow comparisons between higher- and lower-saving agencies and dwellings. As illustrated in Fig. 2.1, there were several

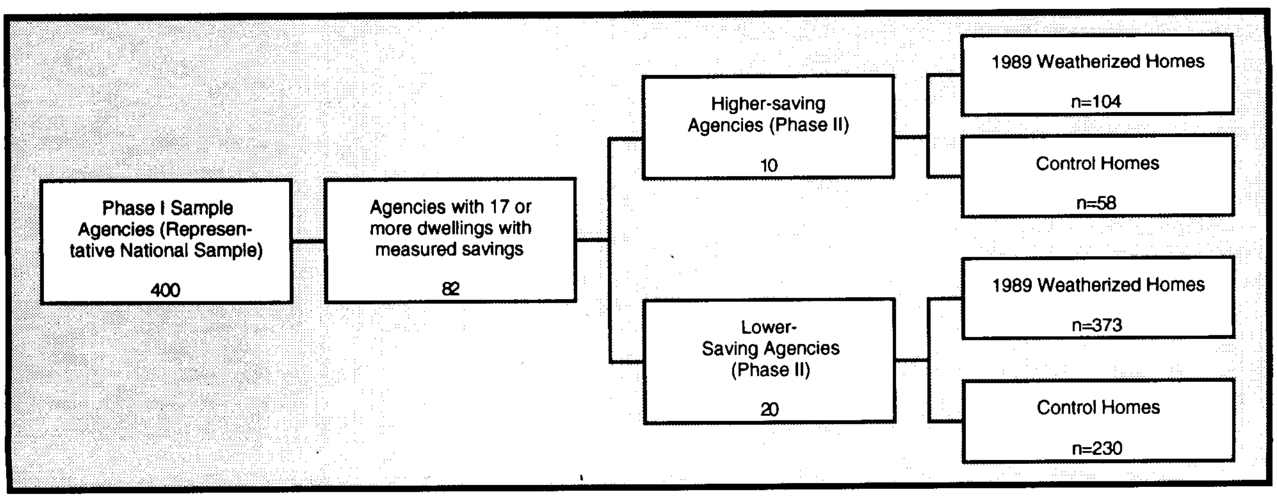

Fig. 2.1 Steps in the Sample Selection Procedures

steps in the sample selection procedure. The first step was to rank agencies according to their average energy savings. The number of agencies by state for which mean energy savings could be determined is shown in Fig. 2.2. Most states contain at least one agency for which average energy savings could be determined. The moderate region had 48 agencies with estimated average savings, while the hot region had 12, and the cold region 22.

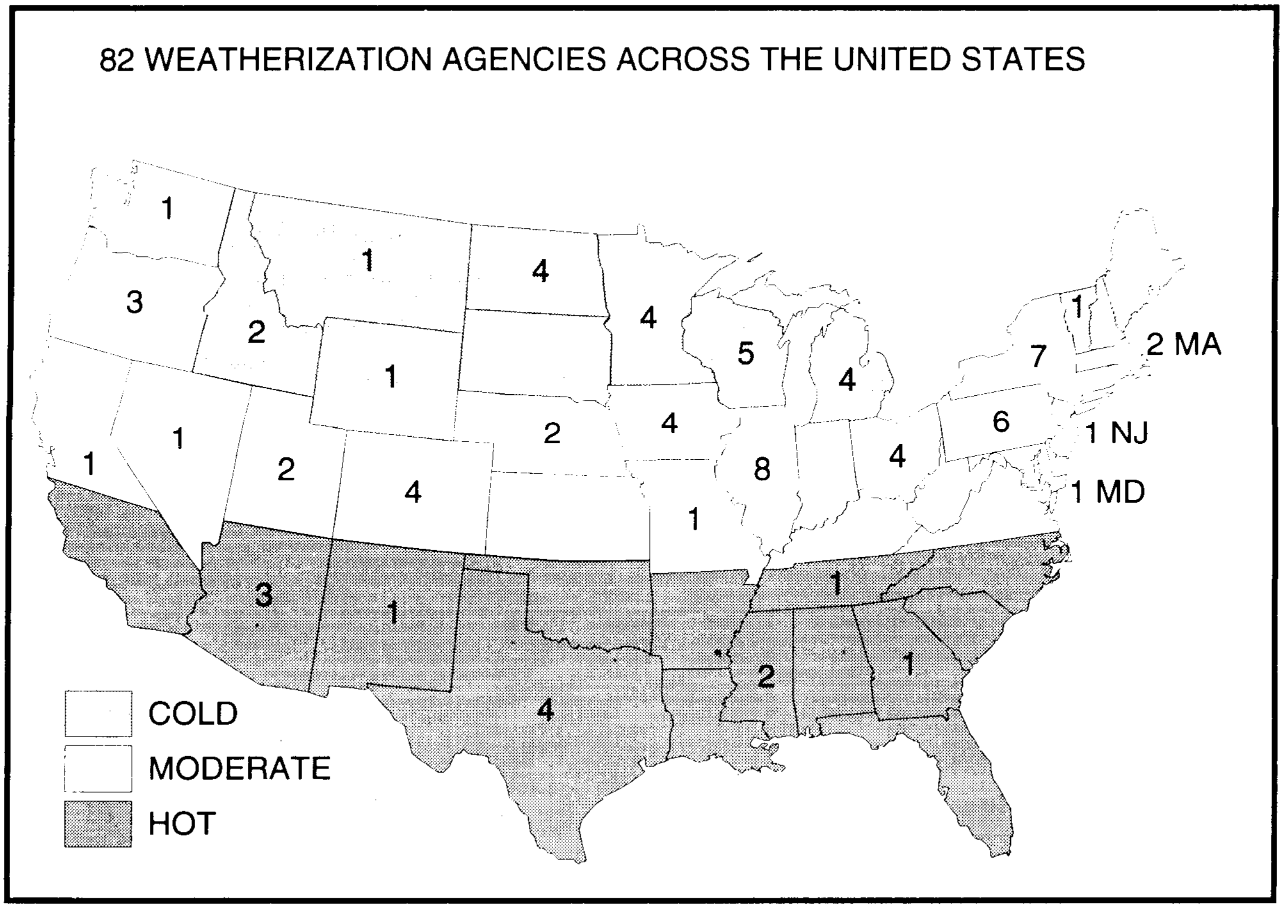

Fig. 2.2 Number of Agencies with Fuel Records for 17 or More Dwellings by State

The next step was to select 10 higher-, and 20 lower-saving agencies to fill the cells as shown in Fig. 2.3. Because preliminary phase one results suggested agency size influenced performance, we included agencies from each size category. Phase one results also documented that the cold region had much higher average savings than the hot region.[1] Therefore, higher- and lower- energy savings were defined in relation to climate region averages, not in relation to the national average. Thus, although

[1] When the phase one analysis was completed, agency size turned out to have only a minor influence on performance. Climate region was, however, a major factor.

higher savers in the hot region had higher-than-average savings for the hot region, they did not save as much as the average agency in the cold or moderate regions.[2]

Size of Agency[a]

CLIMATE REGION	Small	Medium	Large
Cold	n=1 (H=0, L=1)[b] N=2	n=5 (H=2, L=3) N=16	n=2 (H=1, L=1) N=4
Moderate	n = 1 (H=1, L=0) N=4	n = 10 (H=2, L=8) N=33	n = 5 (H=2, L=3) N=10
Hot	n = 1 (H=1, L=0) N=2	n = 4 (H=1, L=3) N=10	n = 1 (H=0, L=1) N=1

a Small agencies weatherized 100 or fewer dwellings in PY 1989, medium-sized agencies weatherized more than 100 and less than 400 dwellings, and large agencies weatherized 400 or more dwellings during that year.

b H = Higher-saving agency; L = Lower- saving agency.
n - number in sample of 30 agencies N = number in sampling frame of 82 agencies

Fig. 2.3 Distribution of Sample of Agencies by Size, Region, and Level of Energy Savings

The sampling process used for phase two did not produce representative samples. Agencies and dwellings were selected mainly because of the availability and reliability of the phase one data on their energy savings and because of their willingness to cooperate.[3] Sample size was determined primarily by budget limitations, not by considerations of the required number of observations for sufficient statistical precision.

2 Again, we remind our readers that because many agencies did not have 17 or more homes with complete gas or electric fuel consumption records, the higher- and lower- saving agencies chosen for this study do not necessarily have the highest or lowest savings in their region.

3 It was especially difficult to obtain the cooperation of lower-saving agencies. Two refused to participate in the study.

2.2 DATA COLLECTION

After the higher- and lower-saving agencies were selected in each climate region and size category shown in Fig. 2.3, they were contacted and asked to assist with data collection. The agencies were assigned the task of contacting their clients to arrange for in-home data collection sessions which would last approximately four hours. Each household was offered a payment of $25 for agreeing to participate in the study. ORNL provided a list of homes weatherized in PY 1989 to agency staff and asked them to obtain the cooperation of 17 of the weatherized households from that list. The lists varied in length from the minimum of 17 to a maximum of 73. In some cases, cooperation could not be obtained from the desired 17 households weatherized in PY 1989. When this occurred, a supplemental list[4] of homes was used to try to recruit sufficient numbers of weatherized study participants.

The agency also was asked to obtain the cooperation of a new phase two control group. This control group consisted of 10 of their clients who had applied for, but as of late 1992 had not yet received, weatherization services. Each agency was asked to obtain the cooperation of 10 clients waiting for services and to make sure they continued to wait for weatherization until after the data collection session was completed.

ORNL hired experienced private contractors (who owned the necessary equipment) to provide two-person teams for conducting the four-hour sessions of in-home measurements and tests (which included blower door, heating system efficiency and CO tests), and to complete an in-person interview with each client. The contractors attended a two-day training session on the study's data-collection procedures that was organized by Synertech, Inc., in September 1992. They began the field work in October 1992 and completed it in March 1993.

The local weatherization agencies provided the contractors with lists of clients who had agreed to participate in the study, a schedule of appointments, and directions to each house. ORNL provided written information about each weatherized home from the phase one data base (see Appendix A for an example of the information package provided on each house).

The types of physical measurements and test results available for each dwelling[5] are shown in Appendix B.[6] 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;

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4 These supplemental lists included control houses from phase one that were weatherized after the phase one study period ended, i.e., after March of 1991, but before phase two data collection began in October 1992.

5 The extensiveness of the data collection effort in phase two exceeded the requirements of this study for two reasons. First, an Electric Power Research Institute study, which paid for the collection of data on distribution systems in homes with central gas heating systems, was conducted in conjunction with our study. Secondly, we wished to obtain a complete characterization of the dwellings, which could be done for a small incremental cost, so that the data base could support additional future analyses.

6 Appendix B also lists the percentage of weatherized dwellings with each of the characteristics or the mean value for the weatherized dwellings.

- air leakage tests performed with blower doors;[7]
- safety inspections of the space- and water-heating systems including measurement of CO levels;
- in-home occupant interviews covering length of residence, house age, demographics, heating fuels, fuel switching, fuel assistance, fuel affordability, thermostat management, heated areas, and perceptions of weatherization impacts on comfort, health, and safety (Appendix C).

Similar data were collected in the Fuel-Oil Study (Ternes and Levins, 1993). The Fuel-Oil Study differs from this study, however, because it obtained air leakage and steady-state efficiency measurements in both a pre- and post-weatherization time period, while this study obtained these measurements at only one point in time (which was post-weatherization for the weatherized group and pre-weatherization for the control group). (See Ternes and Levins, 1993 for a discussion of the various protocols used, especially their Appendix D for a description of air-leakage testing, their Appendix E for a description of steady-state efficiency testing, and their Appendix F for a description of the safety inspection procedures.)

The occupant interviews were pre-tested by experienced interviewers at Response Analysis Corporation, who also helped design the interview for the Energy Information Administration's Residential Energy Conservation Survey (RECS). Separate interview forms were developed for the weatherized and control homes; these forms are shown in Appendix C. A majority of the questions in the occupant interviews were reprinted verbatim from the 1990 RECS. Office of Management and Budget approval was obtained for the house characteristics survey and occupant interview forms.

In addition to the phase two data, data collected in phase one that were available for the weatherized homes included:

- dwelling-specific data on dwelling and occupant characteristics at the time of weatherization, weatherization measures installed, and material and labor costs;
- agency-level cost data on overhead and management costs;
- utility data on fuel consumption; and
- weather data.[8]

Fuel consumption records were not collected from utilities for the phase two control group, although they had been collected for the phase one weatherized and control groups.[9]

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7 See Appendix B and Ternes and Levins (1993) for detailed information on what data were collected and how the measurements were performed.

8 See Brown, et al., 1993a for a description of phase one data.

9 The phase two control group householders were asked to provide the phase two contractors with their fuel consumption records. However, these records were often incomplete, or unavailable. Because most of the weatherized homes in phase two are a subset of phase one weatherized homes, phase one fuel consumption records are available for most of them.

This report focuses on the on-site data collected in phase two. Phase one data were used, however, to identify high- and low-saving dwellings and higher-and lower-saving agencies and to supplement the phase two information as needed.

2.3 CHARACTERISTICS OF THE SAMPLES

In spite of the targeted sampling procedures used in phase two, the characteristics of the dwellings from the 30 agencies that participated in the on-site data collection in phase two differ only marginally from those of the phase one sample. None of the traits examined showed statistically significant differences. The characteristics of the two samples are compared in Appendix D.

Because most of the physical characteristics measured in phase two (such as the floor area, house volume, age, appliance saturations, number of floors, housing type, heating fuels, types of heating systems) are unaffected by weatherization, we expected to find little difference between the weatherized and control groups on these variables. The two groups were roughly matched because they were selected from applicants for services or from weatherized clients of the same 30 local agencies. Although the weatherized and control groups received services in different years, the housing stock and population groups they were drawn from were expected to be nearly identical. This expectation was supported by the data analysis. The weatherized and control groups had no statistically significant differences for most of the dwelling characteristics examined (see Appendices E and F). Thus, the goal of selecting samples of weatherized and control homes drawn from the same housing stock seems to have been achieved.

Although the weatherized and control groups generally do not differ on characteristics that are not affected by weatherization, the data on some of these traits are discussed in Appendix E because they indicate the general characteristics and condition of the low-income housing stock. For example, the majority of both groups occupy one-story dwellings with central gas heat. The typical Program house is small (average of 1,600 square feet) and old (average of 40 years). Although most of the homes have cooking ranges, refrigerators, and clothes washers, most do not have freezers, clothes dryers, or air conditioners.

Variables which weatherization is expected to affect, such as air leakage rates, insulation R-values, the condition of windows, and other indicators of overall energy efficiency, usually differ significantly for the weatherized, treated, and control groups. These differences are examined in Chapter 3.

2.4 ANALYSIS OF HIGH- VS. LOW-SAVING DWELLINGS

The analysis of high- versus low-saving dwellings (Chapter 4) compares weatherized dwellings with especially high savings to weatherized dwellings with especially low savings in order to identify distinguishing features. The focus is on explaining why some dwellings produce greater energy savings than others.

This analysis is limited to gas-heated homes because they represent 90% of the dwellings with energy consumption data. Two types of high- and low-saving dwellings were identified for analysis: a national sample and three regional samples. The national sample was formed by ranking all weatherized dwellings by energy savings and then selecting the 125 dwellings with the highest savings and the 125 dwellings with the lowest savings. The regional samples were formed by ranking the savings of dwellings within each region and then selecting the 25 dwellings within each region that had the highest savings and the 25 dwellings within each region that had the lowest savings. These regional samples were used to identify region-specific factors associated with high and low savings.

Both quantitative and qualitative approaches were used to identify factors that distinguish high and low savers. The quantitative analysis produced average profiles of high- and low-saving dwellings, and used statistical tests to identify key differences. The profiles describe average dwelling characteristics, occupants and occupant behaviors, and types and costs of measures installed. The qualitative analyses involved detailed case studies of a small number of high- and low-saving dwellings, which generally corroborate the findings of the statistical analysis.

2.5 ANALYSIS OF HIGHER- VS. LOWER-SAVING AGENCIES

The analysis of higher- vs. lower-saving agencies (Chapter 5) focuses on matched pairs of agencies from the same state, whenever possible. Because agencies within the same state have similar housing stock and climate conditions, and because they operate under the same state requirements, using matched pairs is expected to highlight differences in procedures that agencies could easily adopt to improve their energy savings. In addition, the matching procedure controls for confounding of relationships due to the contextual factors associated with states and climate regions. We know from phase one that energy savings vary strongly by climate region and by state, and that climate regions and states also differ in the procedures they use and the types of housing stock they serve. Without some control on the geographic location of higher- and lower-saving agencies, many of the differences between them could be due to regional differences. Therefore, geographic matching is used to control the influence of regional differences so that procedural differences and weatherization measures that affect savings could be identified more easily.

Although the agency level analysis focuses on a geographically matched subset of agencies (i.e., 6 pairs consisting of 12 out of the 30 phase two agencies), the dwellings from all 30 of the agencies in the original sample are included in other parts of the analysis. Specifically, the comparisons of weatherized and control dwellings (Chapter 3) include all of the dwellings with phase two data, and the analysis of dwellings with especially high or low savings (Chapter 4) draws on the entire phase two sample.

3. IMPACTS OF WEATHERIZATION

The goals of this study include the quantification of the impacts of weatherization. Improvements in the energy efficiency and structural soundness of dwellings, and in their health and safety conditions are examined in this chapter. These improvements are measured by comparing the results of a variety of in-home measurements and tests performed in the phase two samples of control, weatherized and treated homes. The results are presented for all phase two agencies and dwellings (total sample or "national" results) and by three regions[1] (cold, moderate, and hot). The sample sizes by region are shown in Table 3.1.

Table 3.1 Sample Sizes by Region

Number of Dwellings & Agencies by Region			
Region	Weatherized Dwellings	Control Dwellings	Agencies
Cold	129	80	8
Moderate	269	164	16
Hot	79	44	6
Totals	**477**	**288**	**30**

This chapter is organized in six sections. The first section reports on improvements in air leakage control. The second section discusses health and safety impacts, and the third insulation. Next, heating systems and ducts (3.4), structural problems (3.5), and windows and doors (3.6) are examined. Finally, Program opportunities for additional energy-efficiency improvements are summarized.

3.1 AIR LEAKAGE CONTROL

In PY 1989, over 95% of weatherized homes received one or more air leakage control measures (Brown, et al., 1993a). These measures might include general caulking and weatherstripping (90.1%), air sealing with a blower door (18.3%), air sealing without a blower door (22.9%), distribution system air leakage measures (6.8%), or other air leakage measures (3.1%). In addition, other measures, such as the

[1] In addition to these three regions many variables also were analyzed by the six regions shown in Figure 5.1. Comparisons of means and distributions for weatherized and control groups were performed for over 250 variables for each of these six regions. Many of the comparisons that showed significant differences at the national level were not significantly different when compared at this six-region level (Appendix F). Because so few of the regional differences (based on the six regions) were significant (largely because of the small sample sizes), the presentation of these regional results is limited to Appendix F. In this chapter, however, results for the cold, moderate, and hot climate regions are presented.

installation of storm windows or wall insulation also can be expected to reduce air leakage. The weatherized group received, of course, all types of measures. The treated group in this section, however, is defined as those homes that received air sealing (either with or without a blower door).

3.1.1 National Results

As shown in Fig. 3.1 and Fig. 3.2, the weatherized homes were, as expected, tighter than the control homes. The blower door test results, which were only performed at one point in time, showed that the average post-weatherization air flows measured in cubic feet per minute at a pressure of 50 Pascals[2] were 2,738 for the weatherized homes versus 3,164 for the control homes (Fig. 3.1). This is a difference of 426 cfm_{50}[3], which is significant at $p \leq 0.001$, and is about a 13% difference in air leakage.

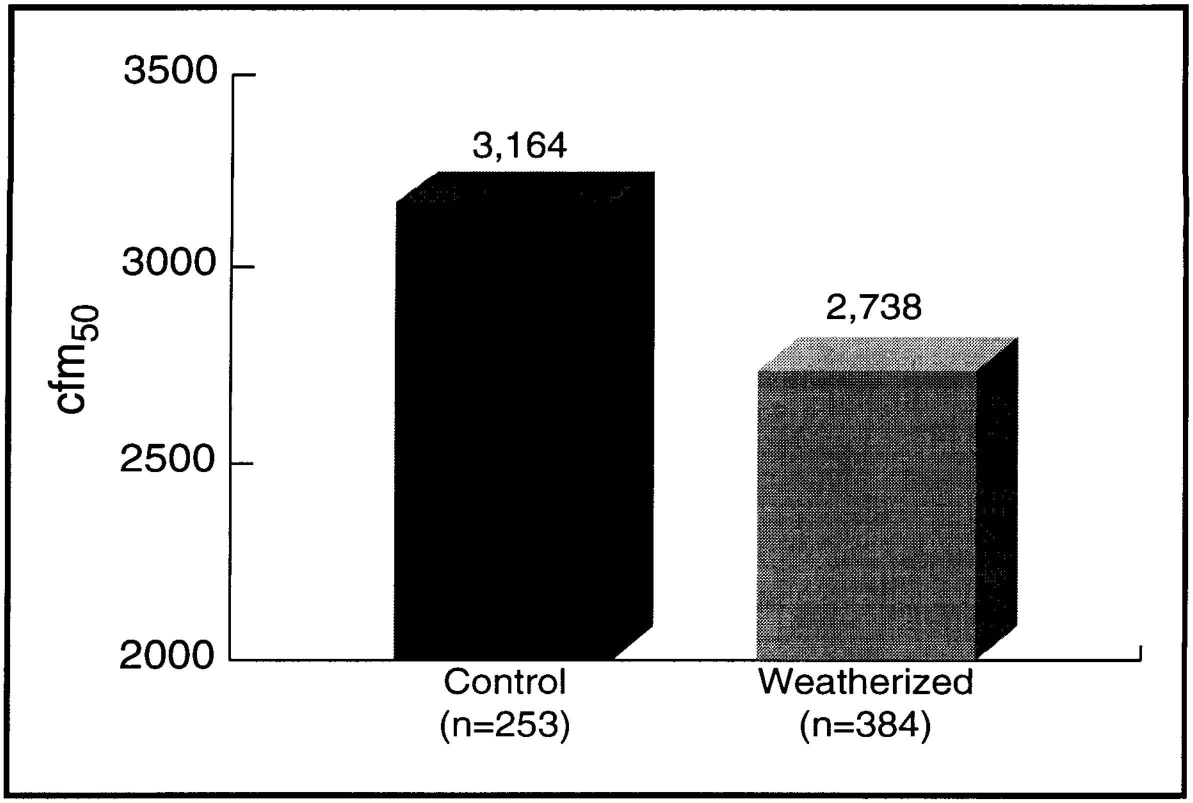

Fig. 3.1 Mean Air Leakage Rates in Weatherized and Control Homes

2 The air tightness of the houses is discussed here using the calculated air flow rate at a 50 Pa pressure difference (house depressurized) across the building shell (cubic feet per minute at 50 Pa is abbreviated as cfm_{50}).

3 In the Fuel Oil Study, post-treatment measurements were 2,725 cfm_{50} for the weatherized homes versus 3,304 cfm_{50} for the control homes, for a difference of 579 cfm_{50}. The Fuel-Oil Study also measured pre-weatherization air leakage at 3,295 cfm_{50} for the weatherized homes versus 3,468 cfm_{50} for the control homes.

Although the weatherized homes were significantly tighter than the control homes, many of them still were not as tight as would be optimal. A threshold below which further tightening is usually not required is 1,500 cfm_{50} or less (Ternes and Levins, 1993). As Fig. 3.2 shows, approximately 20% of the weatherized homes had air infiltration rates of 1,500 cfm_{50} or below. This suggests that the remaining 80% may have more air leakage than is optimal.

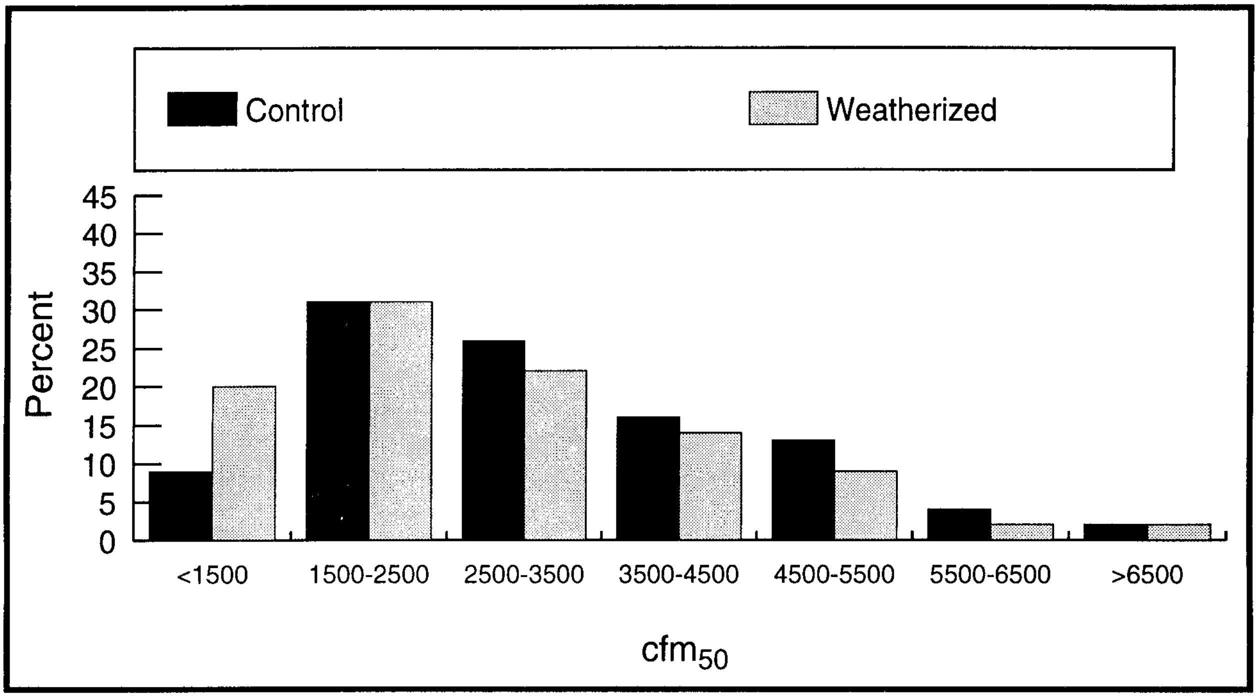

Fig. 3.2 Distribution of Air Leakage Rates for Weatherized vs. Control Dwellings

Among treated[4] homes, air leakage rates averaged 2,965 cfm_{50}, slightly above the average for all weatherized homes. Among homes that received blower door testing, air leakage rates (2,992 cfm_{50}) also were above the average for all weatherized homes (Fig. 3.3). This finding is counterintuitive, because the purpose of blower door testing is to make it possible to reduce air leakage more efficiently and effectively. However, it is consistent with phase one's results, which found no relationship between blower door testing and the amount of energy savings. In addition, Fuel-Oil Study results show that the installation of wall insulation and storm windows may affect air leakage values, which suggests the possibility that homes not receiving blower door testing might have received more other measures that reduce air leakage.

[4] Treated homes for air leakage are defined as those which received air sealing either with or without a blower door. About 41% of homes received one or the other of these treatments.

Using the cfm_{50} estimates to calculate air changes per hour suggested that the weatherized and treated homes had less air leakage than the control homes. The mean air changes per hour at natural pressure for the control homes was 1.23, for the weatherized homes 0.99, and for the treated homes 0.87. About 11% of the control, 19% of the weatherized, and 21% of the treated homes had less than 0.5 air changes per hour, a level below which indoor air quality problems may begin to develop in some homes. Thus, based on air changes per hour, the treated homes seemed to be tighter than other weatherized homes. However, none of these differences were statistically significant

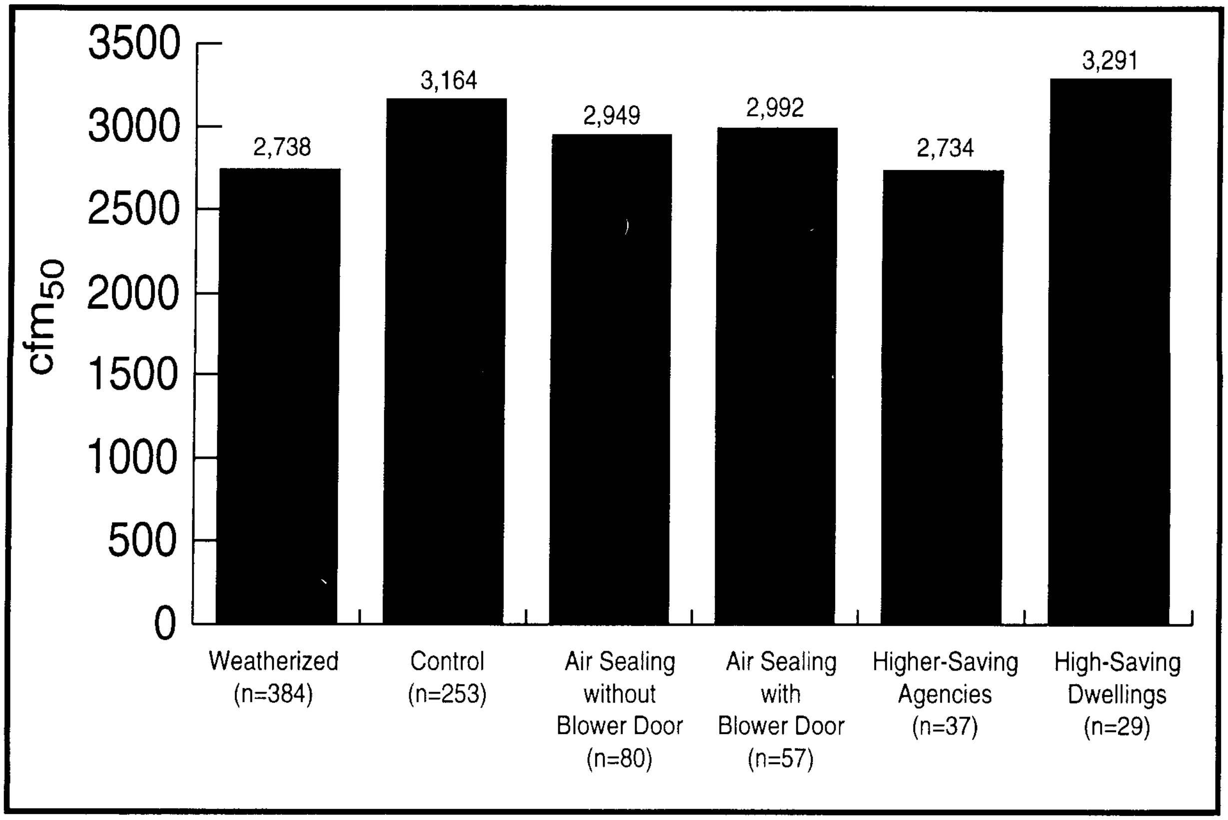

Fig. 3.3 Mean Air Leakage Rates by Subgroups

Higher-saving agencies had air leakage rates (2,734 cfm_{50}) in their weatherized homes that were about the same as the entire sample of weatherized dwellings. High-saving dwellings, however, had air leakage rates that were well above the sample-wide average. The air changes per hour, which take the dwelling's size into account, are slightly lower among homes weatherized by higher savers (0.85) than among those weatherized by lower savers (1.20). Similarly, high-saving dwellings have a lower value for air changes per hour (0.96) than low-saving dwellings (1.13). However, these differences are not statistically significant.

3.1.2 Regional Differences

Regional differences in air leakage rates were noticeable and statistically significant. The control homes were tightest in the cold region and leakiest in the moderate region (Fig. 3.4). Among weatherized homes, too, the mean air leakage rates were lowest in the cold region, followed by the hot and the moderate. Thus, the hot region seems to produce greater reductions in air leakage than the other two regions (Fig. 3.4). In all three regions, there were very slight, and statistically insignificant, differences in air leakage rates between homes that received blower door testing and homes that did not.

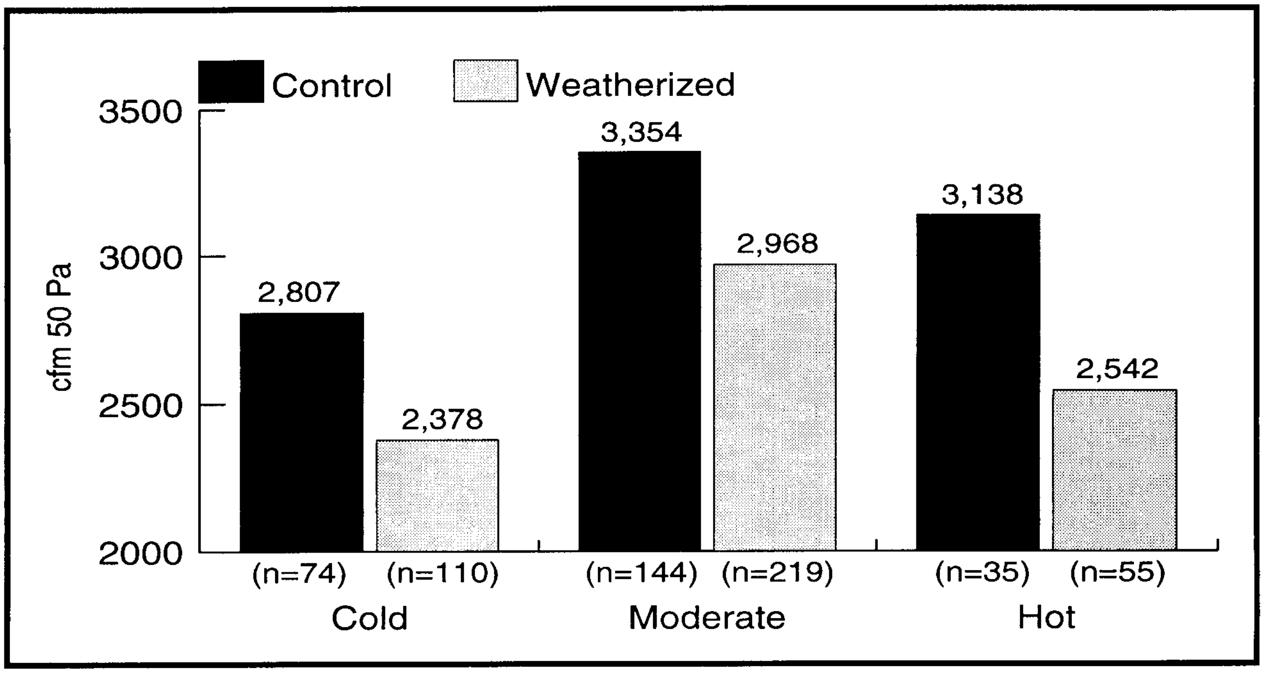

Fig. 3.4 Mean Air Leakage Rates by Region

Distributions by region showed that control and weatherized dwellings in the cold region are significantly more likely to be in the tightest categories (Fig. 3.5), while dwellings in the moderate region are distributed in about the same pattern as the total sample. Dwellings in the hot region tend to be slightly more concentrated in the middle categories.

3.2 HEALTH AND SAFETY MEASURES

Over 50 health and safety checks (See Appendix B, p. 9 for a listing) were performed during each in-home measurement session. Most of the items checked — such as the presence of standing water, peeling paint, holes in walls or ceilings, clutter, dust, combustible materials near heating systems, vermin, and animal waste — reflect the structural soundness of the dwellings, the occupants' ability to make home repairs, and/or their housekeeping practices. The overwhelming majority of the health and safety items that were checked are the responsibility of the occupants to correct and are not meant to be addressed by the Program. Nevertheless, the fact that most dwellings had one or more such problems does reflect the generally poor condition of the low-income housing stock that the Program serves. For example, nearly 15% of the homes examined in phase two had holes in the walls, and slightly over 15% had holes in ceilings. In addition, between 10% and 20% of homes had signs of roof leakage, missing or failed gutter systems, water in the basement, peeling paint, and extensive clutter and dust.

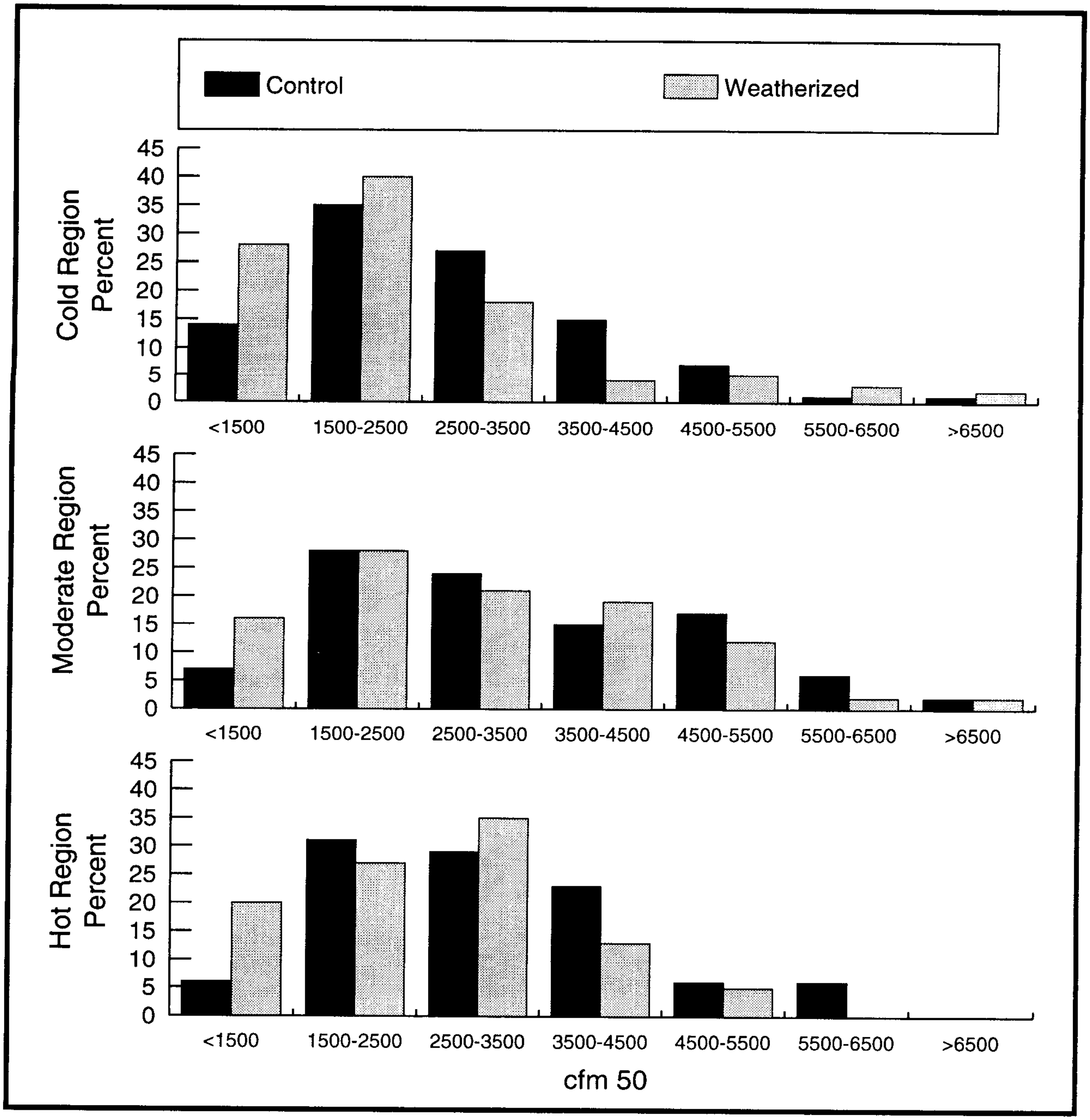

Fig. 3.5 Distributions of Air Leakage Rates by Region

Because most of the health and safety items checked during the inspections are not meant to be addressed by the Program, there is, in general, little difference between weatherized and control dwellings. A few items, however, are clearly receiving Program attention.

Nationwide, in PY 1989, about 18% of agencies routinely provided health and safety-related services (Mihlmester, et al., 1992). Some of these services, such as CO testing; and replacing broken glass or defective windows, are a standard part of the Program, supported by DOE funding. Other services, including the installation of smoke alarms and radon testing, are not a standard part of the Program and must be supported with leveraged funds. The impact of Program installations of smoke alarms and of Program replacements of broken glass and defective windows was clearly seen during the phase two inspections, as is discussed below.

3.2.1 Smoke Alarms and Repairs of Broken Windows

In PY 1989, smoke alarms were installed by the Program in about 3% of weatherized homes. In the phase two inspections, about 68% of weatherized homes had smoke alarms, as compared to about 62% of control homes (Fig. 3.6), which is a statistically significant difference.

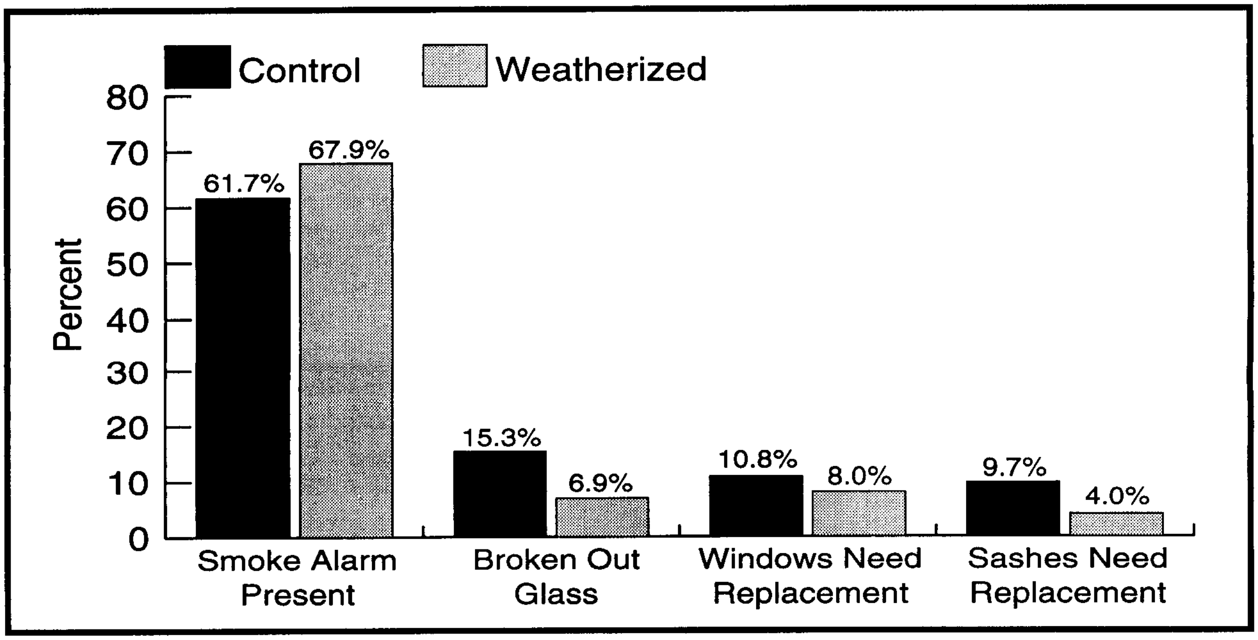

Fig. 3.6 Percentage of Weatherized vs. Control Dwellings with Smoke Alarms and Defective Windows

Weatherized homes, in the phase two sample, also were less likely than the control homes to have broken glass in windows, or to have either windows or sashes that needed replacement (Fig. 3.6). Broken glass and windows that will not close can present a safety hazard, especially in high crime areas. The better condition of the windows in the weatherized homes, inspected during the fall and winter of 1992, is especially significant because these phase two inspections took place three or more years after the homes were weatherized.

3.2.2 Carbon Monoxide Tests

In PY 1989, CO testing was performed in about 23% of the weatherized dwellings, nationwide. Among the phase two sample of 30 agencies, 13 routinely performed CO testing. These 13 agencies performed CO tests in about 75% of the homes that they weatherized in PY 1989.

During the 1992 phase two inspections, carbon monoxide tests were performed in the living space, five feet from the heating system, at the nearest register, and at the furnace flue. Mean CO levels in parts per million (ppm) are shown for each of these locations in Figure 3.7. CO levels at the first three

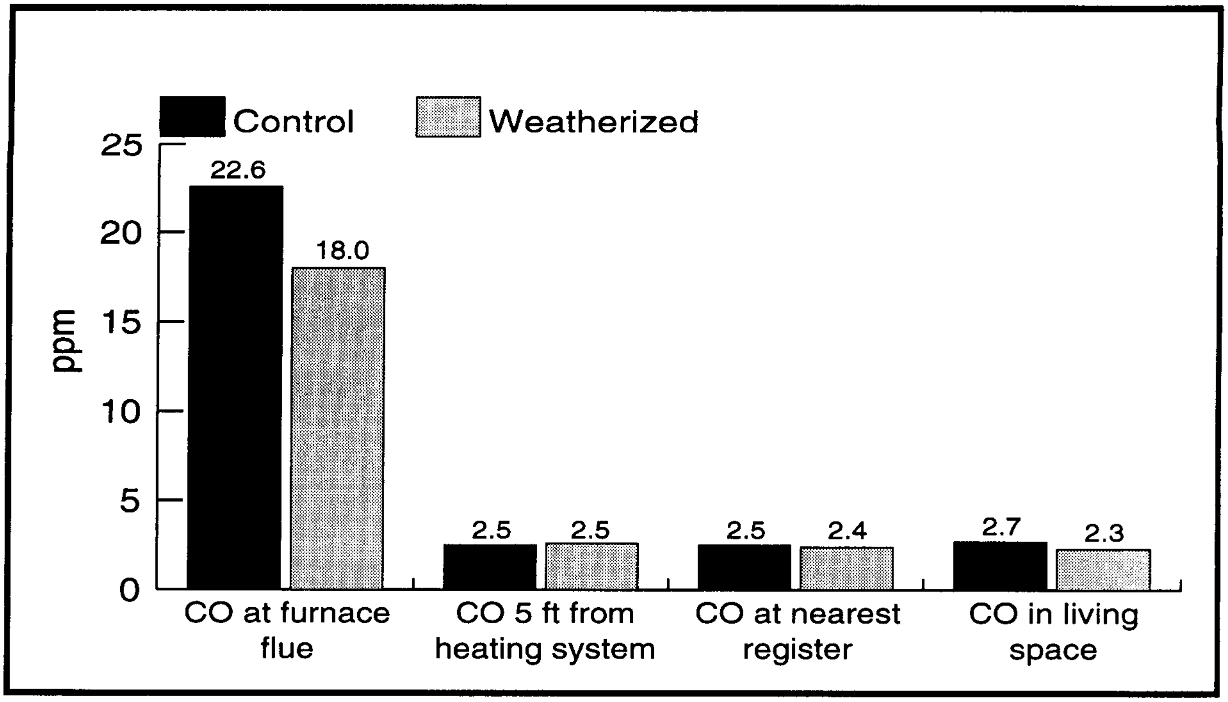

Fig. 3.7 Mean CO Concentrations in Four Locations for Weatherized vs. Control Dwellings

locations exceed safe levels (Table 3.2) in only a few homes, about 1-2% (Fig. 3.8, Fig. 3.9, and Fig. 3.10). Corrective action was taken in all of the homes in which unsafe levels were found. Levels measured at the furnace flue exceeded 250 ppm[5] in about 1% percent of homes (Fig. 3.11). High levels of

[5] In an article published in the May 1993 Energy Exchange Newsletter (pp. 18-19), Tony Checco reports that the American National Standards Institute (ANSI) sets combustion standards as follows: "a furnace shall not produce a concentration of carbon monoxide in excess of 0.04 percent in an air-free sample of the flue gases when tested in an atmosphere having a normal oxygen supply." He then notes that "This means that in perfect combustion, there should be not more than 400 ppm. For field testing purposes, this translates to 250 parts per

CO measured in flue gases is not necessarily a hazard, but it does indicate that there is incomplete combustion, which means that the furnace is inefficient. Normally flue gases are vented outside of the dwelling where they will not affect the occupants. The fact that measurements at the other three locations were nearly always at safe levels indicates that the CO in flue gases seldom entered the living areas. Because CO problems[6] were relatively rare, there were no significant differences in mean values between weatherized and control groups (Fig. 3.8). In addition, there were no differences in mean values at the regional level, or between houses that were tested for CO in PY 1989 and those that were not.

Table 3.2 Standards and Guidelines for Exposure to Carbon Monoxide[a]

CONCENTRATION OF CO IN AIR	INHALATION TIME AND TOXIC SYMPTOMS DEVELOPED
9 ppm (0.0009%)	The maximum allowable concentration for an 8-hour exposure in a living area according to ASHRAE.
35 ppm (0.0035%)	The maximum allowable concentration for a 1-hour exposure according to ASHRAE.
200 ppm (0.02%)	Slight headache, tiredness, dizziness, nausea after 2-3 hours.
400 ppm (0.04%)	Frontal headaches within 1-2 hours, life-threatening after 3 hours, also maximum parts per million in flue gas (on an air free basis) according to EPA and AGA.
800 ppm (0.08%)	Dizziness, nausea and convulsions within 45 minutes. Unconsciousness within 2 hours. Death within 2-3 hours.
1,600 ppm (0.16%)	Headache, dizziness and nausea within 20 minutes. Death within 1 hour.
3,200 ppm (0.32%)	Headache, dizziness and nausea within 5-10 minutes. Death within 30 minutes.
6,400 ppm (0.64%)	Headache, dizziness and nausea within 1-2 minutes. Death within 10-15 minutes.
12,800 ppm (1.28%)	Death within 1-3 minutes.

a This table is taken from Ternes and Levins, 1993, P. 68.

million in the flue. Anything greater in any chamber warrants action." In the phase two sample, 9 houses (5 control and 4 weatherized) had CO concentrations in the flue that were above 250 ppm.

6 In the small percentage of homes with dangerous CO levels, detection and correction is critical to the health and safety of the occupants. Corrective action was taken in all the homes in which unsafe levels were measured during the course of the phase two study.

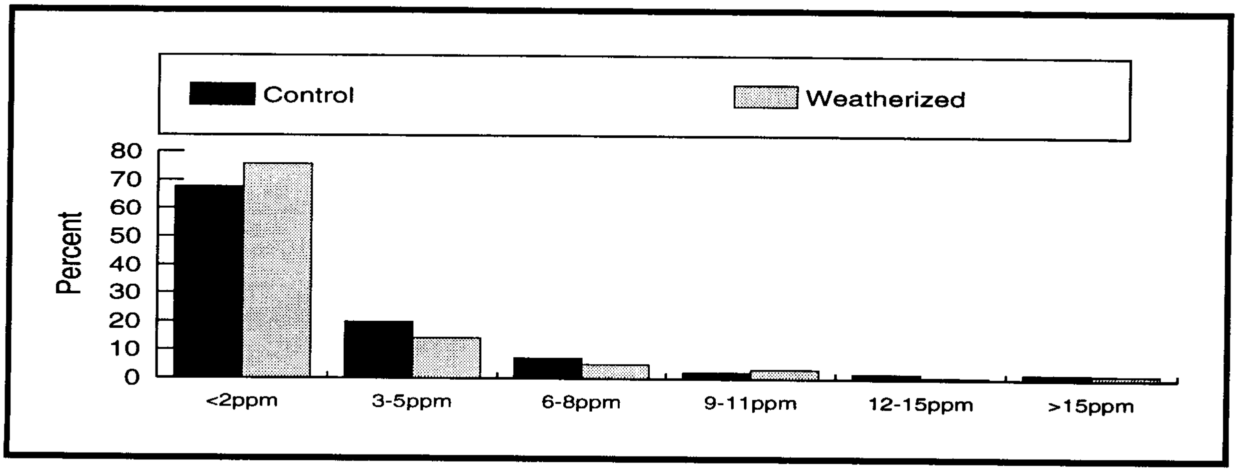

Fig. 3.8 Distribution of CO Concentrations in Living Space for Weatherized vs. Control Dwellings

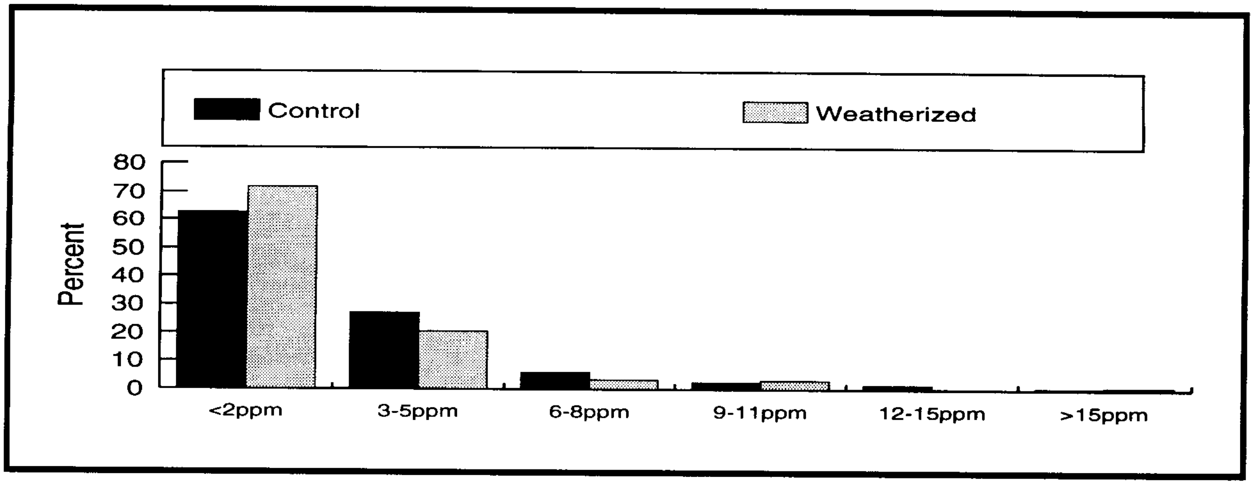

Fig. 3.9 Distribution of CO Concentrations Five Feet from Space-Heating System for Weatherized vs. Control Dwellings

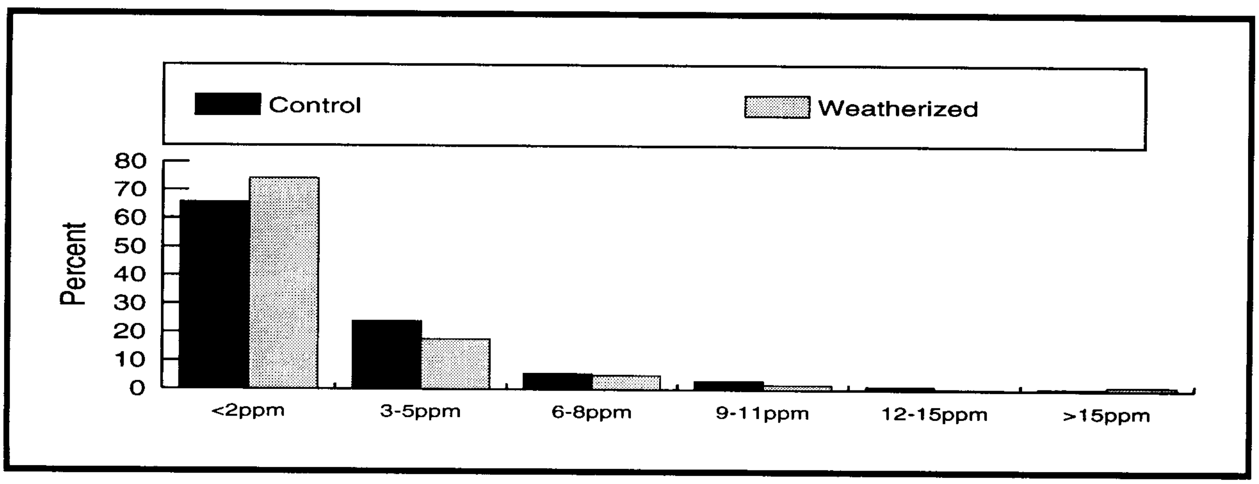

Fig. 3.10 Distribution of CO Concentrations at Nearest Register for Weatherized vs. Control Dwellings

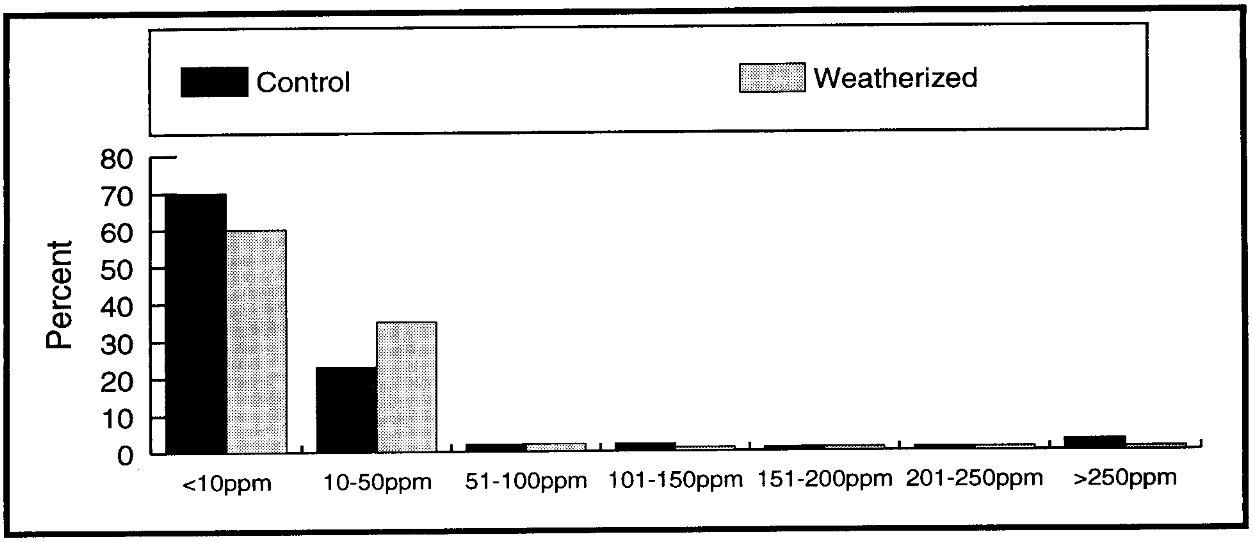

Fig. 3.11 Distribution of CO Concentrations at the Furnace Flue for Weatherized vs. Control Dwellings

3.3 INSULATION

Data from the Energy Information Administration's 1990 Residential Energy Conservation Survey (RECS) show that low-income dwellings are much less likely than the average home to have attic or wall insulation (Fig. 3.12). Differences in penetration by income group are the largest for attic insulation, and somewhat less for wall insulation.

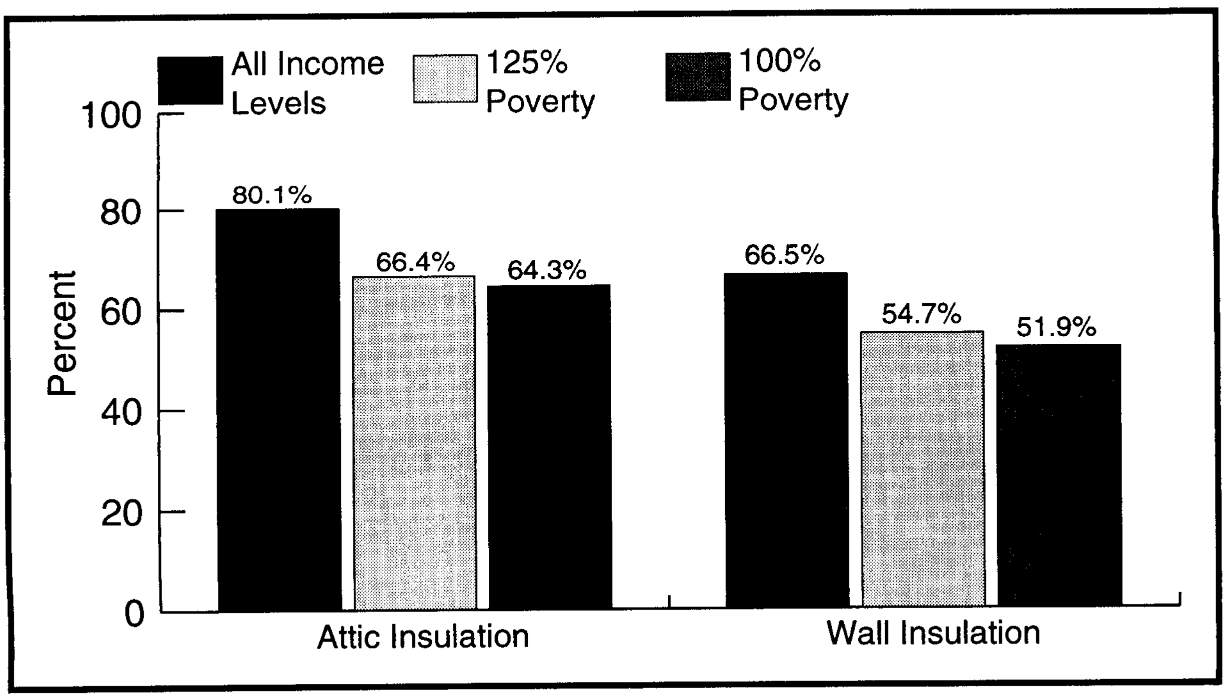

Fig. 3.12 RECS Data on Percentage of Homes with Attic and Wall Insulation by Income Groups

When comparing the weatherized, treated, and control groups on variables measuring the level of insulation measures, the expected improvements due to weatherization were usually apparent. For example, higher percentages of weatherized homes had adequate levels (i.e., R-values that met or exceeded recommended levels for their region) of attic, wall, and water heater pipe insulation. The insulation differences between weatherized (i.e., all weatherized homes), treated (i.e., only those weatherized homes that had a specific type of insulation installed by the Program in PY 1989), and control homes are discussed in the sections below. Results are presented for the total sample and by region. For each kind of insulation (attic, wall, floor, and water heater pipes) differences in types of insulation materials and in R-values are examined.

3.3.1 Attic Insulation

National Overview. In PY 1989 attic insulation was added in 19.9% of weatherized homes and was installed for the first time in 28.0%. The mean R-value of attic insulation was almost twice as high in weatherized homes (R-26) as in the control homes (R-15) (Fig. 3.13). These average values include an R-value of zero for homes with no insulation. 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.

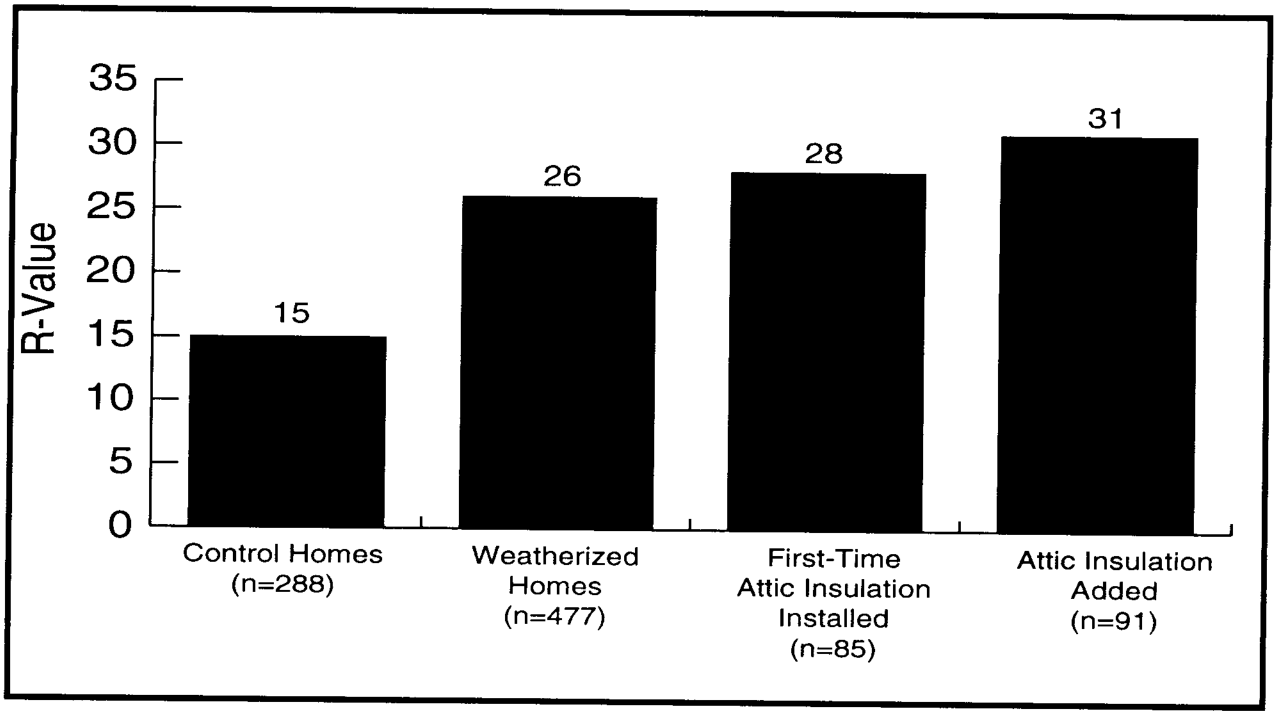

Fig. 3.13 Mean R-Values in Control, Weatherized, and Treated Homes

Nearly three times as many weatherized homes (21.0% vs 7.8%) had insulation that was at or above DOE-recommended R-values for dwellings in their climate region (Table 3.3).[7] Among treated homes, including both those with first-time or added insulation, about one-third had R-values at or above recommended levels.

The type of insulation also differed between the three groups. Weatherized and treated homes were much more likely to have blown cellulose or blown fiberglass insulation in the attic, while control homes had fiberglass batts as frequently as each type of blown attic insulation.[8]

Table 3.3 Percentage of Control, Weatherized, and Treated Homes with R-Values at or Above Recommended Level

	At or Above Recommended Level (%)	Below Recommended Level[a] (%)
Control	7.8	92.2
Weatherized	21.0	79.0
Treated	30.8	69.1

a Dwellings that have no attic insulation where included in the calculation of these percentages.

Although the R-values in weatherized and treated homes are much higher than those in control homes, 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 and 63% have R-values of less than R-30 (Fig. 3.14). R-19 or less is below recommended levels in all climate regions in the U.S. (U.S. DOE Fact Sheet on Insulation, 1988).[9] In the coldest climate regions, R-49 is recommended. In more moderate regions, R-38 is recommended, while in the hottest regions R-30 is recommended. Thus, significant proportions of weatherized and treated homes still have attic insulation with R-values below recommended levels, which suggests that there is a cost-effective opportunity to install additional insulation in many homes.

To put the R-values of weatherized homes into context, it is useful to compare them to the average for all income groups. Market research by Owens-Corning Fiberglass, conducted in 1992,

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7 The DOE Fact Sheet on Insulation 1988 presents recommended levels of insulation for eight climate regions. Recommended levels vary by climate region, location (e.g., crawl space walls, exterior walls, floors over unheated crawlspaces, ceilings below ventilated attics), and type of insulation (e.g., mineral fiber blankets or batts, loose and blown fill, perlite or vermiculite).

8 Fiberglass batts are most likely to be used in do-it-yourself installations, while blown insulation requires equipment used by professionals.

9 The R-value estimates assume that 3 to 4 inches of insulation is about R-11 and each additional inch adds about 3 units to the R-value.

indicated that in dwellings of all income levels the average level of attic insulation was R-21 (Zinn, personal communication, 1993). Thus, the weatherized homes have R-values above the average for the U. S. housing stock that was estimated by the Owens-Corning study. 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.

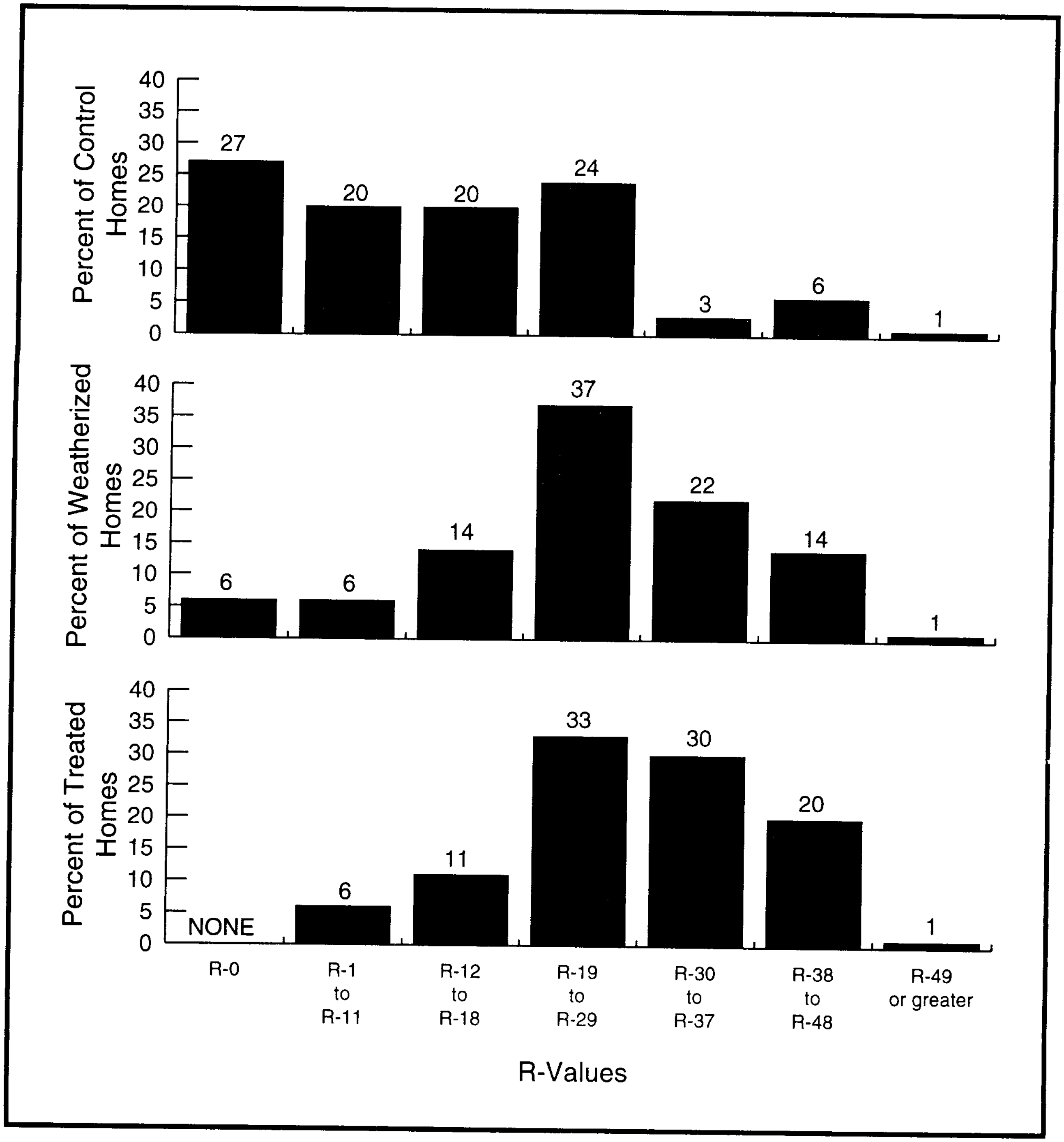

Fig. 3.14 Distributions of R-Values in Control, Weatherized, and Treated Homes

Regional Differences. Rates of installation of attic insulation (first-time or added) in PY 1989 varied across regions, ranging from a low of 43% of jobs in the hot region, to a high of 53% in the cold region. In the cold region, mean R-values for the control homes are slightly lower than those for the weatherized homes and for the treated homes in which attic insulation was added (Fig. 3.15). In the moderate and hot regions, the R-values in control homes are much lower than in weatherized homes or in treated homes that had either added or first-time insulation.

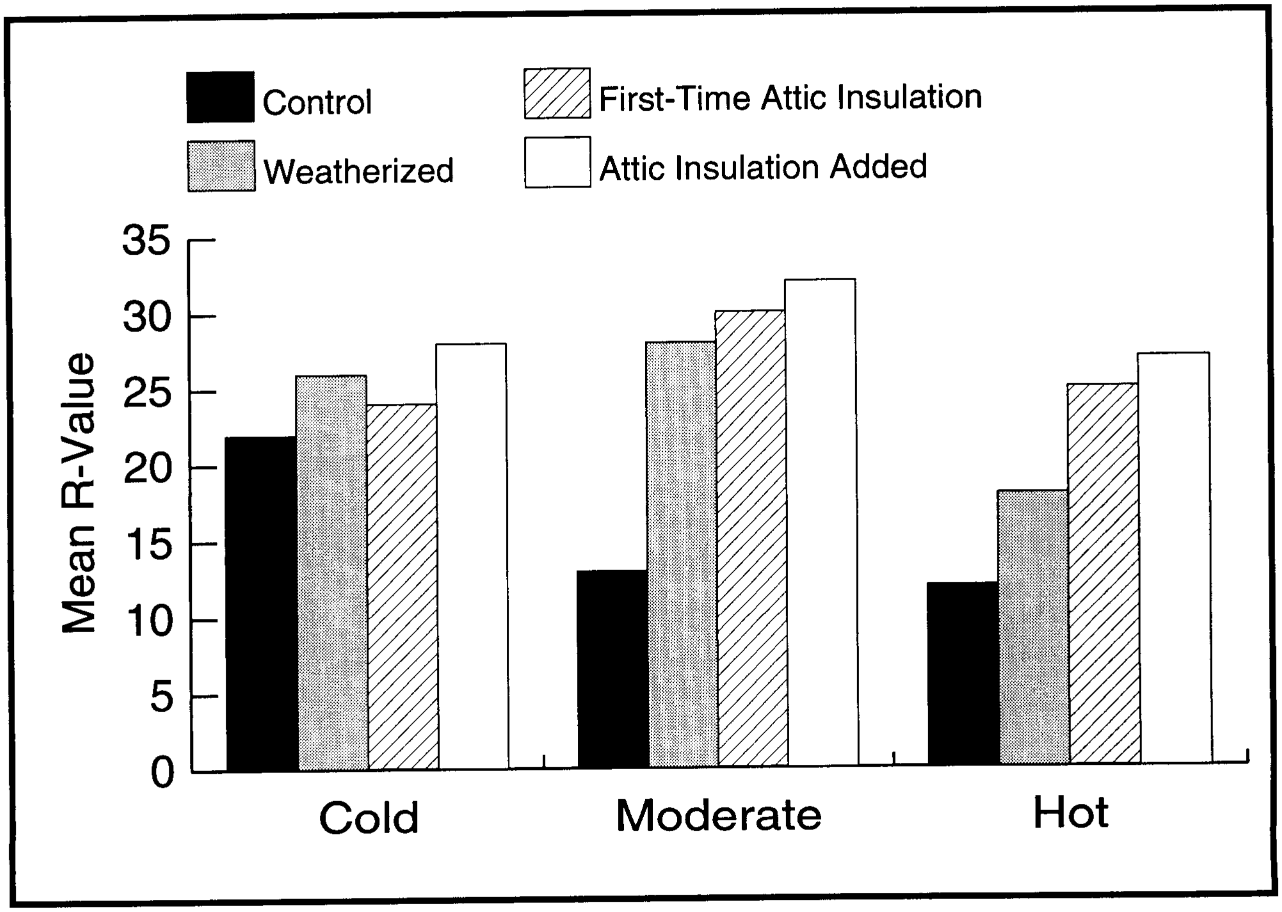

Fig. 3.15 Attic Insulation Mean R-Values for Control, Weatherized, and Treated Groups by Region

As illustrated in Fig. 3.16, the distribution of R-Values varied by region. In the cold region, about 24% of the control group and 32% of the weatherized group had R-30 or higher. The treated group had about 39% at R-30 or higher. About 3% had R-values above R-49, which is the recommended level for the coldest climate regions. About 12% of control homes had no insulation, while only 1% of weatherized homes had none. In the moderate region, only about 7% of the control group had R-30 or higher, while over 44% of the weatherized group, and 58% of the treated group, had this level. About 20% had R-values above R-38, which is the recommended level for the moderate climate regions. About 34% of control homes had no insulation, while only 4% of weatherized homes had none. In the hot region, 4% of the control group, 18% of the weatherized group, and 31% of the treated group had R-30 (which is the recommended level) or higher. About 24% of control homes had no insulation, while about 18% of weatherized homes had none.

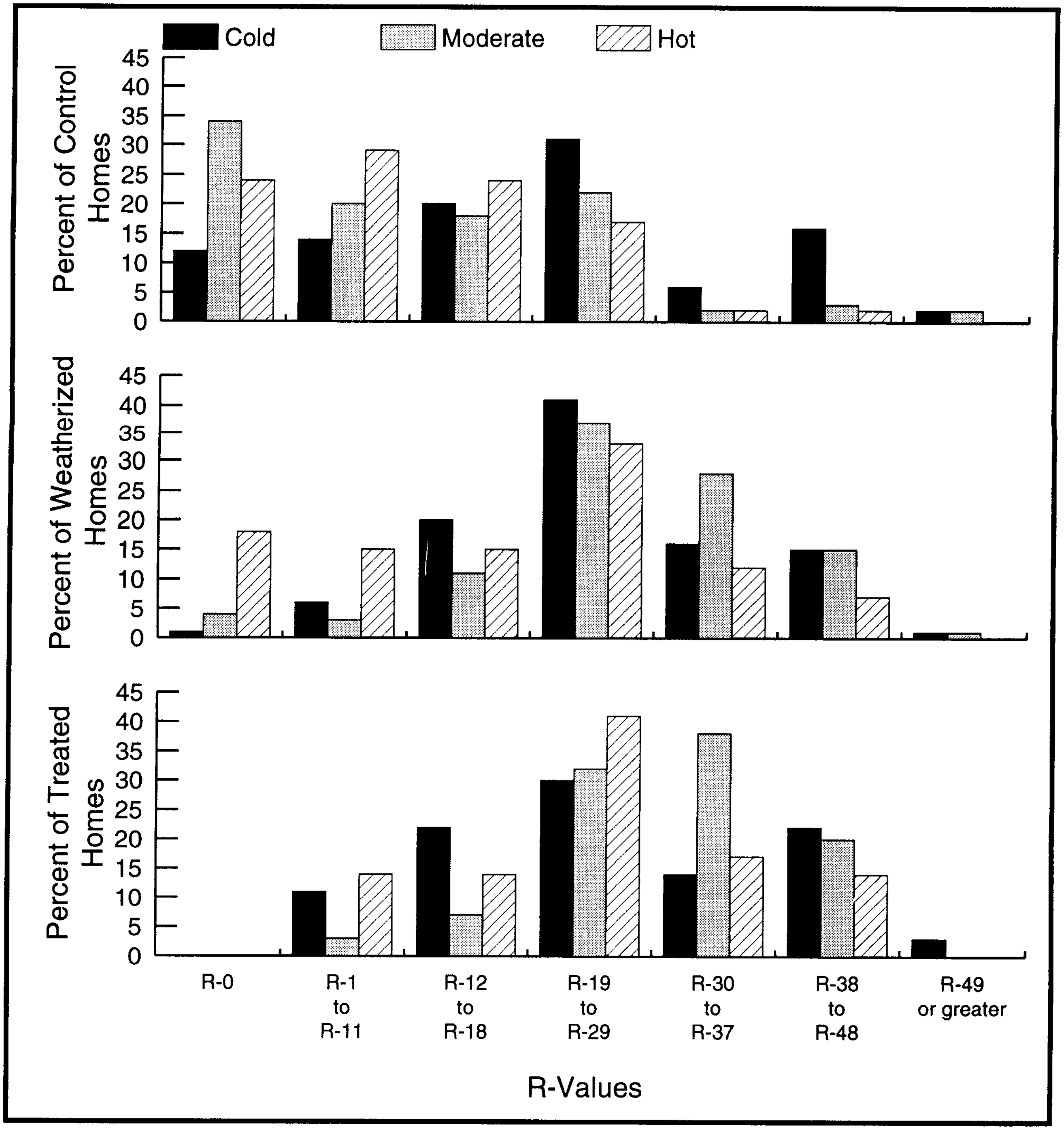

Fig. 3.16 Distributions of Attic Insulation R-Values for Control, Weatherized, and Treated Homes by Region

3.3.2 Wall Insulation

In PY 1989, wall insulation was installed, nationally, in 19.3% of weatherized homes. Rates of installation were much higher in the cold (24.9%) and moderate (24.3%) regions than in the hot region (1.1%).

When wall insulation is present, its R-value is generally near recommended levels (which is R-11 for all climate regions) for control, weatherized, and treated homes in all three climate regions. For all homes in the phase two sample with measurements of wall insulation thickness, the average level of wall insulation in weatherized homes is about R-12, which is slightly above the recommended level of R-11 for exterior walls (U.S. DOE Fact Sheet on Insulation, 1988).

Differences in the type of insulation present in exterior walls were apparent in all of the climate regions. Control homes were more likely than weatherized or treated homes to have fiberglass batts in their walls. This is the type of insulation most likely to be installed by homeowners themselves.

In their comments written on the house characteristics survey forms, the on-site inspectors frequently recommended the installation of additional wall insulation (in 30% of dwellings). This suggests that there is a significant opportunity for the cost-effective installation of more wall insulation. This is especially true in the hot region, where only 1% of PY 1989 weatherization jobs included wall insulation.

3.3.3 Floor Insulation

In PY 1989, floor insulation was installed, nationally, in 12.3% of weatherized homes. It was installed about twice as often in the cold (15.7%) and moderate (13.0%) regions, as in the hot region (7.2%).

When floor insulation is present in weatherized homes, its average level is about R-12. The recommended level is R-19 in cold or moderate climate regions. In the warmest climate regions, floor insulation is not recommended (U.S. DOE Fact Sheet on Insulation, 1988). In addition, floor insulation is not applicable in many homes in the hot region because they have concrete slab foundations.

3.3.4 Water Heater Pipe Insulation

In PY 1989, water heater measures were installed in 56% of weatherized homes. They were installed in over 60% of the homes in the cold and moderate regions, and in about 29% of the homes in the hot region.

Four types of water heater measures were installed in more than 5% of the homes: tank insulation (40%), pipe insulation (34%), temperature reduction (13%), and low-flow shower heads (8%). Tank insulation was installed more than twice as often in the cold (49%) and moderate (45%) regions as in the hot region (29%).[10] Pipe insulation was installed at four times as high a rate in the cold (45%) and moderate (40%) regions, as in the hot region (11%).

In the total phase two sample, 40% of weatherized homes had insulated pipes as compared to 12% of control homes. Much higher proportions of the weatherized group than of the control group had water heater pipe insulation in the cold and moderate regions. In the hot region, however, the control and weatherized homes had about the same water heater pipe insulation levels.

3.4 HEATING SYSTEMS AND DUCTS

Heating Systems. In PY 1989, 29.8% of weatherized homes received some sort of work on the heating system. The most common furnace work was a clean and tune (22.2%), and the next most common was a component retrofit (8.0%). Heating systems were replaced in 3.5% of dwellings, nationally. In the cold region 7% of heating systems were replaced, in the moderate 3%, and in the hot region 1%.

There was no statistically significant difference between the average steady-state efficiency of furnaces in weatherized (75.9%) and control homes (75.6%). This was not surprising since the most common heating-system measure, the clean and tune, is not expected to last for more than a year or two. Because the phase two measurements were made three or more years after clean and tunes were performed in PY 1989, there was no reason to expect to see an impact. This was indeed the case as treated homes (those receiving a clean and tune in PY 1989) had about the same steady-state efficiency as the weatherized and control homes. Only three homes in the phase two sample received replacement heating systems as part of the Program, and their steady-state efficiencies were measured at 75%, which seems low for a new gas furnace.

As shown in Fig. 3.17 and Fig. 3.18, many weatherized and control homes have heating systems that are old and inefficient. Replacing these systems was recommended by the on-site inspectors in 9% of the weatherized and 14% of the control homes. In addition, both phase one Single-Family and Fuel-Oil Study results indicate that the replacement of heating systems is associated with higher than average savings. Thus, replacement of heating systems should probably receive more Program emphasis. Although it would be desirable to replace more heating systems, additional funding would be necessary to do so. Replacement heating systems cost nearly as much as the average agency limit on DOE spending per house, which was $1,600 in PY 1989. Therefore, agencies that replaced heating systems typically used leveraged funds to pay for them.

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10 Phase two data on water heater tank insulation were unreliable because the field inspectors were asked to place a check mark on the form if tank insulation was not present. Because this check mark was often missing (it was checked for only 26% of houses while RECS data suggest that at least 70% of homes lack water heater blankets), it was not possible to assess what proportion of the homes in the phase two sample actually did or did not have tank insulation.

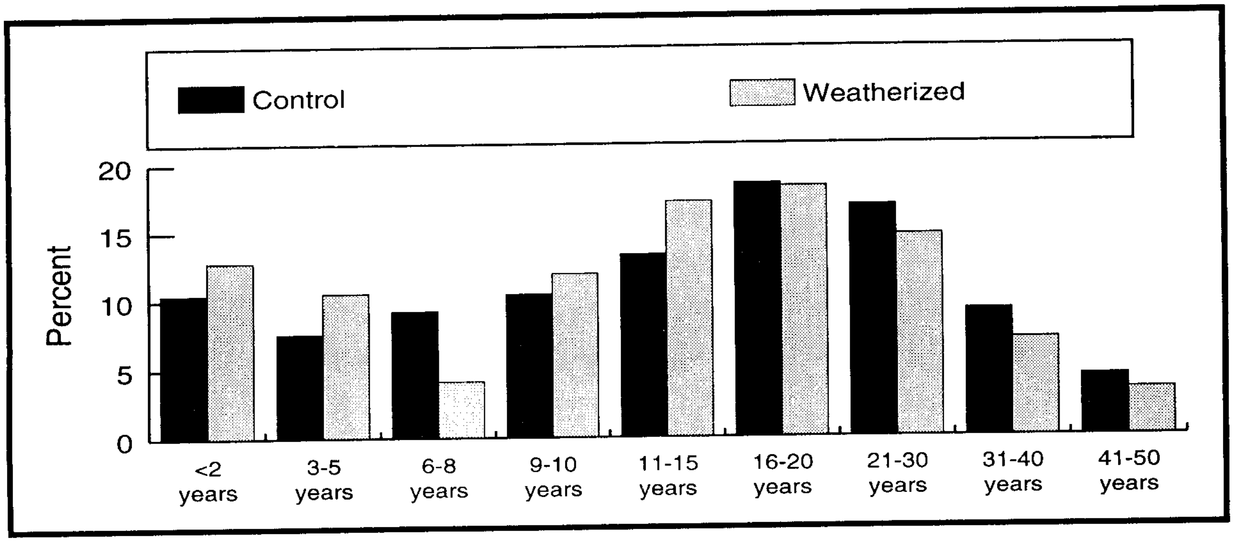

Fig. 3.17 Distribution of Age of Primary Heating System for Weatherized vs. Control Dwellings

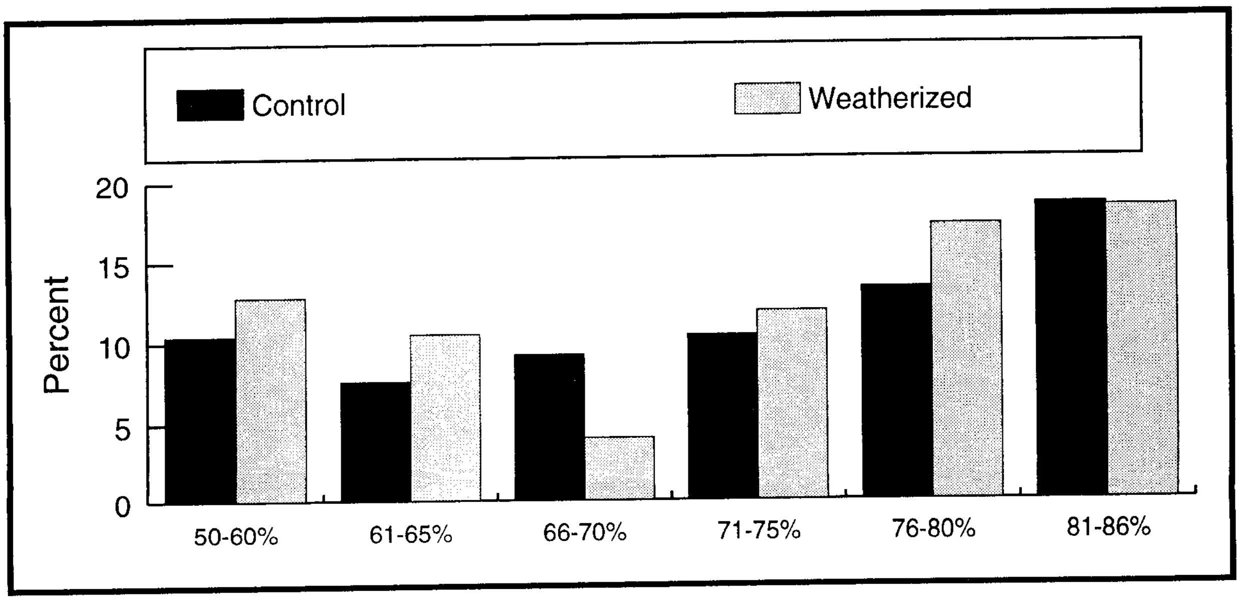

Fig. 3.18 Steady-State Efficiency of Primary Heating System for Weatherized vs. Control Dwellings

Distribution Systems. In PY 1989 distribution system work was completed on less than 7% of homes, far below the proportion that needs duct work.[11] Inspections of the condition of ducts were conducted during the phase two measurement sessions. A sketch of the distribution system and ratings of the condition of up to eight supply ducts were included on the house characteristics survey form

11 It was not possible to analyze a "treated" sample for ductwork because so few dwellings received any work on their distribution systems.

(Appendix B). As Fig. 3.19 shows, about 40% of hot air system ducts were rated as leaky or very leaky, and a somewhat higher percentage were classified as tight. Among weatherized homes about 15% of the ducts were sealed as compared to about 8% of the ducts in control homes.

In addition to an inventory of the condition of all the ducts inspected, it seemed important to quantify the proportion of dwellings that needed duct repairs. From Figure 3.19, it is unclear whether most of the very leaky or disconnected ducts were in a small minority of the houses, or were distributed across a large number of the houses inspected. To develop a classification of each house concerning the overall condition of its ducts, a procedure that used information from all eight of the possible duct ratings was designed. The classification procedure was as follows:

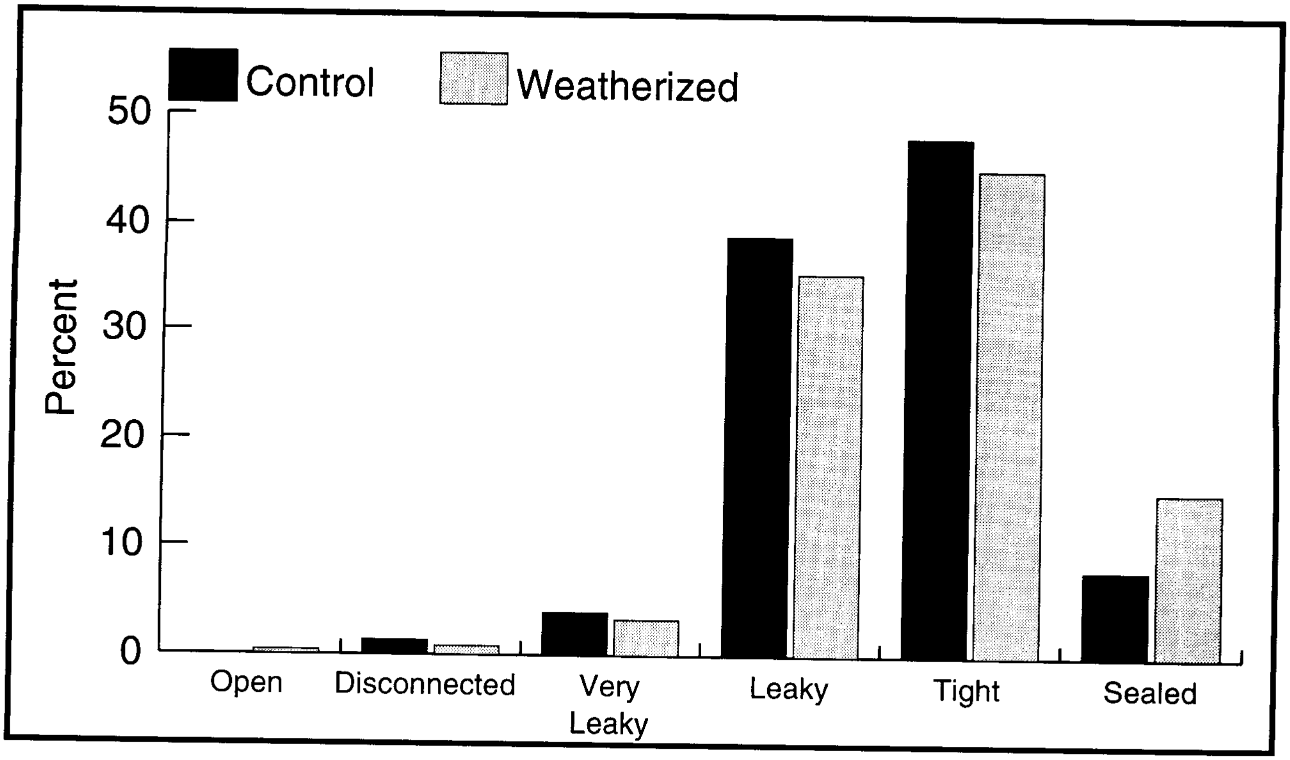

Fig. 3.19 Condition of Ducts in Hot Air Heating Systems for Weatherized vs. Control Dwellings

- If a house had any ducts that were disconnected or blocked, its condition was classified as very poor.
- If a majority of the ducts were leaky, its condition was poor.
- If most, but not all, of the ducts were tight or sealed, its condition was fair.
- If all of the ducts were tight or sealed the condition was good.

Using these definitions, the results are as shown in Table 3.4. About 50% of both weatherized and control homes have ducts that are in the poor category. About 40% of the dwellings were in the good category, which means that all of their ducts were rated as tight or sealed. Small percentages of the homes were in the fair or very poor categories.

Table 3.4 Comparison of Overall Condition of Ducts in Dwellings

	Weatherized (%)	Control (%)
Very Poor	3.1	3.7
Poor	52.8	50.4
Fair	3.5	5.8
Good	40.6	40.2

3.5 STRUCTURAL PROBLEMS

Structural problems are prevalent in the Program-eligible low-income housing stock, especially in the hot region. As Fig. 3.20 shows, nearly 70% of the control homes and over 65% of the weatherized homes in the hot region had one or more structural problems. In every category of structural problem, the hot region had a higher incidence than the national average. In some categories, dwellings in the hot region were more than twice as likely to have a structural deficiency. The high level of structural problems in the hot region undoubtedly has a negative effect on the ability of agencies there to achieve energy savings comparable to the colder regions 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.

In the cold region, 39% of control homes and 34% of weatherized homes had one or more structural problems. In the moderate region, 36% of control homes and 28% of weatherized homes had one or more structural problems (Fig. 3.20). The problems which were less frequent in the weatherized homes (broken glass, windows and sashes that need replacement) are shown in Fig. 3.20. The most common structural problems, however, were holes in walls and holes in ceilings, which were equally common in weatherized and control homes. Nationally, about 15% of both weatherized and control homes had these problems. In the hot region, over 30% of both groups of homes had holes in ceilings and nearly 30% had holes in walls. Repairs to floors, stairs, roofs, and porches also were needed in 5% to 20% of both control and weatherized homes, with homes in the hot region having the greatest need for repairs.

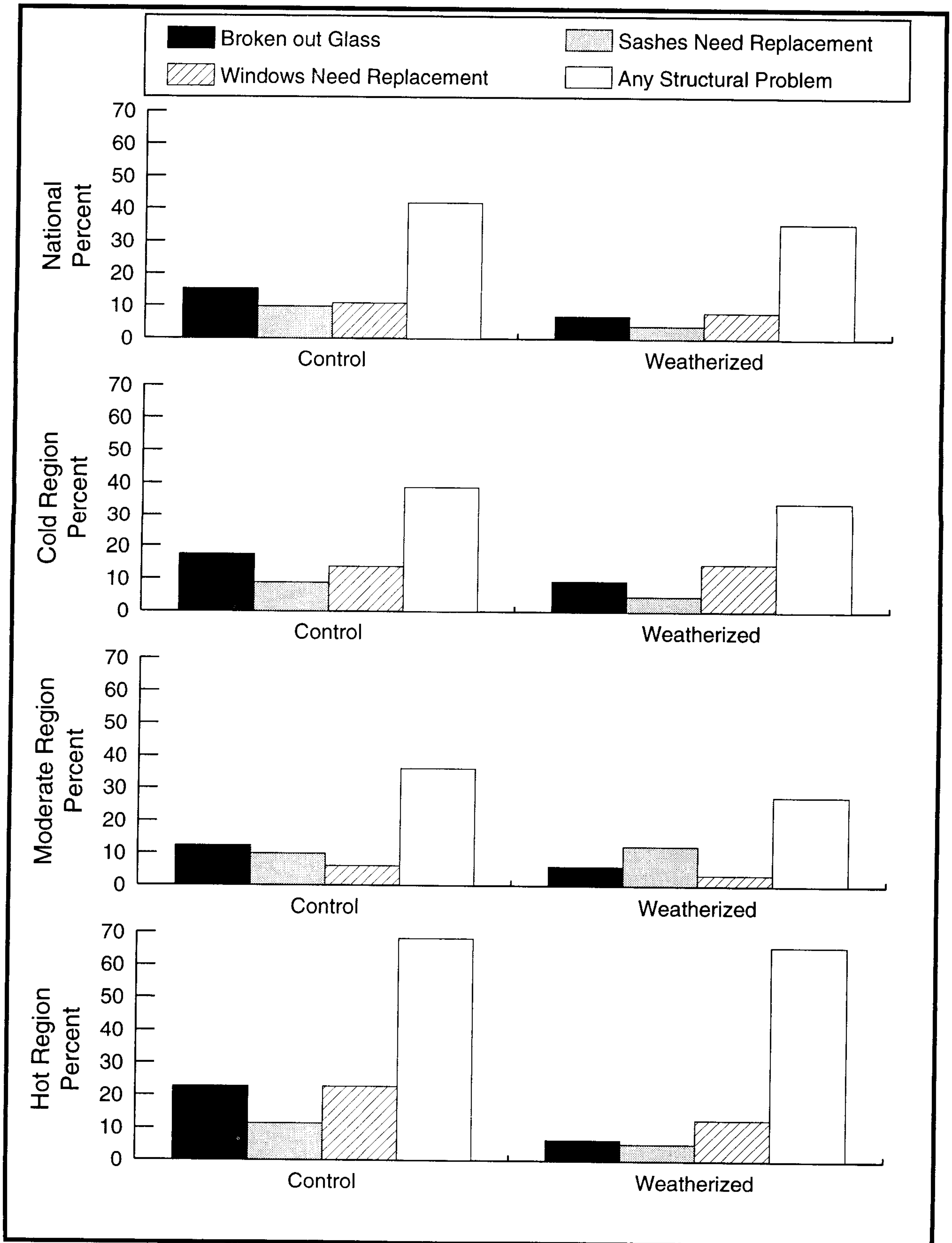

Fig. 3.20 Incidence of Structural Problems by Region

3.6 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 (Table 3.5). Rates of window and door replacements and repairs were lowest in the cold region and highest in the hot region. Doors were replaced in over one-third of weatherized homes, nationally. In the hot region about 58% of homes received replacement doors, as compared to 25% in the cold region, and 34% in the moderate region. Storm windows were installed in over one-third of the weatherized homes, nationally. In the moderate region, nearly 40% of weatherized homes received storm windows, more than in the cold (27%) or hot (36%) regions.

Table 3.5 Percentage of Homes Receiving Window or Door Measures by Region

	National (%)	Cold (%)	Moderate (%)	Hot (%)
Windows/Glazing	47.2	41.7	48.1	49.8
Replacement of Doors	37.8	25.3	34.4	57.8
Replacement of Windows	36.9	26.1	37.0	46.3
Storm Windows	36.3	26.9	39.5	36.2
Door Repairs	23.2	19.4	21.6	31.1

The lower incidence of broken windows and windows and sashes that need replacement in phase two weatherized homes has already been discussed (Sections 3.2.1 and 3.5). For the total phase two sample, 58% of control and 67% of weatherized dwellings had storm windows. 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%). Also, there were marked regional differences in the percentage of the total window area that was covered with storm windows (Fig. 3.21). In the hot region, only 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 window area in the hot region had storms, while 70% in the moderate, and 80% in the cold region were covered.

3.7 OCCUPANT CHARACTERISTICS

During the on-site measurement session, an occupant of each household was interviewed using the survey forms shown in Appendix C. The occupant survey collected a good deal of information that can be used to examine how changes in occupant behaviors affect savings. For example, if occupants change the number of rooms they heat, the amount of supplemental heating fuels they use, or the temperature of their homes, energy savings will be affected. In addition, if the original household occupying the dwelling moves out and a new household moves in, changes in household size, composition, and patterns of behavior are likely to affect energy demand.

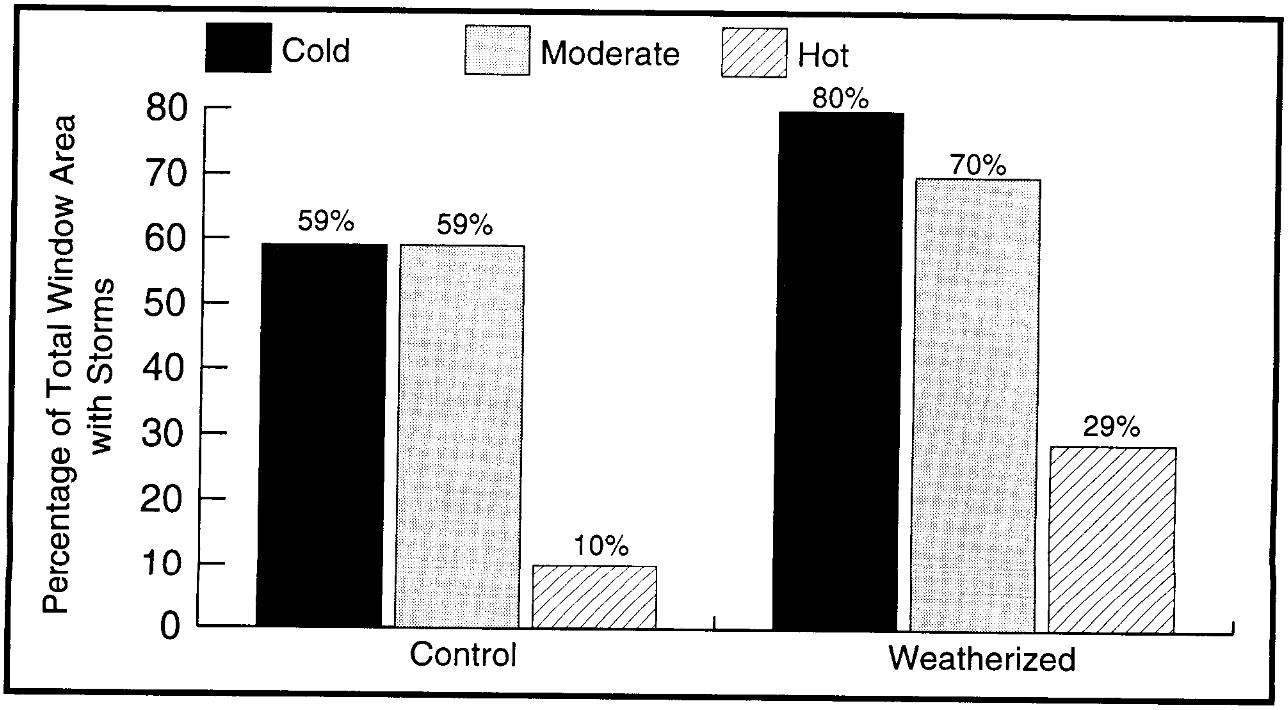

Fig. 3.21 Percentage of Total Window Area that is Covered with Storm Windows by Region

Although changes in behavior clearly can have large impacts on energy use in individual dwellings (which will be examined in Chapter 4), there were only a few statistically significant behavioral differences in the aggregate analyses of the weatherized vs. control groups (Table 3.6). For example, the weatherized dwellings showed lower rates of occupancy change than the control homes. On the other hand, there were no changes in thermostat settings or management in either the weatherized or control groups.

A comparison of patterns of change in the use of supplemental fuels for the weatherized versus the control dwellings revealed no statistically significant differences. Because a shift toward less use of supplemental fuels after weatherization, in gas-heated dwellings, might tend to produce underestimates of gas savings this variable was examined carefully.[12] Although more of the weatherized than of the control homes reported lower post-weatherization use of supplemental fuels (48% vs 35%), these differences were not statistically significant because of small sample sizes. In addition, the phase two

12 All eight of the questions in section B of the occupant surveys (Appendix C) concern the use of supplemental fuels. Results from each question were examined for the weatherized and control groups to uncover any significant differences between the two groups. The proportions of the two groups using the same, more, or less supplemental fuels in the pre-weatherization versus post-weatherization time periods were never significantly different.

weatherized homes which reported discontinuing the use of supplemental fuels and/or using less of a given supplemental fuel post-weatherization, actually had higher gas savings than those weatherized homes which reported increasing their use of supplemental fuels. This finding is complicated by the fact

Table 3.6 Comparison of Occupant Characteristics in Weatherized vs. Control Dwellings

	Weatherized	Control
Number of occupants (pre-weatherization) **	3.0	3.4
Number of occupants (post-weatherization)*	2.8	3.1
No pre-post change in occupants (%)***	67.4	51.4
More occupants pre (%)***	26.5	41.1
More occupants post (%)***	6.1	7.5
Pre-weatherization thermostat setting (°F)	69.4	69.2
Post-weatherization thermostat setting	69.0	69.6
Change in thermostat setting(°F)	0.4	0.4
Heating system broken (pre) (%)	14.0	11.7
Heating system broken (post) (%)***	9.0	17.9
Utility cut-offs (pre)	3.9	5.0
Utility cut-offs (post) (%)	4.5	7.1
# rooms heated (pre)	5.7	4.8
# rooms heated (post)	6.3	6.2
Heated more space post	5.1	1.9
Did not change number of rooms heated	94	96
Did not alter use and intensity of supplemental fuels (%)	90	93

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

that dwellings with supplemental heating also had higher-than-average gas usage and, therefore, higher-than-average savings potential.

In the phase one study, it was shown that gas savings in homes that used supplemental heating fuels were 64 ccf/year less than in homes that had only a primary heating fuel. In phase one, the use or nonuse of supplemental fuels was observed by agency staff before weatherization. No post-weatherization data about supplemental fuel use were collected. Because information on pre- versus post-weatherization shifts in patterns of supplemental fuel use was not available for phase one dwellings, the impact of such shifts could not be assessed in the phase one report.[13] While the phase two data did contain information on pre- versus post-weatherization shifts in supplemental fuel use, they did not reveal any significant weatherized versus control behavioral differences, nor any significant effects on the average levels of gas savings in homes that increased or decreased their supplemental fuel use.

3.8 SUMMARY AND FUTURE OPPORTUNITIES

Nearly every type of measure examined in this chapter showed significant opportunities for additional cost-effective 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 cost-effective efficiency improvements in the low-income housing stock. Without increased funding, all of the available opportunities for cost-effective improvements cannot be realized. At present funding levels, Program implementors typically are able to meet only part of the weatherization needs of their clients.

Several findings discussed in this chapter suggest opportunities for capturing more of the energy-efficiency potential of the housing stock. The frequent observation of air leakage that exceeds optimal levels was discussed in Section 3.1. Only 20% of the weatherized homes had air leakage rates less than 1,500 cfm_{50} — the threshold below which further tightening is not usually recommended. This suggests that the remaining 80% could benefit from further tightening.

Insulation also is below recommended levels in many homes (Section 3.3). Attic insulation of R-30 or above is recommended in all climate regions. The mean R-value for the total sample of weatherized homes, however, was R-26. In the hot region, the mean R-value for weatherized homes was R-16. In addition, the on-site inspectors indicated that additional attic insulation was needed in 43% of the total sample of weatherized homes, and in 56% of the hot region's sample (Table 3.7). Because these recommendations were not a required part of the house characteristics survey form, but rather were added in the comments section or as marginal notes, it is likely that the need for additional insulation is even greater.

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.

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[13] Comparisons of the phase one homes that used supplemental fuels with phase one homes that did not use supplemental fuels revealed many significant differences in dwelling characteristics, regional locations, and types of weatherization measures installed. Thus, resolving the question of the impact of supplemental fuel use on gas savings is complicated by the many other differences between the homes that did and did not use supplemental fuels.

Table 3.7 Percentage of Homes for Which Need for Additional Insulation Was Indicated by Surveyor's Comments, by Region

	Attic	Wall	Floor
National (%)	43	30	35
Cold (%)	33	28	45
Moderate (%)	44	29	33
Hot (%)	56	35	22

Floor, basement and foundation wall insulation also should be installed in more homes. The on-site inspectors noted that additional floor insulation was needed in 35% of the total sample of weatherized homes. This measure was recommended more often in the cold (45%) and moderate regions (33%), than in the hot region (22%).[14] Nationally, floor insulation was installed in 12.3% of weatherized homes in the 1989 Program Year.

These findings suggest that there is a substantial need for additional attic and wall insulation, especially in the hot region. The phase one findings that high energy savings are associated with first-time attic insulation and with wall insulation (Brown, et al., 1993) add support to these conclusions.

Two other important 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 are generally old and inefficient. When heating systems are replaced, as they were in 4% of PY 1989 homes, high energy savings typically are produced. Replacement of heating systems also is a measure that is heavily emphasized by one of the agencies with the highest average energy savings (Brown et al., 1993b). These findings suggest that the Program should give higher priority to the replacement of heating systems. Again, additional funding would be needed to make more heating system replacements possible. The condition of ducts is poor in over 50% of the phase two homes, and there is little difference between the weatherized and control groups in the incidence of duct problems. Here again there is an unrealized opportunity to improve the energy efficiency of low-income dwellings.

In summary, there are many opportunities for improving the energy efficiency of dwellings that are not being realized. Increased funding is needed to take full advantage of these opportunities. Some of the most important areas for increased Program emphasis and funding are:

- more attic and wall insulation, especially in the hot region,
- more heating system replacements, and
- more distribution system sealing and repairs.

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14 Many homes in the hot region do not have basements or crawlspaces that can be insulated.

In addition, many homes need extensive structural repairs, which must be paid for with leveraged funds. In such homes, leveraging of housing rehabilitation funds is essential to achieving a minimal level of structural integrity and energy efficiency.

4. COMPARISONS OF HIGH- VS LOW-SAVING DWELLINGS

This chapter focuses on dwellings that have unusually high or low energy savings — that is, the dwellings that are in the "tails" of the distribution of energy savings. The goal is to explain why some dwellings produce significant energy savings while others fail to save any energy, and to identify features of dwellings, occupants, and weatherization practices that differentiate high from low savers.

This analysis of high- vs. low-saving dwellings is limited to gas-heated homes because they represent 90% of the dwellings with energy consumption data. Two types of high- and low-saving dwellings were identified for analysis: a national sample and three regional samples. The *national sample* is used to identify factors that are important nationwide in explaining the occurrence of high- and low-saving dwellings. The *regional samples* are used for region-specific analysis of the factors associated with high vs low savings.

The chapter begins with a quantitative analysis of the national sample (Section 4.1) and then turns to an analysis of the regional samples (Section 4.2). These sections profile high- and low-saving dwellings and report the results of statistical tests to identify key differences. The profiles describe average dwelling and occupant characteristics, types and costs of measures installed, and energy-efficiency characteristics. An in-depth qualitative analysis is then presented, which involves detailed case studies of two high- and two low-saving dwellings (Section 4.3). The chapter ends with a summary of its findings (Section 4.4).

4.1 THE NATIONAL SAMPLE OF HIGH- AND LOW-SAVING DWELLINGS

The national sample of high- and low-saving dwellings was defined by ranking the weatherized dwellings by energy savings and selecting the 125 dwellings with the highest savings and the 125 dwellings with the lowest savings. The average gross gas savings for the 125 high performers was 499 ccf/year (Table 4), or more than three times the national average based on the Phase I Study (Brown, et

Table 4.1 Distribution of National Sample of High- and Low-Saving Dwellings

	High-Saving Dwellings		Low-Saving Dwellings	
	Number (and %) of Dwellings	Average Gross Gas Savings (ccf/year)	Number (and %) of Dwellings	Average Gross Gas Savings (ccf/year)
Cold (N=77)	39 (31.2%)	477	38 (30.4%)	-50
Moderate (N=125)	75 (60.0%)	532	50 (40.0%)	-239
Hot (N=48)	11 (8.8%)	348	37 (29.6%)	-74
Total (N=250)	125 (100%)	499	125 (100%)	-133

al., 1993a). The average gross gas savings for the 125 low performers was -133 ccf/year, meaning that this sample consumed significantly more gas in the year following weatherization than during the year before weatherization.

As expected, many of the high savers were located in the moderate climate region (60%), and few were in the hot climate region (9%). In contrast, many of the low savers were located in the hot climate region (37%). Thus, some of the differences between high- and low-saving dwellings (noted in the following sections) are due in part to differences in their geographic locations.

4.1.1 Characteristics of Weatherized Dwellings

The high-saving dwellings used about 70% more energy before weatherization than low savers (Table 4.2). After weatherization, the high savers used only about 6% more than the lower savers. Before weatherization, the high savers were significantly more energy inefficient, consuming 25 Btu's per square foot per heating degree day, compared with 20 Btu/square foot/heating degree for the low savers. After weatherization, the energy intensity of the high savers declined significantly to 18 Btu/square foot/heating degree day, which was less than that of the low savers (22).

Table 4.2 Comparison of Dwelling Characteristics in High- vs. Low-Saving Dwellings

	High Savers (N=125)	Low Savers (N=125)
Single-Family Detached	72%	65%
Single-Family Attached	5%	4%
Mobile Homes	5%	11%
Small Multifamily	18%	20%
Dwelling Size (square feet)**	1,219	1,013
Age of dwelling (years)***	59.0	41.9
Pre-weatherization Normalized Annual Consumption (ccf)***	1,678	982
Post-weatherization Normalized Annual Consumption (ccf)***	1,180	1,117
Change in Normalized Annual Consumption	499	-133
Btu/sq. ft./HDD (pre)**	25	20
Btu/sq. ft./HDD (post)**	18	22
Heating degree days***	6,181	5,038

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

As is consistent with their high pre-weatherization energy consumption, the high-saving dwellings are both larger and older than the low-saving dwellings. In addition, the high savers are composed of slightly more single-family homes and slightly fewer mobile homes compared to the low savers, although these differences are not statistically significant. Together with the fact that the high savers are located proportionately more in the moderate and cold climate regions, these findings indicate that the high savers offer a greater-than-average potential for energy savings.

4.1.2 Occupant Characteristics

High- and low-saving dwellings have similar numbers of occupants both before and after weatherization (Table 4.3). Low savers have more households with elderly occupants and persons with disabilities, partly reflecting their more frequent location in the hot region where larger proportions of elderly and disabled persons participate in the Weatherization Program. However, the differences between high and low savers in terms of the frequency of elderly or disabled occupants are not statistically significant.

Table 4.3 Comparison of Occupant Characteristics in High- vs. Low-Saving Dwellings[a]

	High Savers	Low Savers
Number of occupants (before weatherization)	3.1	3.0
Number of occupants (after weatherization)	2.9	2.8
Elderly occupants (%)	37	45
Person with disabilities (%)	31	37

a None of these differences between high and low savers is statistically significant at the 0.05 level.

Comparisons of the impacts of weatherization on heating costs showed that high savers reduced their annual bills from $929 to $649, which represents a savings of $280. In addition, reductions in household energy burdens (defined as the cost of the main heating fuel divided by the annual income), were significant among the high savers (Table 4.4). Low savers, on the other hand, increased their bills from $546 to $624, and increased their energy burden from 11.7% to 12.8%.

Several aspects of occupant behavior have potentially important impacts on energy savings. For example, if weatherization causes occupants to increase the number of rooms they heat, keep their indoor temperatures higher during winter, or use less supplemental heating fuel, energy savings will be reduced. In addition, if the original household occupying the dwelling moves out and a new household moves in, changes in household composition and patterns of behavior are likely to affect energy demand.

Table 4.4 Comparison of Dwelling Characteristics in High- vs. Low-Saving Dwellings

	High Savers (N=125)	Low Savers (N=125)
Annual cost[a] of main heating fuel before weatherization (1989$)***	$929	$547
Annual cost of main heating fuel after weatherization (1989$)	$649	$625
Reduction in annual cost of main heating fuel (1989$)***	$280	$-78
Energy burden (pre)	13.8%	11.7%
Energy burden (post)	9.8%	12.8%
Change in energy burden***	4.1%	-1.1%

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

a This is the amount of weather-normalized annual gas consumption multiplied times the average state price for natural gas in 1989 dollars.

The occupant survey collected information to determine whether or not any of four types of changes occurred that might have influenced savings. These included changes in the number of occupants, the number of heated rooms, indoor temperatures, utility service, and supplemental heating fuels (Table 4.5).

Most dwellings had no change in the number of occupants during the study period (71% of high savers and 69% of low savers). Decreased occupancy was more characteristic of low savers (25%) than high savers (22%). Increased occupancy was more characteristic of high savers (7%) than low savers (5%). Since, all else being equal, an increase in the number of occupants tends to increase consumption, these occupancy changes clearly do not explain why, as a group, the high savers saved more than the low savers.

Indoor temperatures before weatherization were similar for the high savers (72.2 °F) and low savers (71.8 °F). Indoor temperatures were also similar after weatherization (70.9 °F for the high savers and 71.7 °F for the low savers). The apparent trend toward decreased temperatures indicated by these numbers is underscored by the frequency of decreases relative to increases. Based on the survey data, 41% of the high savers and 38% of the low savers decreased their indoor temperatures after weatherization, and only 4% of the high savers and 5% of the low savers increased their indoor temperatures after weatherization. None of these differences are statistically significant.

There was a small but insignificant increase in the number of rooms heated before versus after weatherization for both the high savers (6.0 rooms before and 6.5 rooms after weatherization) and the low savers (5.8 rooms before and 6.4 rooms after weatherization). Five percent of the high savers and 6% of the low savers heated more rooms after weatherization, and only 1% of the high savers and 1% of the low savers heated fewer rooms after weatherization. None of these differences are statistically significant.

Table 4.5 Energy-Related Behavioral Changes Associated With High- vs. Low-Saving Dwellings[a]

Behavioral Change	Percent of High Savers	Percent of Low Savers
More occupants before weatherization[1]	22%	25%
More occupants after weatherization[2]	7%	5%
Indoor temperature during winter decreased after weatherization[1]	41%	38%
Indoor temperature during winter increased after weatherization[2]	4%	5%
More rooms heated during winter before weatherization[1]	1%	1%
More rooms heated during winter after weatherization[2]	5%	6%
Utility disconnection before weatherization[1]	2%	0%
Utility disconnection after weatherization[2]	3%	7%
Used more supplemental heating fuel after weatherization[1]	3%	3%
Used less supplemental heating fuel after weatherization[2]	16%	6%
One or more behavioral factors associated with high savings	51%	46%
One or more behavioral factors associated with low savings	17%	16%

1 Behavioral factor associated with high savings.
2 Behavioral factor associated with low savings.
a None of these differences between high and low savers is statistically significant at the 0.05 level.

Utility disconnections were a relatively infrequent occurrence for both the high and low savers. Although the low savers appear to have experienced an increase in utility disconnections from 0% before weatherization to 7% afterwards, this increase is not statistically significant due, in part, to the small sample size. The rate for high savers was 2% before weatherization and 3% afterwards. These are not significantly different from either the pre- or post-weatherization rates for the low savers.

Changes in the use of supplemental heating fuels do not explain why some households save a great deal of energy and others do not save any. Less use of supplemental heating fuel after weatherization should lead to lower savings of the main heating fuel, because more of the household's heating needs are now met by the main fuel. Thus, this action should be more characteristic of low savers. In fact, the opposite is true. Among the high savers, 16% used less supplemental heating fuel after weatherization than before, while the same is true of only 6% of the low savers. To the extent that high saving might be a greater motivation to move away from supplemental fuels, this finding is not surprising.

Another way to analyze behavioral factors is to consider them in aggregate, rather than focusing on them individually as was done above. Various indexes of behavioral changes were created to test the hypothesis that, taken together, the five pairs of changes shown in Table 4.5 could explain a significant number of the high and low savings.[1] None of these indexes offered significant explanation.

As a final check on the role of behavioral changes, each of the records for the 250 dwellings in the regional high/low sample was reviewed. The purpose was to identify any additional behavioral changes that were noted by the occupants or on-site inspectors as a key to understanding the occupant's pattern of energy consumption. For a small number of the these dwellings, the on-site inspectors indicated that actions taken by occupants were a major determinant of unusually high or low savings. Some examples are discussed below:

- A number of clients installed new furnaces during the year following weatherization. Since the agency was not responsible for these improvements, they were not recorded by the agency as installed weatherization measures and thus were not part of the analysis of furnace replacements. In most of the cases, the on-site inspectors conjectured that the new furnaces significantly reduced gas consumption because the previous gas furnaces were highly inefficient. In other cases, however, the new furnaces caused greater gas consumption because the old system was rarely used or because the previous reliance on supplemental fuels was substantially reduced.

- Changes in other equipment were noted that could have major impacts on energy use. For instance, one client added a new gas dryer, thereby adding to the base load. Another replaced a water heater; unlike the old one that was wrapped with insulation by the weatherization agency, the new water heater had no insulation wrap and was set on the highest temperature (resulting in 148-degrees Fahrenheit water). Both of these additions occurred after weatherization and may have contributed to the dwellings being low savers.

- Changes of occupancy during either the pre- or post-weatherization year were noted in some cases to be a primary determinant of altered consumption patterns, including periods of low usage while dwellings were vacant. These changes are not necessarily associated with changes in the number of occupants, a behavioral change that was analyzed above. The net impact of household turnover on energy savings, however, could be positive or negative, depending on the circumstances.

In summary, none of the five pairs of behavioral measures shown in Table 4.5 was found to be consistently associated with high or low savings. In addition, no aggregate index of individual behaviors could be created that offered any overall explanation of high or low savings. In a small number of the 250 cases examined, on-site inspectors indicated that actions taken by occupants were the dominant determinant of the unusually high or low level of savings. Unfortunately, these behaviors cover a wide range of circumstances, no one of which can be described as typical.

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[1] One index involved a value of "1" if one or more of the behavioral changes associated with high savings occurred, and a value of "0" otherwise. A similar index of "1" and "0" values was created to account for the occurrence of one or more behavioral changes associated with low savings. Another index was the difference between the number of factors associated with high savings and the number associated with low savings.

4.1.3 Weatherization Costs and Measures Installed

In general, the amount of investment in weatherizing a home is closely related to the magnitude of energy savings. This relationship is illustrated first by examining a cross-section of weatherized dwellings and then by comparing high- vs. low-saving dwellings.

Cross-Sectional Analysis

The first phase of the Single-Family Study provides insight into the strength and nature of the relationship between level of investment and energy savings. Data on energy savings and total direct costs (i.e., labor and materials costs, excluding administrative and overhead costs) are available for 1,850 gas-heated dwellings weatherized in PY 1989 (Table 4.6). A simple regression analysis of these data for individual homes documents a significant relationship between costs and savings, in which savings increase by 11 ccf/year for every $100 increase in direct costs (Table 4.7)[2]. The scatter diagram of these 1,850 observations shows that energy savings vary a great deal across dwellings that received comparable levels of investment.[3]

To provide a visual illustration of the relationship between investment and savings, the 1,850 observations were grouped into strata of direct costs spanning $100 ranges (See Table 4.6). The mean gas savings for categories of costs that include at least ten dwellings are shown in Table 4.6 and are the basis of the regression analysis of grouped data shown in Table 4.7. The scatter diagram of this grouped data (Fig. 4.1) 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.

Analysis of High- and Low-Saving Dwellings

The national sample of high-saving dwellings benefited from a significantly larger investment in weatherization than the sample of low-saving dwellings (Fig. 4.2). The cost of weatherization materials for high savers averaged $602 and the cost of labor averaged $590, while the cost of weatherization materials for low savers averaged only $427 and the cost of labor averaged $287. The average cost of materials and labor for all dwellings weatherized in 1989 were $594 and $456, respectively. Thus, the high savers benefited from total direct costs of $1,192 that were slightly (14%) higher than the national average of $1,050, while the low savers received only $714 (or 68%) of the average national investment.

[2] The regression line was forced to pass through the origin, since energy savings are expected to be zero when no materials or labor are invested in weatherizing a dwelling.

[3] This "scatter" is documented also by the low R-squared (0.02), which suggests that only two percent of the variation in energy savings can be explained by level of investment.

In addition to the difference in overall level of weatherization investment, the high and low savers received a different mix of investments (Table 4.8). In particular, high savers received $134 more in materials for insulation, $28 more in air leakage materials, $11 more in water-heating measures, and $9 more in space-heating system materials. Compared to all single-family and small multifamily dwellings weatherized in 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.

Consistent with their higher levels of investment, installation rates for most weatherization measures were higher in high-saving dwellings than in low-saving dwellings (Fig. 4.3). In particular, 86% of the high savers received some type of insulation, while the same is true for only 57% of the low

Table 4.6 Data for Regression Analysis of Gas Savings Using Grouped Data

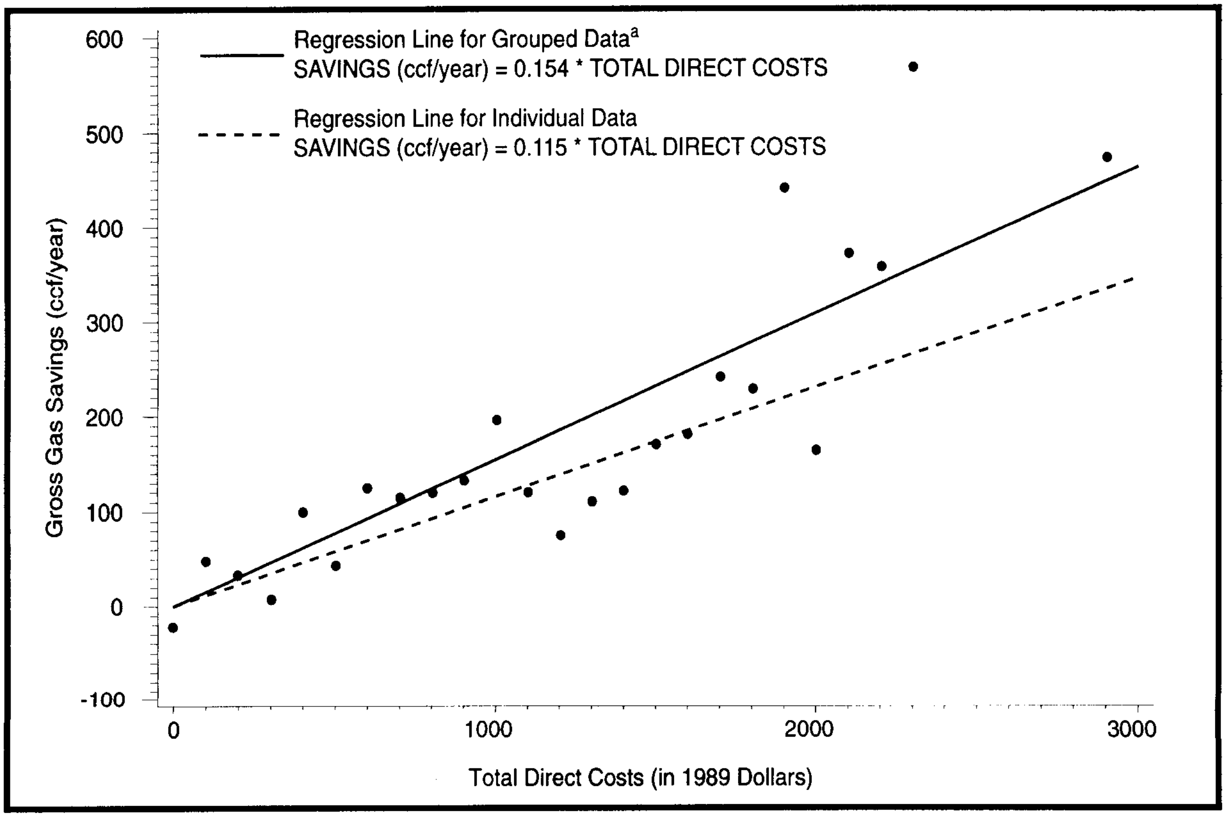
Total Direct Costs[a]	Mean Gas Savings	Number of Dwellings
$0-$50	-21.4	15
$51-$150	48.4	35
$151-$250	33.7	76
$251-$350	7.9	93
$351-$450	100.2	94
$451-$550	43.5	107
$551-$650	124.9	129
$651-$750	114.8	133
$751-$850	120.0	129
$851-$950	132.8	166
$951-$1,050	196.4	131
$1,051-$1,150	120.4	124
$1,151-$1,250	75.4	125
$1,251-$1,350	110.7	119
$1,351-$1,450	121.8	50
$1,451-$1,550	170.9	68
$1,551-$1,650	181.3	38
$1,651-$1,750	241.1	44
$1,751-$1,850	228.6	27
$1,851-$1,950	440.7	19
$1,951-$2,050	164.0	18
$2,051-$2,150	371.3	16
$2,151-$2,250	357.2	14
$2,251-$2,350	568.3	11
$2,351-$2,450	350.2	10
$2,851-$2,950	472.8	11

[a] Ranges of direct costs were excluded from this table and the regression analysis if data were not available for at least 10 dwellings.

Table 4.7 Results of Regression Analysis of Gas Savings

	Regression Analysis of Grouped Data	Regression Analysis of Individual Data
Intercept	0	0
Unstandardized Coefficient	0.154***	0.115***
T-statistic	14.38	15.59
R^2	0.89***	0.02***
Number of Observations	25	1,850

*** Significant at the .001 level.



[a] The points plotted in this figure are grouped data that illustrate the gas saved by $100 intervals of total direct costs.

Fig 4.1 Relationship of Amount Invested in Weatherization Measures to Energy Savings

savers. (The average installation rate nationwide is 62%). The installation rates for attic, wall, and rim or band joist insulation are markedly higher for the high savers. The installation rates for floor insulation differ only slightly between the high and low savers.

After insulation, water-heater measures have the most distinct installation rates. Although the installation rates for this category of measure do not differ significantly between high and low savers (82% versus 71%), two of the individual measures have distinct rates. In particular, more than half (59%) of the high savers received a water-heater tank wrap, while the same is true for only 35% of the low savers. Similarly, water-temperature reductions were made to 25% of the high-saving dwellings, but only 12% of the low-saving homes.

Air leakage control measures were undertaken in virtually every one of the high- and low-saving dwellings (96% versus 99%). However, the high savers received more air sealing (62% versus 44%), a difference that is significant at the 0.01 level. High savers received less general caulking and weatherstripping (85% versus 91%), but this difference is not statistically different.

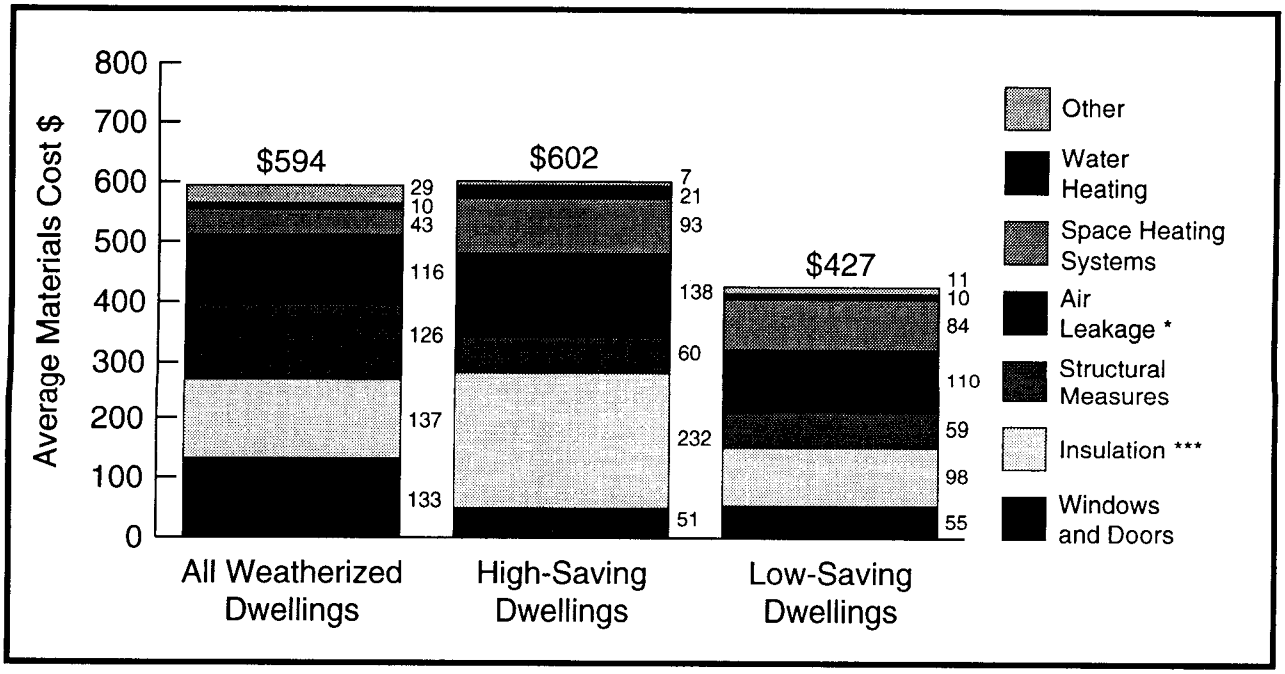


Fig. 4.2 Average Materials Costs (in 1989 dollars): All Weatherized Dwellings vs. High- and Low-Saving Dwellings

Table 4.8 Comparisons of Percentage of Materials Dollars Spent by Measure Type in High- vs. Low-Saving Dwellings

Percent of Total Materials Cost Spent On:	High-Saving Dwellings	Low-Saving Dwellings
Air Leakage***	30	26
Insulation***	38	27
Heating Systems***	16	3
Structural Repairs***	7	25
Water Heating***	5	3
Windows and Doors***	4	15

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Space-heating replacements occurred at almost twice the frequency among the high savers, but the rates are too low (7% versus 4%) to be statistically different. In contrast, installation rates for two other space-heating measures (component retrofits and clean and tune-ups) were quite similar across the two groups.

High and low savers received almost identical rates of installation of storm windows and doors (consistent with their comparable dollar expenditures on windows and doors). Compared with a national average of 36%, only 24% of the high savers and 22% of the low savers received storm windows. The low level of investment in storm windows and doors among the low savers is consistent with their overall low level of weatherization. The low level of investment among the high savers is in spite of their high levels of overall weatherization. Despite their low investment level in storm windows and doors, the high savers had a larger percentage of their total window area covered with storm windows (70%), than the low savers (53%). This is probably due to the concentration of high savers in the colder regions where storm windows are more prevalent.

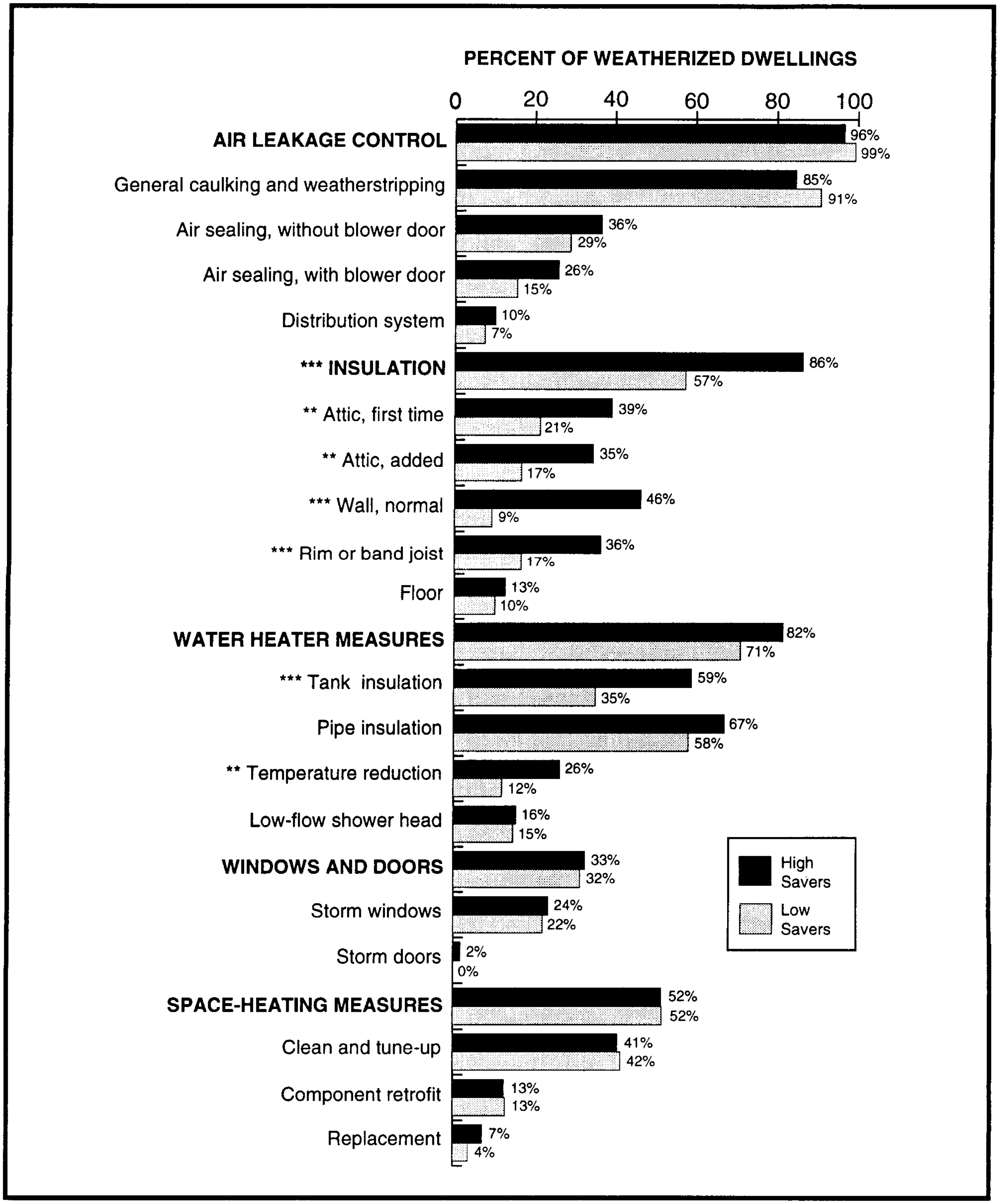
Overall, these findings reinforce the conclusions of the first phase of the Single-Family Study, that attic and wall insulation, water-heater measures, and furnace replacements are the measures that are associated with high levels of savings.

A greater percentage of the high-saving dwellings received structural and health and safety measures (Fig. 4.4). Among the structural measures, the biggest differences were with window and glazing repairs, door repairs, and attic ventilation. Compared with the low savers, agencies weatherizing high savers rely more on repairing windows and doors (a relatively low-cost measure) than replacing them (a high-cost activity). This may account for the fact that high and low savers benefitted from comparable levels of expenditure on structural measures, even though more high savers received structural measures.

The higher frequency of attic ventilation is related to the greater frequency with which attic insulation is installed in the high-saving dwellings. Although the two groups of homes experience comparable installation rates for most space-heating measures (the exception being system replacements), the high savers received almost twice as many carbon monoxide tests as the low savers. This distinction indicates that the high savers benefited from a more thorough weatherization job, including the assessment of health and safety problems.

4.1.4 Energy-Efficiency Characteristics of Weatherized Dwellings

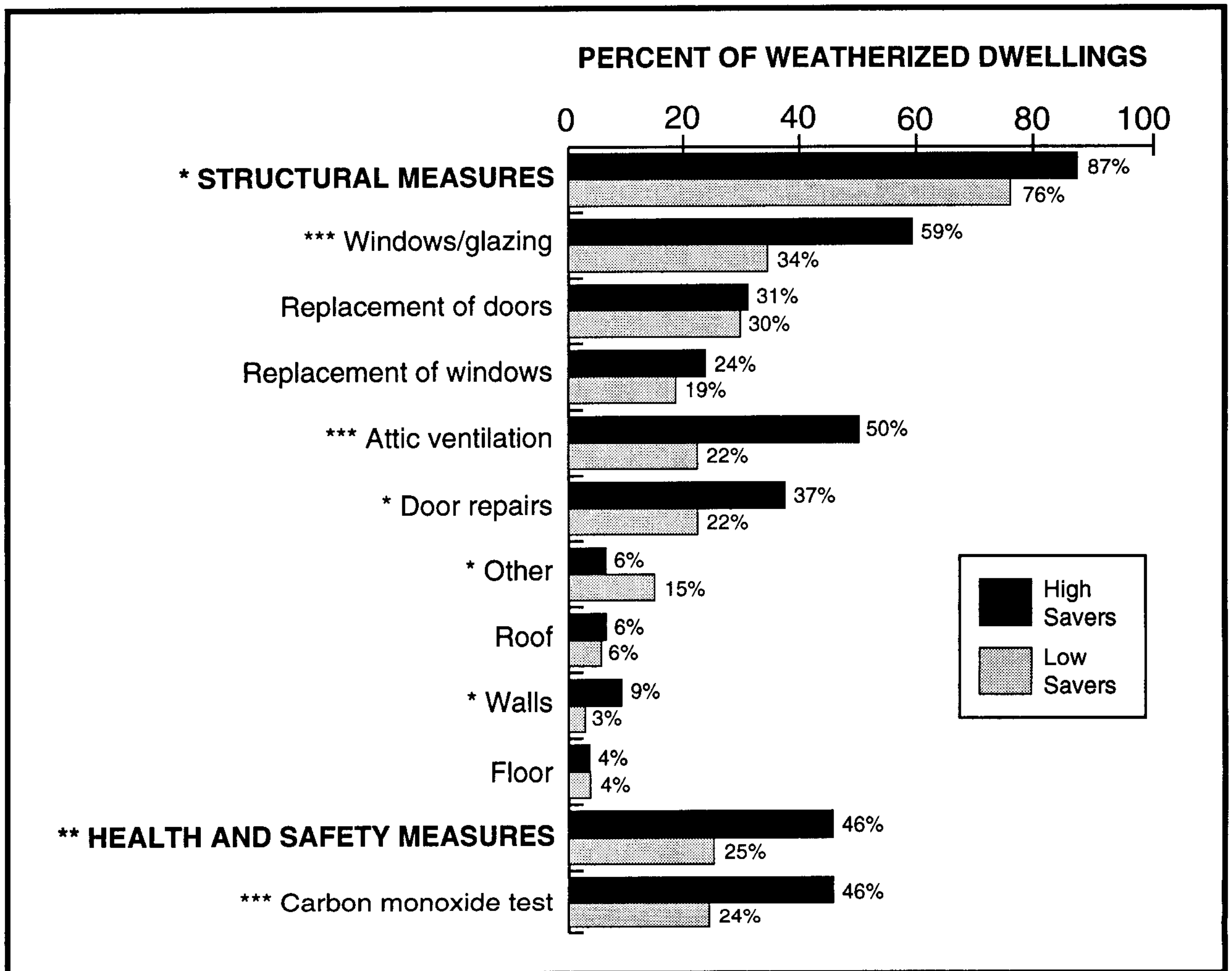
After weatherization, the high savers had significantly more attic insulation than the low savers, both in terms of thickness (Fig. 4.5) and R-value. Specifically, the attic insulation in high-saving dwellings was almost one inch thicker than the attic insulation in low-saving dwellings, and the attic insulation R-value in high savers (R-27) was significantly higher at the 0.05 level than the R-value of the attic insulation in low savers (R-24). Similarly, the floor insulation in high-saving dwellings was almost



*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Fig. 4.3 Percentages of High- and Low-Saving Dwellings Receiving Various Types of Measures

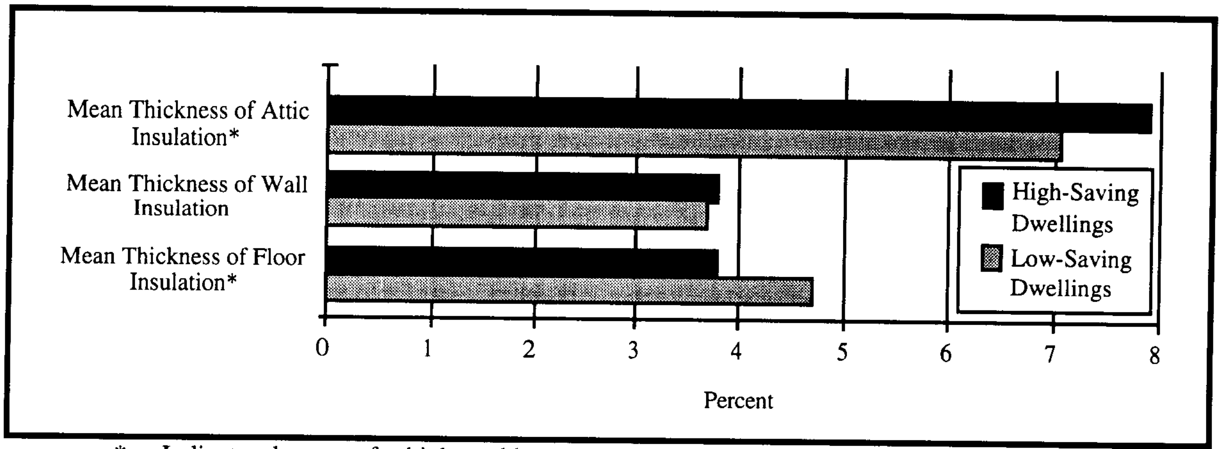
one inch thicker than the floor insulation in low-saving dwellings. Thus, not only do the high-saving dwellings receive insulation more frequently, but the thickness of the insulation they receive tends to be greater.



*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Fig. 4.4 Percentages of High- and Low-Saving Dwellings Receiving Various Structural and Health and Safety Measures

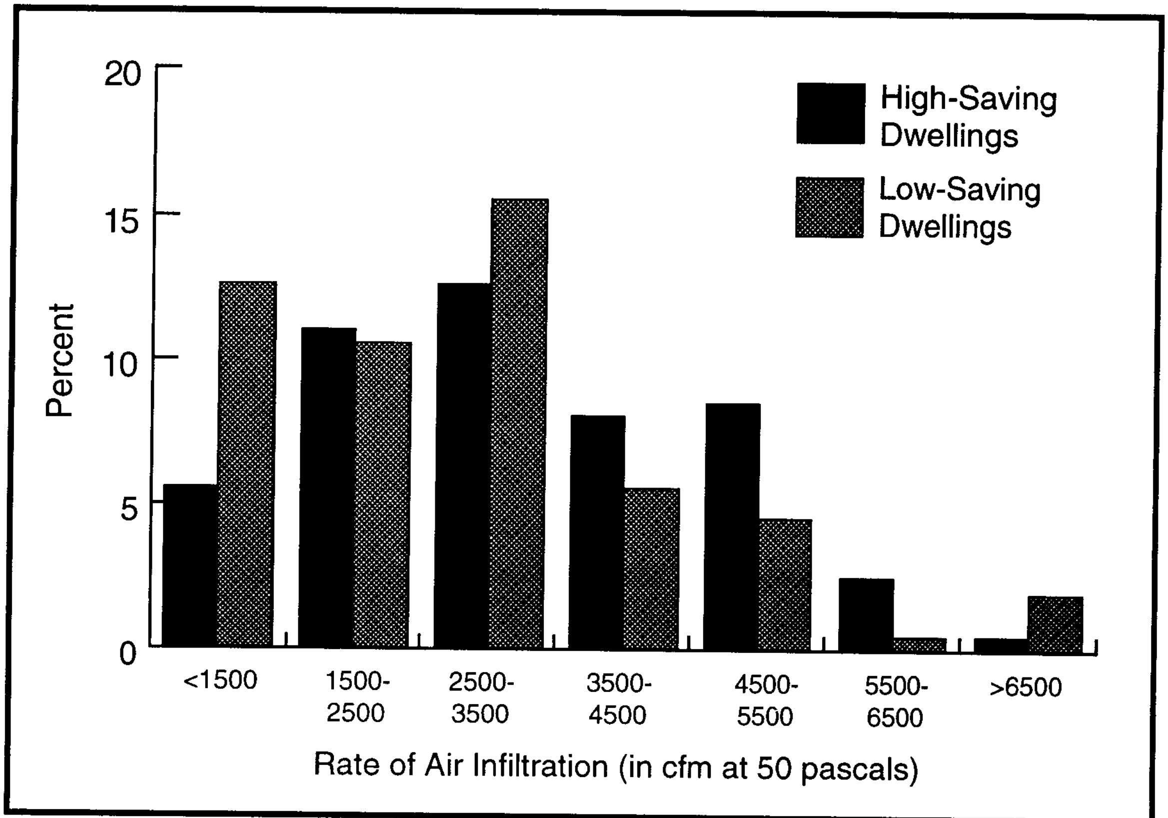
After weatherization, the high-saving dwellings were significantly leakier than the low-saving dwellings, with air infiltration rates of 3,291 vs 2,775 cfm_{50}. The tightest category of air leakage (1,500 cfm_{50} or less) characterizes 13% of the low savers and only 6% of the high savers (Fig. 4.6). These results suggest that the high-saving dwellings were considerably leakier before weatherization than the low-saving dwellings, and that weatherization narrowed this gap, but did not eliminate it entirely. This hypothesis is consistent with the high savers' higher levels of pre-weatherization gas consumption per square foot and heating degree day. It also reinforces the point that more opportunities for air leakage reduction remain, even among the high savers.



* Indicates the mean for high- and low-saving dwellings are significantly different at 0.05.

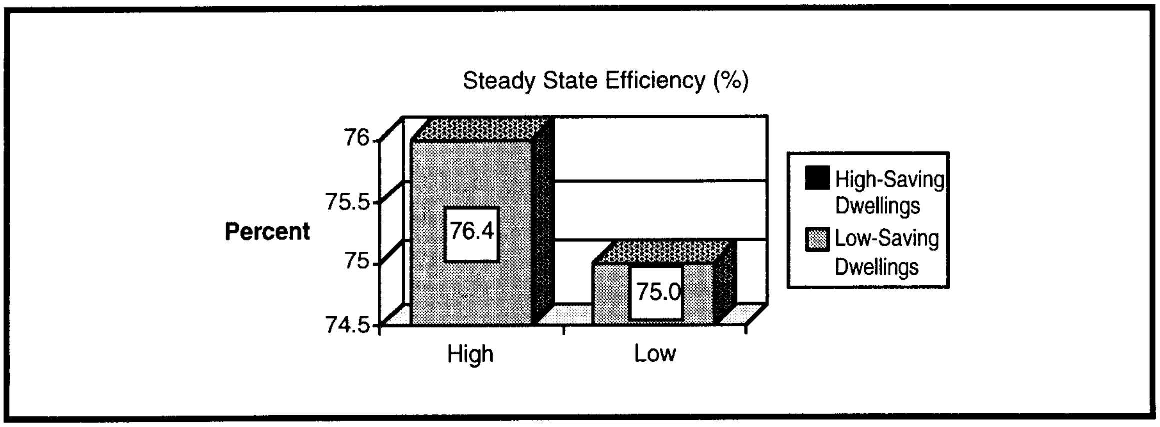
Fig. 4.5 Mean Thickness of Various Types of Insulation in High- and Low-Saving Dwellings

The steady-state efficiency tests showed that the high-saving dwellings had slightly more efficient heating systems than the low savers, but the differences were not statistically significant (Fig. 4.7). Recall that only 7% of the high savers received new furnaces, compared to 4% of the low savers. It is not surprising that such a small difference had little impact on the sample averages.



* The distributions for low- and high-saving dwellings are significantly different at the 0.05 level.

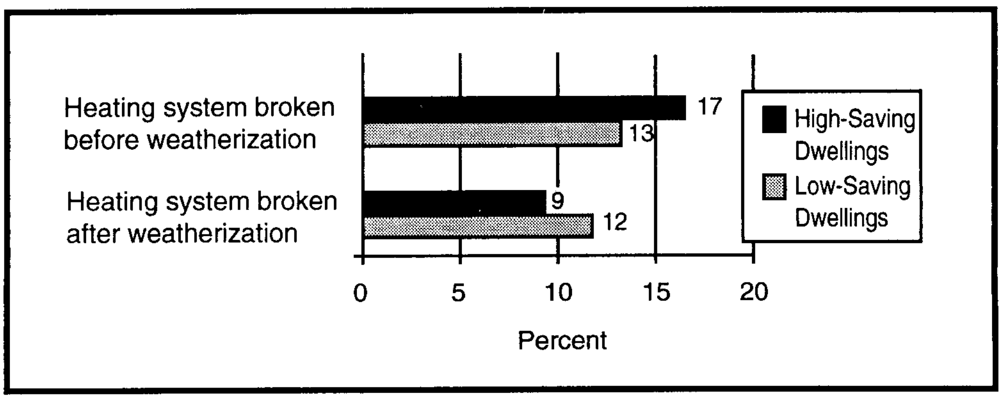
Fig. 4.6 Distribution of Blower Door Test Air Flow Rates for High- and Low-Saving Dwellings



The difference between high and low savers is not statistically significant at the 0.05 level.

Fig. 4.7 Steady-State Efficiency of Primary Heating System for High- and Low-Saving Dwellings

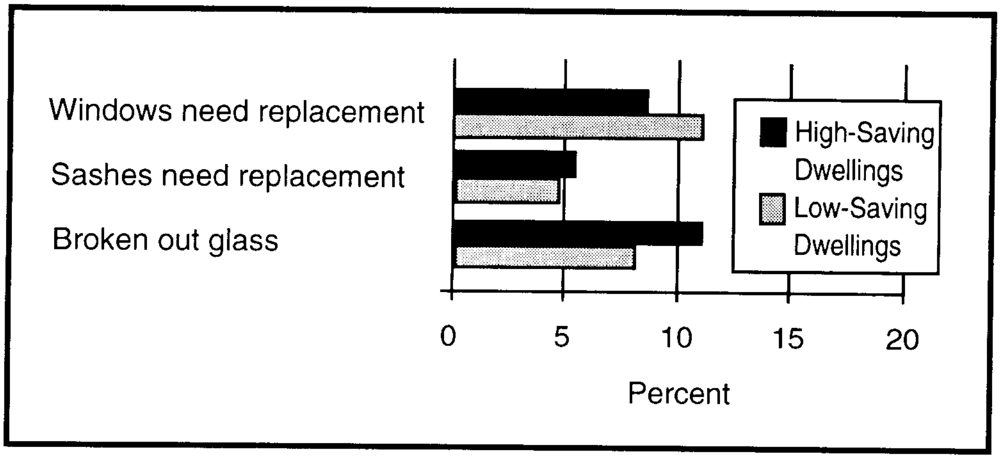
High and low savers did not differ significantly in the frequency with which their heating systems failed: before weatherization failures occurred in 13% to 17% of the homes and after weatherization they occurred in 9% to 12% of the homes. However, the high savers had an 8% decrease in the frequency of broken heating systems before versus after weatherization, while the low savers experienced only a 1% decrease (Fig. 4.8).



Neither of these differences between high and low savers is statistically significant at the 0.05 level.

Fig. 4.8 Frequency of Broken Heating Systems in High- and Low-Saving Dwellings

There were no significant differences between high- and low-saving dwellings in the incidence of safety hazards at the time that the on-site inspections occurred two to three years after weatherization. The rates of window-related problems are shown in Fig. 4.9, but none of these differences are significant.



None of these differences between high and low savers is statistically significant at the 0.05 level.

Fig. 4.9 Incidence of Structural Problems in High-and Low-Saving Dwellings

4.1.5 Summary of Results of National Sample of High and Low Savers

The national analysis of high and low savers identified a number of factors that distinguish high- from low-saving dwellings. In particular, high savers tend to be older and larger dwellings that consume more energy prior to weatherization, they benefit from a greater investment in weatherization, and they receive more attic, wall, and rim or band joist insulation, more water-heater tank insulation and water temperature reductions, more air sealing, and more furnace replacements. No single behavioral measure consistently predicted high or low savings Considered in aggregate, the behavioral measures also were unable to explain variations in energy savings.

4.2 THE REGIONAL SAMPLES OF HIGH AND LOW SAVERS

The primary purpose of this regional analysis is to examine the ability of the factors identified in Section 4.1 to explain high and low savings within each of the three climate regions. A secondary purpose is to identify the role of factors associated with savings by examining the complete files for a small number of individual dwellings.

Three regional samples of high- and low-saving dwellings were defined by ranking the weatherized dwellings in each region according to their energy savings and selecting the 25 dwellings with the highest savings and the 25 dwellings with the lowest savings from each region. These regional samples help to identify region-specific factors associated with high versus low energy savings. A comparison of Tables 4.1 and 4.9 shows that the high savers in the regional samples have higher savings than the high savers in the national sample, and the low savers have lower savings. This difference is a result of the fact that the regional samples are smaller than the national sample and therefore represent more extreme cases of high and low savings.

Table 4.9 Distribution of Regional Samples of High- and Low-Saving Dwellings

	High-Saving Dwellings		Low-Saving Dwellings	
	Number (and %) of Dwellings	Average Gross Gas Savings (ccf/year)	Number (and %) of Dwellings	Average Gross Gas Savings (ccf/year)
Cold (N=50)	25 (33.3%)	617	25 (33.3%)	-72
Moderate (N=50)	25 (33.3%)	944	25 (33.3%)	-367
Hot (N=50)	25 (33.3%)	245	25 (33.3%)	-111
Total (N=150)	75 (100%)	602	75 (100%)	-183

The region-by-region analysis was initiated by establishing definitions of those factors expected to be associated with high and low savings. The factors selected were those that the national analysis had identified as correlates of savings. Two types of variables were defined: 1) continuous variables (including the size and age of the dwelling, its pre-weatherization consumption and the amount invested); and 2) dichotomous variables (which indicate whether or not various weatherization measures were installed).

The continuous variables differ significantly across the climate regions. For instance, the cold climate region has the oldest and largest homes; the moderate climate region has the highest pre-weatherization gas consumption and the highest level of weatherization investment; and the hot region has the smallest and newest homes, which consume the least gas before weatherization, and receive the lowest level of weatherization investment. Because of this variability, region-specific definitions of factors associated with high and low savings were created (Table 4.10). This was accomplished for the four continuous variables by calculating each climate region's mean values and standard deviations and then creating "tails" by adding or subtracting the standard deviation from the mean value. The results are shown in Table 4.10.

For the dwelling characteristics and weatherization measures expected to correlate with high savings, percentages were calculated and compared for the high-and low-saving dwellings within each region (Tables 4.11, 4.12 and 4.13). To the extent that higher percentages of high-saving dwellings receive a measure, or have a characteristic, its importance for achieving high savings within the region is demonstrated. Based on the results of the first phase of the Single-Family Study, it is expected that the correspondence between these variables and high savings will be weakest in the hot climate region.

Table 4.10 Region-Specific Definitions of Conditions Associated With High and Low Savings

	Mean Value	Standard Deviation	Tail Associated With Low Savings	Tail Associated With High Savings
Cold Climate Region				
Pre-weatherization gas consumption (ccf/year)	1,325	580	≤ 745	≥ 1,905
Age of dwelling (years)	49	26	≤ 23	≥ 75
Size of dwelling (square feet)	1,210	601	≤ 609	≥ 1,810
Total direct weatherization costs ($-1989)	$995	$773	≤ $222	≥ $1,769
Moderate Climate Region				
Pre-weatherization gas consumption (ccf/year)	1,536	820	≤ 717	≥ 2,356
Age of dwelling (years)	35	30	≤ 5	≥ 66
Size of dwelling (square feet)	1,186	602	≤ 584	≥ 1,788
Total direct weatherization costs ($-1989)	$1,076	$693	≤ $383	≥ $1,769
Hot Climate Region				
Pre-weatherization gas consumption (ccf/year)	735	397	≤ 339	≥ 1,132
Age of dwelling (years)	36	14	≤ 22	≥ 50
Size of dwelling (square feet)	1,041	338	≤ 703	≥ 1,380
Total direct weatherization costs ($-1989)	$891	$459	≤ $432	≥ $1,350

4.2.1 Cold Climate Region

The results of the analysis of high and low savers in the cold climate region are summarized in Table 4.11. The four dwelling and cost characteristics (consumption level, age and size of dwelling, and total costs) clearly distinguish between high and low savers in this region. Perhaps the weakest of these four predictors is age of dwelling; nevertheless, 40% of the high savers are among the oldest homes (while the same is true for only 12% of the low savers), and 20% of the low savers are among the newest homes (while the same is true only for 4% of the high savers).

Most of the weatherization measures that distinguish high from low savers at the national level also distinguish high from low savers in the cold region. The differences between rates of furnace replacement, wall insulation, and rim or band joist insulation are particularly pronounced. The exceptions to the national findings are limited to the two water-heater measures. There is little difference between the high and low savers in the installation rates for tank insulation and water-temperature reductions.

Table 4.11 Frequency of Factors Associated With High- vs. Low-Saving Dwellings in the Cold Climate Region

	High-Saving Dwellings		Low-Saving Dwellings	
Dwelling & Cost Characteristics	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean
Pre-weatherization gas consumption (ccf/year)	32	0	0	36
Age of dwelling (years)	40	4	12	20
Size of dwelling (square feet)	12	0	0	8
Total direct weatherization costs ($-1989)	40	0	4	28
Weatherization Measures	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure
Attic insulation, first-time	40	60	12	88
Attic insulation, added	24	76	36	64
Wall insulation	60	40	28	76
Rim or band joist insulation	44	56	16	84
Water-heater tank insulation	44	56	52	48
Water-temperature reduction	4	96	8	92
Air sealing	60	40	56	44
Furnace replacement	20	80	4	96

4.2.2 Moderate Climate Region

The results of the analysis of high and low savers in the moderate climate region are summarized in Table 4.12. As in the cold region, the four dwelling and cost characteristics (consumption level, age and size of dwelling, and total costs) clearly distinguish between high and low savers in the moderate region, and the weakest of these four predictors—age of dwelling—is still significant. Forty-eight percent of the high savers are among the oldest homes (while the same is true for only 28% of the low savers), and 20% of the low savers are among the newest homes (while the same is true for 0% of the high savers).

Most of the weatherization measures that distinguish high from low savers at the national level also distinguish high from low savers in the moderate region. The differences between rates of attic and wall insulation, the two water-heater measures, and air sealing are particularly pronounced. The more frequent installation of new furnaces among high-saving dwellings that was found in the national sample and the cold region is not reflected in the moderate region; this is partly because furnaces are replaced much less frequently overall in the moderate than the cold region.

Table 4.12 Frequency of Factors Associated With High- vs. Low-Saving Dwellings in the Moderate Climate Region

	High-Saving Dwellings		Low-Saving Dwellings	
Dwelling & Cost Characteristics	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean
Pre-weatherization gas consumption (ccf/year)	40	0	0	8
Age of dwelling (years)	48	0	28	44
Size of dwelling (square feet)	20	4	4	20
Total direct weatherization costs ($-1989)	16	8	4	44
Weatherization Measures	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure
Attic insulation, first-time	32	68	24	76
Attic insulation, added	48	52	13	87
Wall insulation	63	37	16	84
Rim or band joist insulation	24	76	21	79
Water-heater tank insulation	80	20	54	46
Water-temperature reduction	48	52	21	79
Air sealing	64	36	46	54
Furnace replacement	4	96	4	96

4.2.3 Hot Climate Region

The results for the hot region show the least similarity to the national analysis of high and low savers, although many consistencies exist. Among the similarities is the fact that the four dwelling and cost characteristics exhibit the same patterns; they're just not as strong. In particular, there are almost as many dwellings that received high levels of investment among the high savers (40%) as the low savers (36%), indicating that weatherization costs are not as strong a determinant of energy savings in this region as elsewhere. In addition, the difference between the savings of high- versus low-savers in the hot climate region is only 356 ccf/year, while the differences in the moderate (1,311 ccf/year) and cold regions (689 ccf/year) are much greater (Table 4.9).

Only two of the weatherization measures that discriminated between high and low savers at the national level also distinguish high from low savers in the hot region. Specifically, rates of attic insulation and air sealing are substantially greater among high savers relative to low savers. All of the other measures, on the other hand, are installed in at least as many low savers as high savers. As is apparent from Table 4.13, the installation rates for these other measures are considerably lower in the hot region than in the other two regions, which may contribute to the minimal differences between the two groups.

Table 4.13 Frequency of Factors Associated With High- vs. Low-Saving Dwellings in the Hot Climate Region

	High-Saving Dwellings		Low-Saving Dwellings	
Dwelling & Cost Characteristics	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Above Mean	% Of Dwellings With Value ≥ 1 Standard Deviation Below Mean
Pre-weatherization gas consumption (ccf/year)	32	0	12	28
Age of dwelling (years)	40	4	12	32
Size of dwelling (square feet)	12	0	12	24
Total direct weatherization costs ($-1989)	40	0	36	32
Weatherization Measures	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure	% Of Dwellings That Received Measure	% Of Dwellings That Did Not Receive Measure
Attic insulation, first-time	40	60	12	88
Attic insulation, added	16	84	12	88
Wall insulation	0	100	0	100
Rim or band joist insulation	0	100	0	100
Water-heater tank insulation	20	80	20	80
Water-temperature reduction	4	96	4	96
Air sealing	64	36	40	60
Furnace replacement	0	100	8	92

4.2.4 Conclusions

The region-by-region analysis underscores the association of extremely high savings with high pre-weatherization energy consumption, old and large dwellings, and high weatherization expenditures.

Equally strong is the association between extremely low savings and low pre-weatherization energy consumption, new and small dwellings, and low weatherization expenditures.

Only one of the weatherization measures that distinguishes high from low savers at the national level also distinguishes high from low savers in the each of the climate regions, and that is attic insulation. In the cold and moderate regions where there is sufficient wall insulation being installed to analyze its impact, this measure also tends to separate high from low savers. Rim and band joist insulation and the two water-heater measures are associated with high savings in the moderate region, air sealing is associated with high savings in the moderate and hot regions, and furnace replacements are associated with high savings only in the cold region.

The results for the hot region were most dissimilar from the national findings. The house and cost characteristics of high and low savers in the hot region generally followed the national pattern, but the differences between high and low savers were not as distinct. In addition, installation rates for high- and low-saving dwellings tended to be more alike in this region, the exceptions being attic insulation and air sealing. For the other weatherization measures, the similar rates of installation for high and low savers were partly due to the low regional rates. If more wall insulation, rim and band joist insulation, water-heater measures, and furnace replacements were installed in this region, they might have emerged as common characteristics of high savers.

4.3 PROFILES OF INDIVIDUAL DWELLINGS

The following profiles of four weatherized dwellings illustrate many of the findings of the statistical analysis of high- and low-saving dwellings presented above. Two of these dwellings are low savers, and two are high savers. As a set they reinforce the following findings:

- the importance of pre-weatherization levels of consumption as a determinant of the potential for higher energy savings;
- low-saving dwellings tend to have more energy-conservation measures in place prior to weatherization;
- high-saving dwellings benefit from larger investments in weatherization measures;
- occupants of both high- and low-saving dwellings notice the benefits of weatherization in terms of increased comfort, reduced draftiness, and lower energy costs;
- even in homes where energy savings are substantial, opportunities often remain for further cost-effective energy conservation measures and for important home repairs; and
- weatherization is sometimes accompanied by reduced use of supplemental fuels for home heating.

4.3.1 Limited Opportunities for Energy-Efficiency Investments

This one-story Vermont home with 952 square feet of heated living space offered few opportunities for saving significant amounts of energy (Photo 4.1). Prior to weatherization, all 16 of the home's windows were double paned or had storm windows, and both exterior doors had storms. Its attic had 12 inches of fiberglass batt insulation, and its walls were partially insulated. Reinsulating the sidewalls was impractical because of the rigid corner posts of its aluminum siding. The home was heated primarily by a forced air gas furnace which had a steady-state efficiency of 75% and ductwork that was judged to be tight.

The middle-aged female occupant is energy conscious. She consumed only 740 ccf of natural gas prior to weatherization, which was slightly more than half of the average consumed by weatherized dwellings in the cold region during that same year (Fig. 4.10). Even when factoring in the small size of the heated living space, the energy intensity of home heating fuel use is still low — 9.7 Btus of natural gas per square foot per heating degree day. Despite this low level of gas consumption, the occupant's gas bills required 8% of her income. Therefore, she tried hard to keep her heating bills under control. She kept her thermostat at 62° F during the night and when she was out, and at 68° F when she was at home during the day. She used an electric space heater to supplement her central heating system.

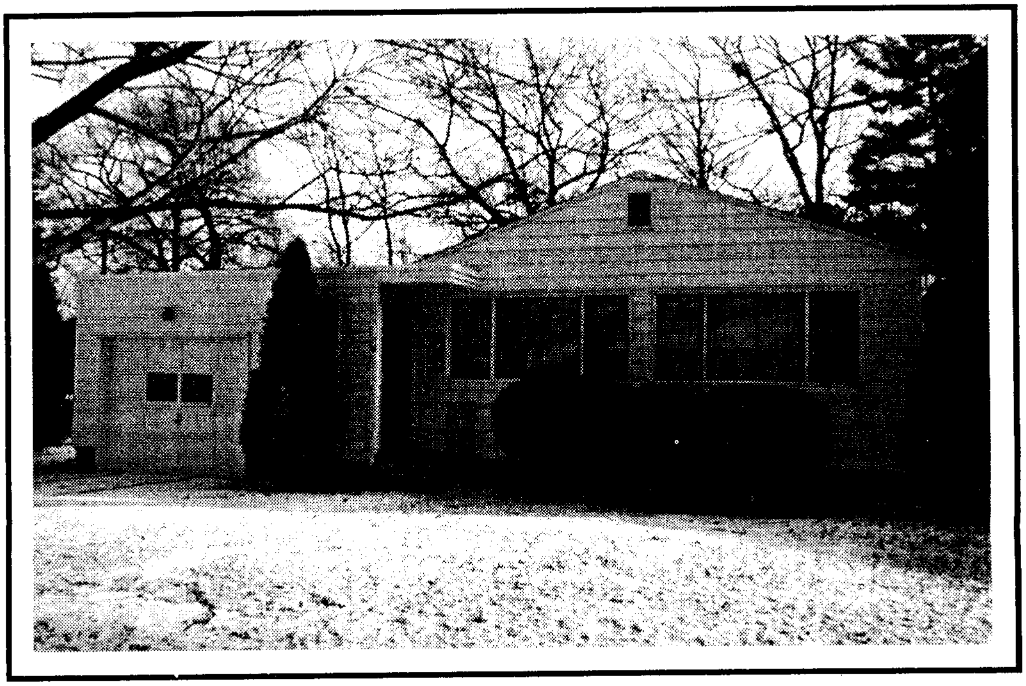


Photo 4.1 A Low-Saving House in Vermont

The weatherization agency spent $410 in materials and $164 in labor to weatherize this house. The job involved caulking and weatherstripping, air sealing with a blower door, and a clean and tune of the heating system. After weatherization, the home's rate of air leakage was measured at 1,530 cfm_{50}. The only additional weatherization action noted by the evaluation's inspectors that might have been cost effective was to seal the leaky seams in a closet located in the "open vestibule" between the living room and garage, which essentially was open to the outside. The inspector conjectured that "A tube and a half of caulk and about five minutes would have shaved 200 cfm_{50} off the total leakage rate."

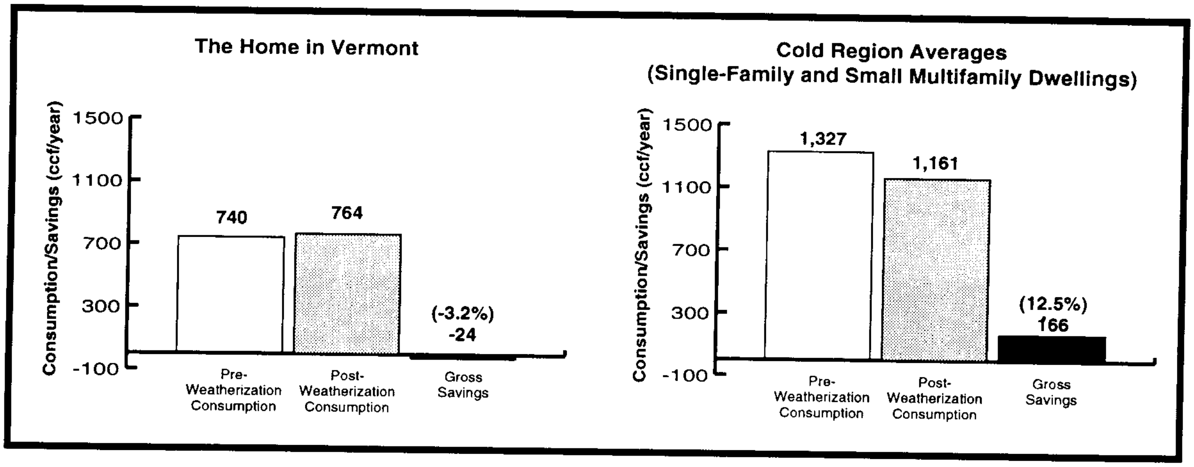


Fig. 4.10 Limited Opportunities for Energy-Efficient Investments

During the year after weatherization, the client used 764 ccf of natural gas, representing an increase of 24 ccf (3%). Two behavioral changes contributed to the low level of savings: (1) the occupant used less electric space heating following weatherization; and (2) she increased her indoor temperatures two degrees to 70° F when she was at home during the day.

4.3.2 Targeting Savings Potential

This 90-year old home in Nebraska has 4,086 square feet of heated living space and 43 windows for its 10 occupants (eight children and two parents) (Photo 4.2). Although the home had 43 storm windows prior to weatherization, and all four of its exterior doors had storms, the home offered numerous opportunities for cost-effective energy-efficiency investments. There were only a few inches of attic insulation, and no floor, wall, collar beam, or kneewall insulation was present. The water heater and its pipes were uninsulated, and the heating system was inefficient. The furnace tested at 62% steady-state efficiency in 1992, which is not unusual for a heating system that is 30 years old.

Before weatherization, the house consumed 4,825 ccf of gas each year, which was more than three times the average consumed by weatherized dwellings in the moderate region during that same year (Fig. 4.10). Because of the large amount of heated living space, the intensity of home heating fuel use is about average at 17.1 Btus per square foot per heating degree day. Annual gas costs averaged $2,500, which represented 13% of the household's total income — a significant energy burden for a household with many demands on its resources. Natural gas fueled the home's forced air furnace, its water heater, and its clothes dryer. Electric space heaters were used for supplemental heating.

Photo 4.2 A High-Saving House in Nebraska

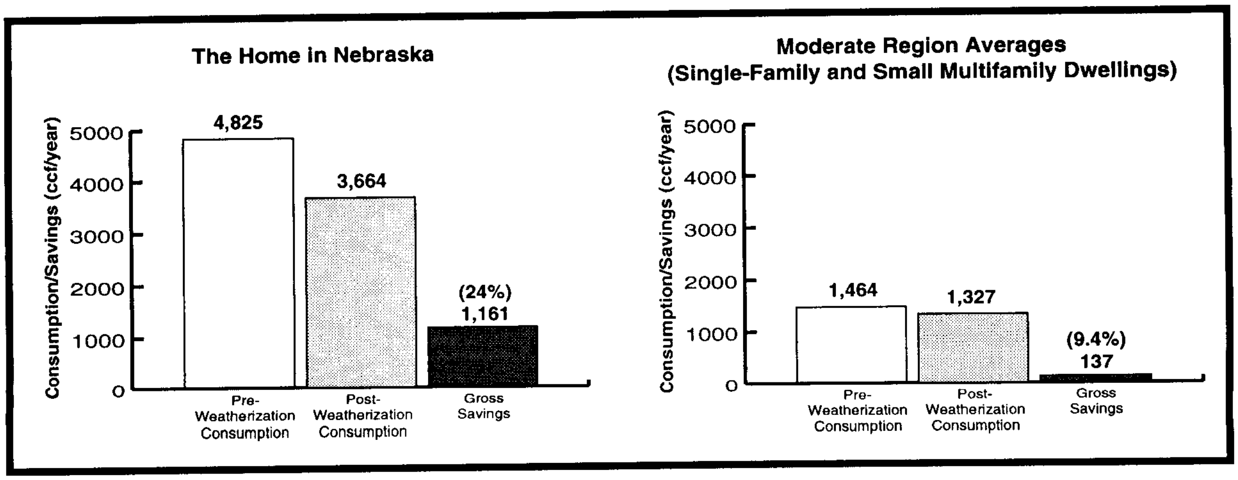


Fig. 4.11 Targeting Savings Potential

The local weatherization agency spent $1,354 in materials and $903 in direct labor (for a total of $2,257) to weatherize this home. Funds came from a variety of sources, including DOE's Weatherization Program, the Petroleum Violation Escrow fund, and the Department of Health and Human Services' Low Income Home Energy Assistance Program. Most of these resources were spent on adding insulation to the attic, sidewalls (both fiberglass batts and blown-in high density cellulose insulation), kneewalls, collar beams, and floor. In addition, the water heater received an insulation blanket and the water pipes were insulated with rigid preformed fiberglass pipe insulation. Air leakages were addressed by caulking and weatherstripping, and the space heating system was cleaned, tuned, and repaired. Finally, a broken door was replaced and several windows were fixed.

These weatherization measures reduced the household's annual gas consumption to 3,664 ccf, resulting in savings of 1,161 ccf, or 24%, of total gas use. During the field work on this house, blower door testing estimated an air infiltration rate of 6,812 cfm_{50}. The volume of the house made it impossible to achieve 50 pascals of pressure with the blower door, so the Minneapolis criteria were used to estimate the infiltration rate at 50 pascals. Although this is a high value, the on-site inspection team did not identify any serious leakage problems and judged the house to be moderately tight. As an indication that air infiltration was reduced during weatherization, the occupants described their home as "very drafty" prior to weatherization and "not at all drafty" afterwards. This reduction in draftiness may have contributed to the occupants' decision to reduce the thermostat setting from 72° F to 68° F during the day, after weatherization. In addition, the residents relied less on their electric space heaters after weatherization.

4.3.3 Weatherizing Substandard Housing in the Hot Climate: A Typical Low-Saving Dwelling

This 14 by 36 foot four-room home in Mississippi is typical of the substandard housing occupied by many low-income households in the Southeast (Photo 4.3). The weatherization agency was faced with a house that needed substantial repair and numerous energy conservation measures. The home had no insulation in its attic, walls, or foundation; its eight wooden window frames were rotten and leaky; its two doors were warped and ill-fitting; there were signs of water damage from a leaky roof; the floor was uneven and spongy; and extension cords were everywhere, including two hung from overhead lights to power the television and refrigerator. The home was heated entirely by a single gas space heater. It also had a gas water heater with a negative sloping flue that would not draft. The home was built around the year 1935 with rolled asphalt siding on its walls and roof.

The middle-aged female homeowner kept her gas bills low by turning her space heater off when she left the house and at night, unless the temperatures were extremely cold. She did not have a thermostat. Even when the space heater was on, the house could not be kept warm on cold days because of the numerous air leakages. The occupant consumed only 464 ccf of natural gas during the year prior to weatherization, which was slightly more than half of the average consumed by weatherized dwellings in the hot region during that same year (Fig. 4.12). When factoring in the small size of the heated living space and few heating degree days (2,783), the intensity of home heating fuel use was high — 33.1 Btus per square foot per heating degree day. The occupant's gas bills required 8.6% of her income.

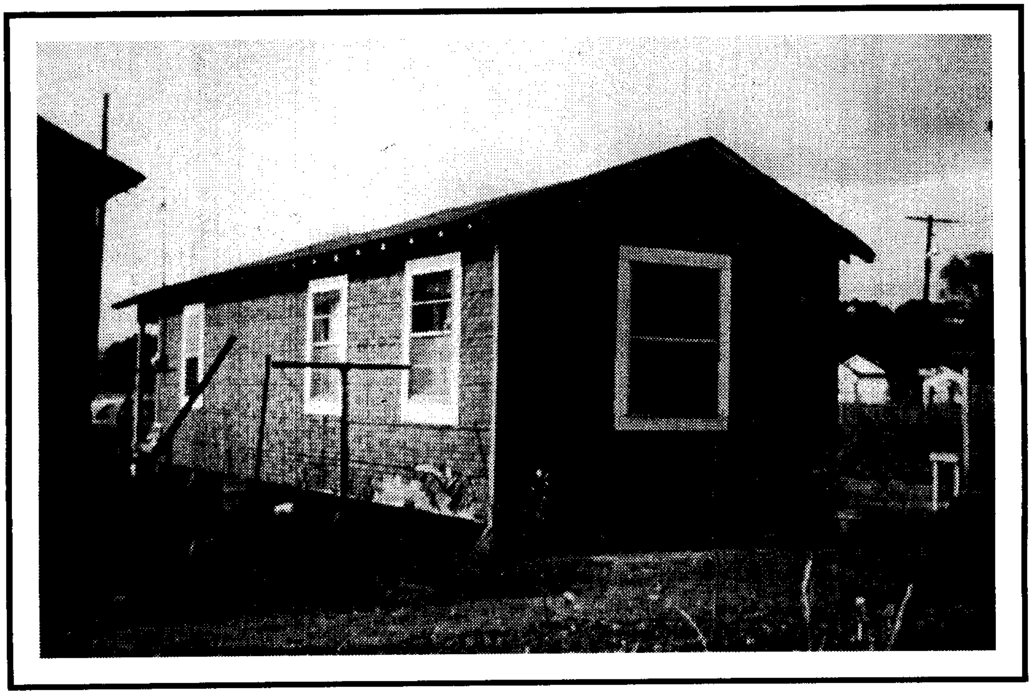


Photo 4.3 A Low-Saving House in Mississippi

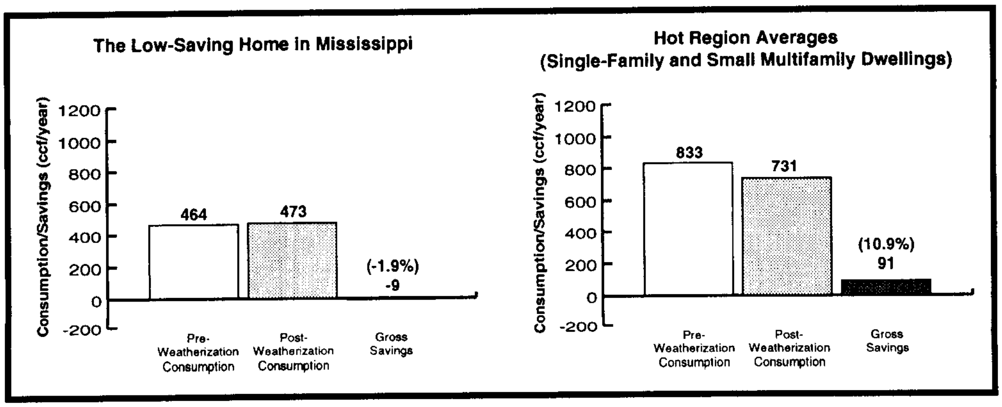


Fig. 4.12 Weatherizing Substandard Housing in the Hot Climate

The weatherization agency spent $498 in materials and $268 in labor to weatherize this house. Based on the state-wide priority list of measures, the weatherization agency's contractors replaced all eight of the home's windows with new, single-pane, aluminum-framed windows; installed two new solid-core wood exterior doors, including a storm door on the front door; and caulked and weatherstripped around these. No insulation was added. After weatherization, the home's rate of air leakage was measured at 3,960 cfm_{50}. The inspectors noted that the house would have benefited from attic insulation. With an exposed floor, due to the open crawlspace below the house, the addition of floor insulation might also have been cost-effective.

During the year after weatherization, the client used 473 ccf of natural gas, representing an increase of 9 ccf (-2% savings). In early December, 1990, approximately one year after weatherization, a portion of the roof blew off during a storm. It took more than a month to repair the roof, during a period when outside temperatures were particularly cold for Mississippi (28 HDD's per day). The high consumption of natural gas during that December (102 ccf) undoubtedly contributed to the low level of savings. Nevertheless, the homeowner was pleased with the work done on her house and reported greater comfort and lower bills.

4.3.4 The Value of Insulating Attics in the Hot Climate: A Typical High-Saving Dwelling

The core of this wood-framed home in Mississippi was built in approximately 1955; since then, two small additions have been constructed, resulting in 1,277 square feet of living space and a complicated roof-line prone to water and air leakage (Photo 4.4). Prior to weatherization, the home had no insulation in its attic, walls, or foundation, and its 14 wooden window frames and two wooden doors were rotten and leaky. The home was heated by two gas space heaters — one in the living room and the other in one of the four bedrooms. The 30-gallon water heater and the stove also used natural gas.

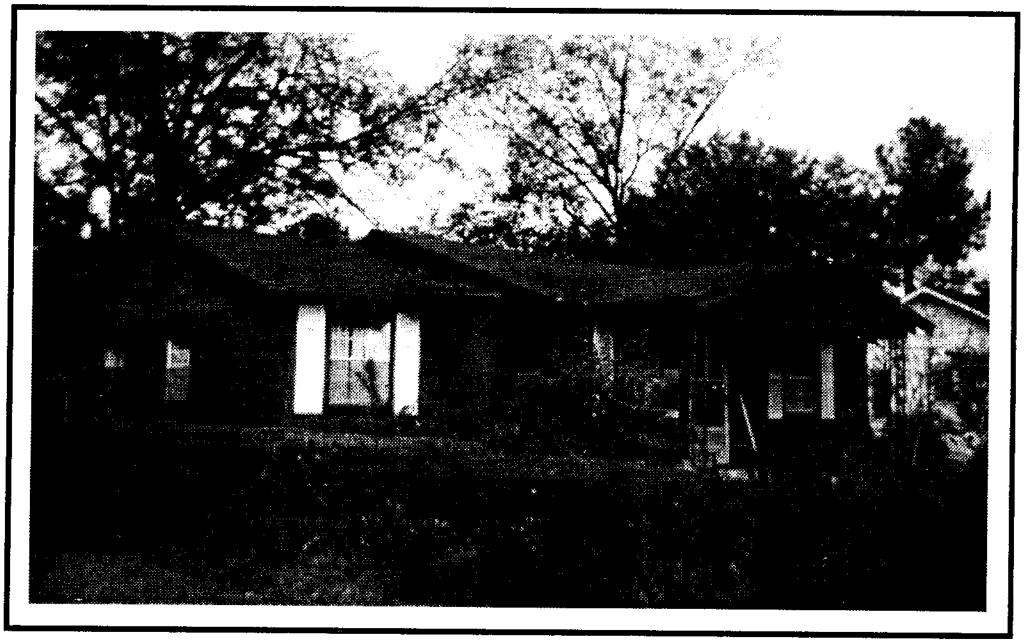


Photo 4.4 A High-Saving House in Mississippi

The couple who live in this home were also the home's first occupants. They reared their family here, adding to the house as needed. The occupants consumed 1,143 ccf of natural gas prior to weatherization, which was one-third more than the average for weatherized dwellings in the hot region during that same year (Fig. 4.12). The intensity of home heating fuel is somewhat higher than average in the hot region — 28.2 Btus per square foot per heating degree day, and the gas bills required 7.2% of the household's income. The couple attempted to minimize their gas bills by turning their bedroom space heater off when they were sleeping.

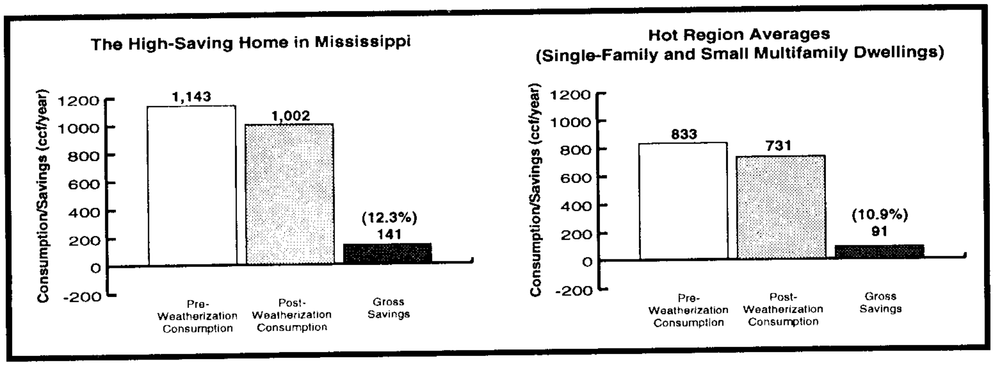


Fig. 4.13 The Value of Insulating Attics in the Hot Climate

The weatherization agency spent $900 in materials and $400 in labor to weatherize this house. A state-wide priority list of measures was used to select the weatherization measures. The job involved blowing approximately 3" of loose-fill fiberglass insulation across the attic floor, adding two gravity vents for each of the bathrooms, repairing and replacing several windows, replacing one of the doors, and generally caulking and weatherstripping. Due to the existence of a whole-house fan, the home's air leakage was not assessed with a blower door. However, the on-site inspectors noted that gaps in the rooflines where different additions were joined should have been fixed by the weatherization crews, because the attic insulation underneath was moist. In addition, they noted that the blown-in fiberglass insulation in the attic is uneven and too thin in many areas.

During the year after weatherization, the client used 1,002 ccf of natural gas, representing a decrease of 141 ccf (12.3%). The occupants judged their home to be slightly more comfortable after weatherization, noticeably less drafty, and much less expensive to heat.

4.4 CONSISTENCY WITH OTHER PARTS OF THE NATIONAL EVALUATION

The national analysis of high and low savers identified a number of factors that distinguish high- from low-saving dwellings. In particular, high savers tend to be older and larger dwellings that consume more energy prior to weatherization. They also benefit from a greater investment in weatherization, and they receive more attic, wall, and rim or band joist insulation, more water-heater tank insulation and water temperature reductions, more air sealing, and more furnace replacements. No single behavioral measure, or index of behavioral changes, was found to correlate with high or low savings.

Phase one results showed that climate region, pre-weatherization consumption, the installation of attic and wall insulation, and furnace replacements were highly correlated with energy savings. Thus, the findings presented in this report are consistent with those of phase one.

5. PAIRED COMPARISONS OF HIGHER- VS. LOWER-SAVING AGENCIES

The focus of this chapter is on comparisons of matched pairs of agencies with higher-than-average and lower-than-average energy savings. Because these paired agencies deal with similar housing and climate conditions, and because those from the same state operate under the same rules, comparing these pairs was expected to highlight differences in procedures that agencies could easily adopt to improve their average energy savings.[1]

The analysis in this chapter used six climate regions instead of the three used previously. This was done to try to make the pairs of agencies from the same region as similar as possible. To obtain the six climate regions we began with the three regions (cold, moderate, hot) used in phase one on the north-south axis, and then divided each of these three larger regions into two parts on the east-west axis. Each of the six regions (cold east, cold west, moderate east, moderate west, hot east, hot west) except the cold west contains at least one of the ten higher-saving agencies (Fig. 5.1). These ten higher savers were profiled in an earlier phase two report (Brown, et al., 1993b). Figure 5.1 shows the location of the ten higher-saving agencies, and the average gas savings (in ccf/year and as a percentage of pre-weatherization consumption) of their gas-heated weatherized dwellings. Each of the six climate regions also contains several average- or lower-saving agencies.

The best matched pairs of a higher- and a lower-saving agency were selected from the same climate region in all cases and from the same state, whenever possible.[2] In three of the five pairs, the agencies are from the same state. Among these three pairs, the agencies are 50 to 150 miles apart and serve similar types of housing stocks. In the hot east pair, which is from adjacent states, the two agencies are about 400 miles apart. In the cold region, the pair is from distant states, located more than 1,000 miles apart.[3] These paired agencies have nearly identical levels of heating degree days: 4,905 for higher savers and 4,894 for lower savers.

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1 Phase one data provide better characterizations of agency procedures than phase two data for two reasons. First, phase one collected information from agency records on the weatherization measures installed, on their costs, and on the selection, audit and diagnostic procedures used at the time of weatherization in 1989. This type of information was not collected in phase two, which concentrated on a complete characterization of current (in 1992) conditions in both 1989 weatherized and 1992 control homes. Second, phase one has larger and more representative samples of dwellings (often 100 or more as compared to 17 per agency in phase two). These larger phase one samples produce a better characterization of an agency's typical procedures and make it easier to identify significant differences between the pairs of higher- and lower-saving agencies. For these reasons, phase one data are used for most of the comparisons in this chapter. Exceptions are variables, such as blower door test results or steady-state efficiency measurements, which were measured in phase two but not in phase one.

2 Four of the six climate regions shown in Fig. 5.1 have matched pairs that are examined in this chapter. The exceptions are the cold east and the cold west which are combined into a single cold region comparison. This was done because suitable matched pairs were not available for the cold east or cold west regions.

3 It was not possible to find suitable matched pairs for the cold east or cold west regions. There were no phase two agencies in the cold east region that had the target number of phase two homes and measured savings for the phase two sample that were at or below the cold region's overall average in phase one. In other words, all of the phase two cold east agencies with measured savings were higher savers. In the cold west region, on the

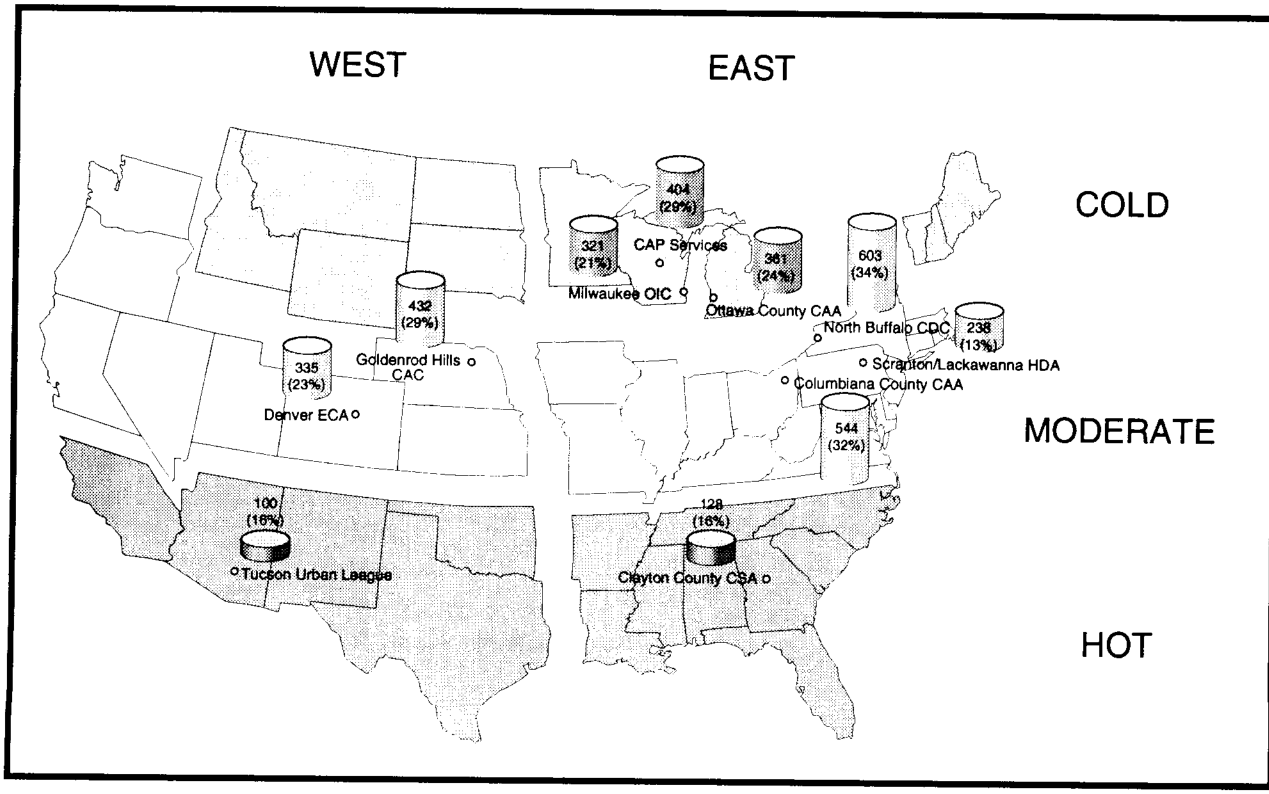

Fig. 5.1 Climate Regions and Higher-Saving Agencies for the Phase Two Single-Family Study

The analysis of matched pairs was limited to those agencies with the target number of dwellings in their phase two samples.[4] It also was limited to those agencies with measurements of energy savings in their phase two samples that were about the same as the energy savings measured in the phase one sample. This limitation was necessary to ensure that the smaller sample of phase two homes was representative of the agency's savings and practices as measured in phase one.[5] In addition, because only

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other hand, no higher saver could be identified. There was, however, an agency in the cold west region that had the target number of dwellings and phase two savings that were below the average phase one savings for the cold region. Therefore, the pair for the cold region includes one agency from the cold east and one agency from the cold west.

4 The pairs are limited to agencies that obtained the cooperation of the target numbers of 17 weatherized and 10 control dwellings in phase two. Some agencies obtained cooperation for the field work from fewer households, too few to support the analysis.

5 The pairs are limited to agencies which had consistent natural gas energy savings ranks for both phase one and phase two data. When average gas savings were calculated for the gas-heated phase two homes (which are the subset of the phase one weatherized dwellings that agreed to participate in phase two), the relative position of agencies in a ranking by gas savings sometimes changed. For example, one agency with fuel consumption data on 73 weatherized homes in phase one had an estimated average savings for these 73 homes of 214 ccf/year. However, the average savings for the subset of the 16 out of 73 homes that agreed to participate in phase two was only two ccf/year. Thus, this agency no longer ranked as a higher saver based on the subset of the 16 (out of 73) homes for which on-site data were collected in phase two, even though it was a ranked as a top saver with the complete set of 73 homes in phase one data base. This inconsistency in rankings occurred in several agencies. Therefore, agencies that did not have consistently higher or consistently lower rankings with both the

gas-heated homes were included in the phase two rankings of energy savings, only gas-heated homes are included in the phase one data used in this analysis.

Within climate regions, each pair of higher- versus lower-saving agencies is compared on two dimensions:

- housing stock characteristics; and
- rates of installation of weatherization measures.

These comparisons use phase one data. Detailed tables showing the housing characteristics and the weatherization installation rates for the higher and lower saver in each region are presented in Appendix G. Appendix G also reports the statistical significance of any differences between the higher and lower saver in each region. The discussion in Sections 5.2 through 5.6 focuses on statistically significant differences between the pairs. Similarities are largely ignored in these Sections because they do not suggest reasons for the difference in performance. Both similarities and differences, however, are shown in Appendix G.

Six pairs of agencies (12 agencies out of the original 30) are examined in the aggregate analysis presented in Section 5.1. This section compares average values for dwellings weatherized by all six of the higher savers to the average values for dwellings weatherized by all six of the lower savers.[6] These aggregate comparisons examine differences between all of the phase one gas-heated dwellings (n=482) weatherized by the higher savers (in the six pairs) and all of the gas-heated dwellings (n=337) weatherized by the lower savers (in the six pairs). A few variables that were measured only in phase two, such as blower door test results and steady-state efficiency measurements, also are discussed in the aggregate comparisons. The sample sizes for the phase two data are 103 weatherized dwellings for the higher savers and 84 weatherized dwellings for the lower savers. Following the aggregate comparisons in Section 5.1, the next five sections (Sections 5.2 to 5.6) compare a higher saver to a lower saver in each climate region. The last section presents a summary of the findings.

5.1 HIGHER VS. LOWER-SAVING AGENCIES: AGGREGATE COMPARISONS

To explore and clarify the differences between the higher- and lower-saving agencies, mean agency values on a number of dimensions were compared for all phase one dwellings weatherized by six higher savers (n=482) and all those weatherized by six lower savers (n=337) (Table 5.1). In general, higher-saving agencies weatherized lower proportions of single-family detached and mobile homes,

phase one and the phase two samples of homes were dropped from the agency-level analysis presented in this chapter.

6 The comparison of all dwellings weatherized by higher savers to all those weatherized by lower savers uses six pairs of agencies: the five discussed in the Sections 5.2 through 5.6 plus a sixth pair. The sixth pair comes from the moderate west region. In this region, there were two states that had well-matched pairs. A pair from one of these states, the one with the larger number of sample homes, is discussed in Section 5.4. Both of the pairs are included in the aggregate analysis in Section 5.1.

and higher proportions of small multifamily homes. The proportion of single-family attached homes weatherized was about 1% for both the higher and lower savers.

Table 5.1 Comparisons of Weatherized Dwelling Characteristics in Higher- and Lower-Saving Agencies

	Higher-Saving Agencies	Lower-Saving Agencies
Single-Family Detached	67%	86%
Single-Family Attached	1%	1%
Mobile Homes***	3%	9%
Small Multifamily***	29%	4%
Dwelling Size (square feet)	1,335	1,068
Age of Dwelling (years)	67	50
Pre-weatherization Normalized Annual Consumption (ccf)**	1,219	932
Post-weatherization Normalized Annual Consumption (ccf)	963	881
Change in Normalized Annual Consumption (ccf)***	255	52
Btu/square foot/HDD (pre)*	24.9	19.3
Btu/square foot/HDD (post)	20.2	18.5
Change in Btu/square foot/HDD***	4.6	0.8
Heating Degree Days	4,905	4,894
Blower Door Test Results (cfm_{50})	2,734	2,584
Steady-State Efficiency of Heating System*	76.9	73.8
Percent of Total Window Area with Storms*	47%	62%

*, **, and *** indicate that differences between dwellings weatherized by higher- and lower-saving agencies are significant at the 0.05, 0.01, and 0.001 levels, respectively.

The higher savers weatherized larger, older homes, with higher pre-weatherization gas consumption. Because of the greater reductions in energy use achieved by the higher savers, the post-weatherization consumption among homes weatherized by the two groups of agencies was about the same. As is consistent with the changes in consumption patterns, dwellings weatherized by the higher savers used more Btu/square foot/HDD, both before and after weatherization, than those weatherized by the lower savers. They also showed more change in their Btu/square foot/HDD usage. This suggests that the pre-weatherization energy efficiency of the dwellings weatherized by the higher savers was less, and that they had more room for improvement. Thus, from both indicators it is clear that weatherizing dwellings that use more energy produces more savings.

Following weatherization, the dwellings weatherized by the higher-saving agencies had about the same air leakage rates as those weatherized by the lower-saving agencies (2,734 cfm_{50} and 2,584 cfm_{50}). The distribution of air leakage rates for the dwellings weatherized by the higher versus lower savers is shown in Fig. 5.2. About 28% of the dwellings weatherized by the lower savers had air leakage rates of 1,500 cfm_{50} or less, as compared to about 19% of the dwellings weatherized by the higher savers. The same counterintuitive association between the tightness of dwellings and their savings was also evident in Chapter 4, which compared high- and low-saving dwellings. In that case, the high-saving dwellings were leakier than the low-saving dwellings. Dwellings weatherized by the higher-saving agencies had a significantly higher steady-state efficiency for their heating systems, probably because of higher rates of heating system replacements by these agencies. Dwellings weatherized by lower-saving agencies had a higher percentage of the total window area that was covered with storm windows (Table 5.1).

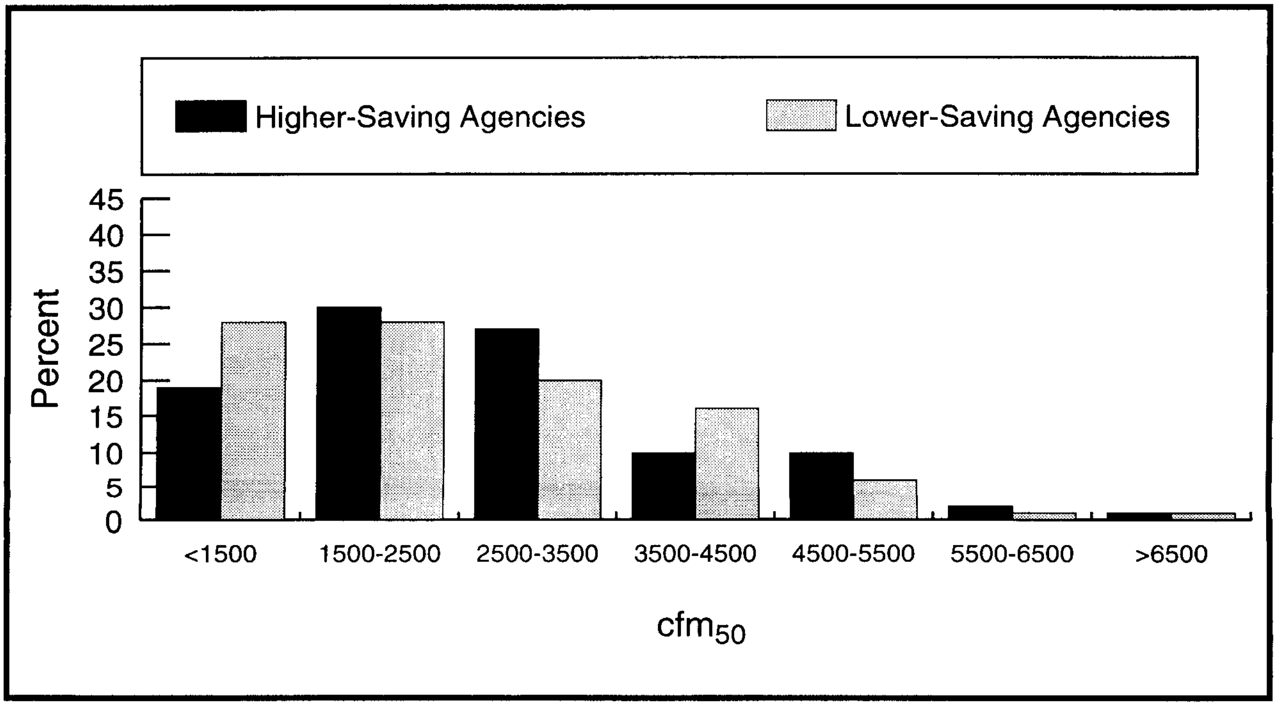

Fig. 5.2 Distribution of Air Leakage Rates for Dwellings Weatherized by Higher- and Lower-Saving Agencies

Comparisons of the occupant characteristics and behaviors of the higher- and lower-saving agencies showed a few significant differences (Table 5.2). For example, the higher savers served more elderly and disabled clients. Clients of the higher savers were less likely to move, or to have a utility cut-off after weatherization.

Table 5.2 Comparisons of Occupant Characteristics in Higher- and Lower-Saving Agencies

	Higher-Saving Agencies	Lower-Saving Agencies
Number of occupants (pre-weatherization)	2.8	3.3
Number of occupants (post-weatherization)	2.6	3.1
No pre-post change in occupants* (%)	76.8	60.3
More occupants pre* (%)	17.2	32.4
More occupants post* (%)	6	7.4
Pre thermostat setting (°F)	69.6	69.4
Post thermostat setting (°F)	68.9	69.9
Heating system broken (pre) (%)	14.5	10.9
Heating system broken (post) (%)	10.1	16.4
Utility cut off post* (%)	2.7	10.3
Heated more space post (%)	3.6	7.4
Seniors** (%)	51	29
Disabled** (%)	34	14

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Comparisons of the impacts of weatherization on heating costs showed, as expected, that dwellings weatherized by higher savers reduced their bills by almost five times more than those weatherized by lower savers. In addition, reductions in household energy burdens (defined as the cost of the main heating fuel divided by the annual income), were greater among households weatherized by the higher savers (Table 5.3).

Comparisons of the rates of installation of various measures for dwellings weatherized by the higher-saving and lower-saving agencies showed that attic and wall insulation were installed more often by the higher-saving agencies (Table 5.4). Water-heating measures of all types also were installed more frequently by the higher savers. Higher-saving agencies replaced the heating system in 13% of the dwellings they weatherized as compared to less than 1% of the dwellings weatherized by lower savers. In contrast, window and door measures were installed much more frequently by the lower savers (Table 5.4). Surprisingly, the lower-savers did distribution system work on a higher percentage of their dwellings than the higher savers, but the percentages were very low (4% and 1%) in both groups. The lower savers did more structural repairs than the higher savers, while the higher savers did more CO testing (Table 5.4).

Table 5.3 Comparisons of Heating Costs and Energy Burden in Higher- and Lower-Saving Agencies

	Higher-Saving Agencies	Lower-Saving Agencies
Annual Cost of Main Heating Fuel (pre)***	$652	$469
Annual Cost of Main Heating Fuel (post)*	$518	$442
Reduction in Annual Heating Cost***	$134	$27
Energy Burden (pre)	10.3%	8.7%
Energy Burden (post)	8.3%	8.1%
Change in Energy Burden	2.0%	0.6%

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

Because attic insulation was installed at higher rates by the higher savers, more of the homes they weatherized had attic insulation with R-values at or above R-30 (50% versus 33%). In treated homes, however, the mean R-value was about the same in the homes weatherized by the higher savers (R-28) and the lower savers (R-30). Thus, the more effective use of attic insulation by the higher savers results not from a difference in how much insulation is installed when it is installed, but rather from the fact that insulation is installed in a substantially higher percentage of homes.

A final difference between the dwellings weatherized by the higher- and lower-saving agencies was in the amount and patterns of investments (Fig. 5.3). The higher savers invested an average of $727 per house in materials, while the lower savers invested $537. Higher savers invested more in air leakage, insulation, space-heating, and water-heating measures, while the lower savers invested more in structural repairs and in windows and doors. Similar differences were documented in the analysis of high- and low-saving dwellings (Chapter 4).

Table 5.4 Comparisons of Percentage of Weatherized Dwellings Receiving Measures in Higher- and Lower-Saving Agencies

	Higher-Saving Agencies	Lower-Saving Agencies
Air Leakage	96%	98%
General Caulking and Weatherstripping	96%	97%
Air Sealing with Blower Door ***	47%	16%
Air Sealing without Blower Door***	31%	1%
Distribution System ***	1%	4%
Insulation ***	84%	65%
First-time Attic***	43%	27%
Added Attic*	27%	21%
Normal Wall*	40%	31%
High-Density Wall	0.4%	0%
Floor***	4%	16%
Water Heating***	87%	65%
Tank Wrap***	67%	38%
Pipe Wrap***	78%	54%
Low-Flow Showerheads***	15%	5%
Temperature Reduction***	33%	14%
Windows and Doors***	16%	23%
Replace Windows	6%	32%
Replace Doors***	14%	47%
Storm Windows***	6%	20%
Heating System Retrofit***	9%	19%
Heating System Replacement***	13%	0.3%
Distribution System*	1%	4%
Structural Repairs*	89%	93%
Repair Doors***	48%	61%
Repair Windows***	61%	78%
Repair Floor	0.4%	8%
CO Testing***	49%	18%

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

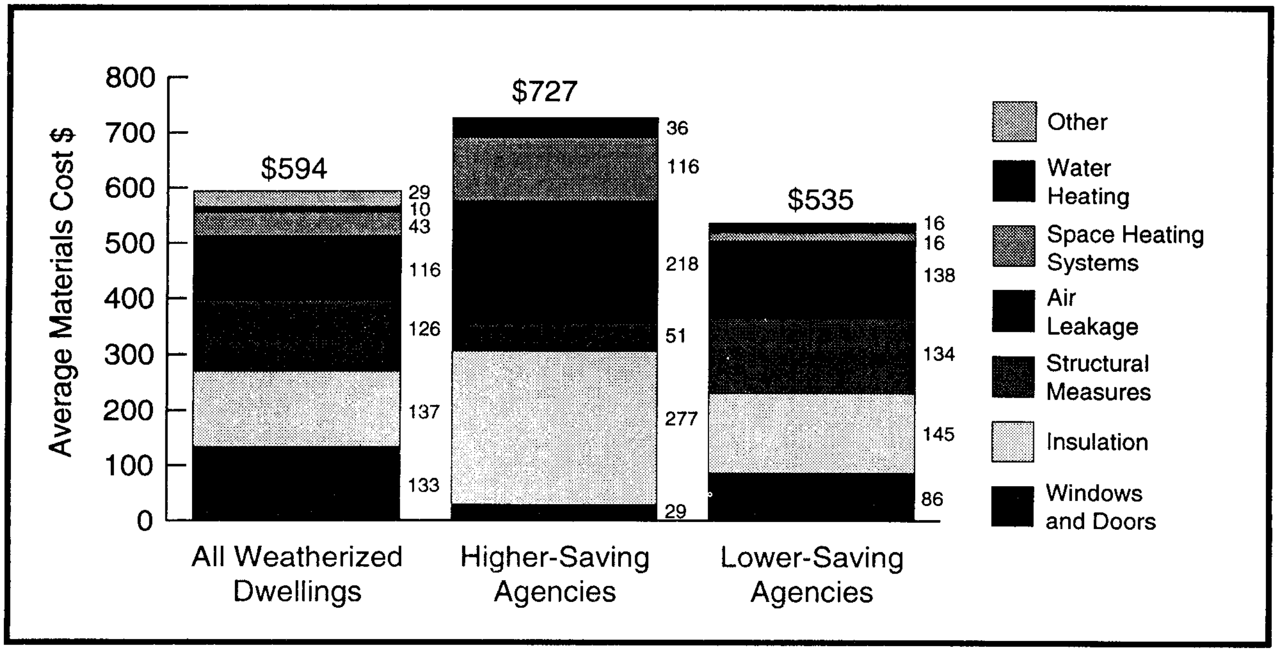

Fig. 5.3 Average Materials Expenditures by Measure Type in Higher- and Lower-Saving Agencies

Table 5.5 Comparisons of Percentage of Materials Dollars Spent by Measure Type in Higher- vs. Lower-Saving Agencies

	Higher-Saving Agencies	Lower-Saving Agencies
TOTAL MATERIALS COST* **	727	535
Percent of Total Materials Cost Spent On:		
Air Leakage* **	30	26
Insulation* **	38	27
Heating Systems* **	16	3
Structural Repairs* **	7	25
Water Heating* **	5	3
Windows and Doors* **	4	15

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

5.2 COLD REGION: EAST VS. WEST

For the cold region, only one pair of agencies is compared: a cold west agency that is a lower-saving agency is compared to a cold east agency that is a higher saver. Not surprisingly, the housing stock was quite different in the two locations (Appendix G). The homes weatherized by the higher saver were older and larger than those weatherized by the lower saver and used, on average, 800 ccf/year more before weatherization (1,605 ccf/year versus 764 ccf/year). The higher saver weatherized no mobile homes, and a high proportion of small multifamily dwellings (Fig. 5.4). In contrast, over half of the dwellings weatherized by the lower saver were mobile homes.[7] This pattern is consistent with phase one findings about the low savings typically achieved in mobile homes, and the higher savings typical of small multifamily dwellings.

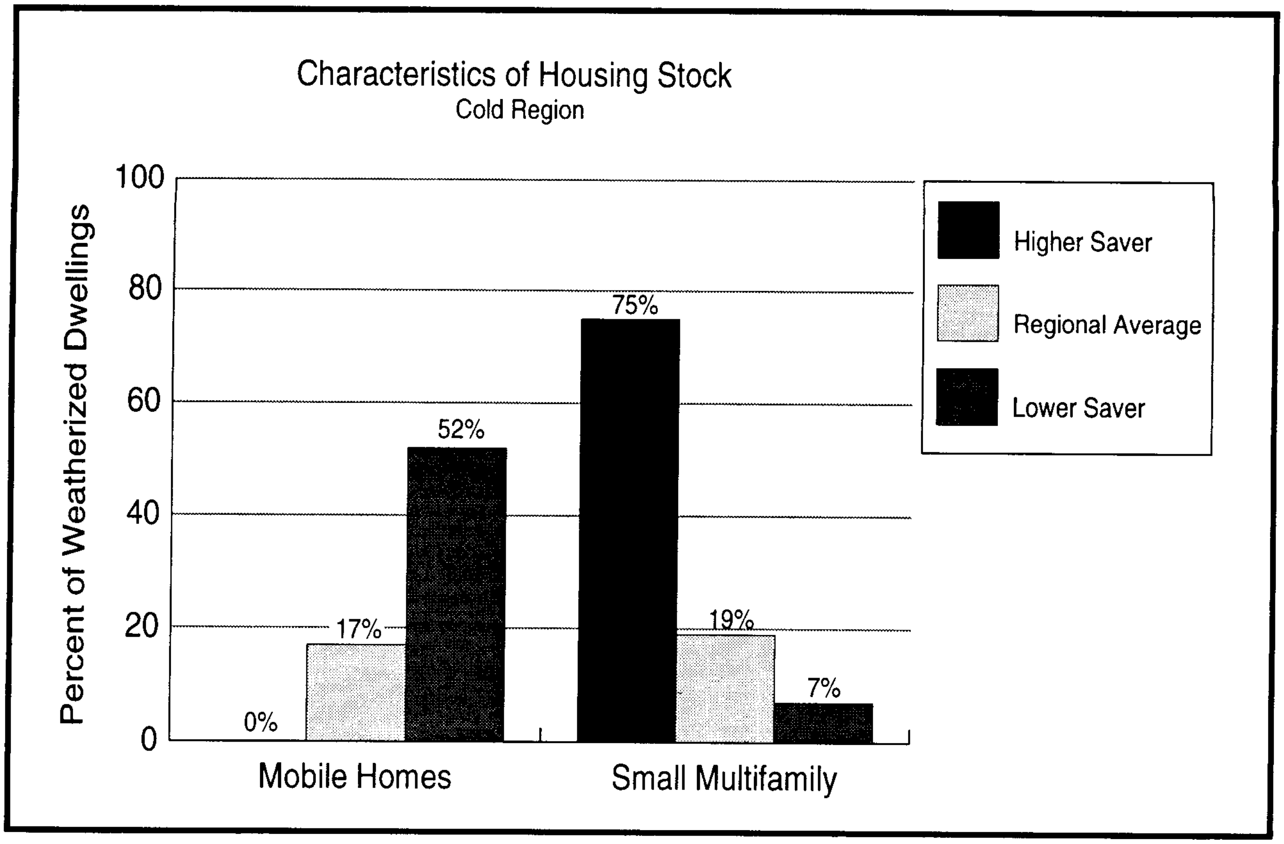

Fig. 5.4 Comparisons of Dwelling Types for Higher- and Lower-Saver in Cold Region

As Fig. 5.5 shows, the higher saver installed much more attic and wall insulation than the regional average, while the lower saver installed less. The R-values for attic insulation were at R-30 or higher for 33% of the dwellings weatherized by the higher saver and for 13% of those weatherized by the lower

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[7] The differences between the higher and lower savers are statistically significant as are all of the other differences shown in the graphics in this chapter. The levels of significance are shown in Appendix G.

saver. The higher saver also installed more water heating measures (Appendix G). The higher saver installed replacement windows in less than 1% of the dwellings it weatherized and replacement doors in only 4%. The lower saver, in contrast, installed replacement windows in 20% of its dwellings and replacement doors in 37% (Fig. 5.5). In this region, the lower saver installed storm windows much more frequently. The higher saver replaced heating systems in 26% of its dwellings, while the lower saver replaced them in 2%. These patterns are consistent with the findings of phase one concerning the high savings associated with the installation of attic and wall insulation and with the replacement of heating systems.

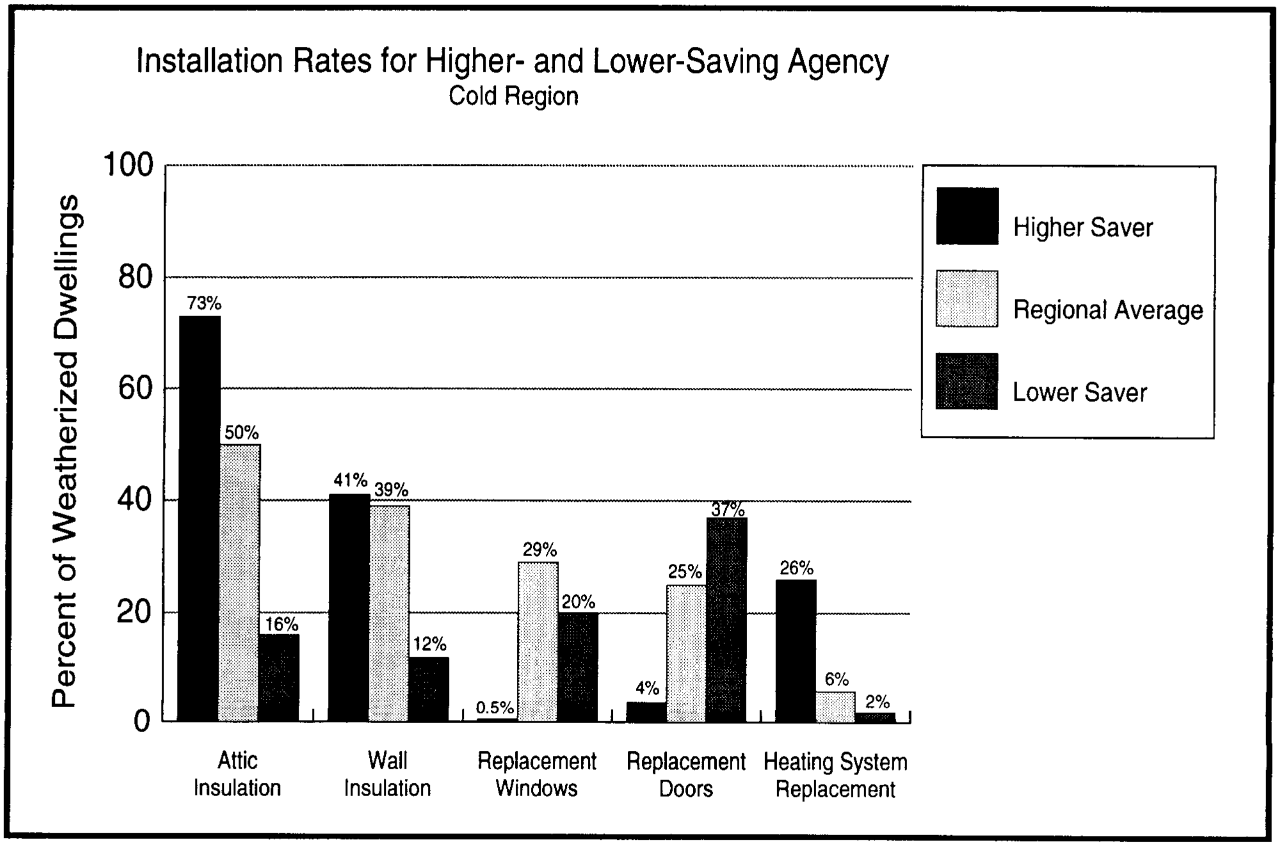

Fig. 5.5 Comparisons of Weatherization Measure Installation Rates for Higher- and Lower-Saver in the Cold Region

Both of these agencies used advanced audits and had access to some leveraged funds. The higher saver, however, spent, on average, over twice as much per house. HUD and state housing rehabilitation funds paid for improvements in about 20% of the higher saver's dwellings.

In summary, the superior savings of this higher-saving agency appear due to:

- weatherizing dwellings with higher energy use before weatherization;
- weatherizing many small multifamily dwellings and no mobile homes;
- installing attic and wall insulation in more dwellings;

- installing more water-heater measures;
- replacing more heating systems;
- investing more resources in each dwelling; and
- investing a higher proportion of its resources in high-saving measures and less in replacement windows and doors.

5.3 MODERATE EAST REGION

A suitable pair of agencies from the same state was available for the moderate east region. This pair of agencies served the same mix of housing types, with similar percentages of mobile homes, single-family, and small multifamily dwellings. Both had dwellings that averaged close to 70 years in age and had about 1,300 square feet. Over 96% of the homes in both agencies had central heat. Neither had high percentages using supplemental fuels, although the incidence was somewhat higher in the higher-saving agency. In spite of the similarities in the housing stock, the higher saver's dwellings used over 400 ccf/year more gas before weatherization (1,653 cf/year versus 1,229 ccf/year).

In this region, the higher saver installed attic and wall insulation more frequently (Fig. 5.6) than the lower saver. The R-values for attic insulation were at R-30 or higher for 58% of the dwellings weatherized by the higher saver and for 50% of those weatherized by the lower saver. The lower saver installed more floor insulation.

Rates of performing structural repairs were approximately the same in the two agencies. Neither agency replaced any heating systems, although both did tune-ups. The lower saver did tune-ups on over 90% of its dwellings, while the higher saver did them on only about 10%. The higher saver did air sealing with blower doors on about 25% of its dwellings, while the lower saver did this procedure on only about 2%. Both used a priority list for the selection of measures.

In summary, the superior savings of this higher-saving agency appear due to:

- weatherizing dwellings with higher energy use before weatherization;
- doing more air sealing with blower doors; and
- installing attic and wall insulation in more dwellings.

5.4 MODERATE WEST REGION[8]

In the moderate west region, the higher saver weatherized no mobile homes, while the lower saver weatherized 14%. The higher saver also weatherized more single-family detached dwellings than

8 Two suitable pairs of agencies, located in the same state, were available for the moderate west region. Only one of these pairs, the one with the larger sample sizes, is examined in this section. Both of the pairs, however, are included in the aggregate analysis presented in Section 5.6.

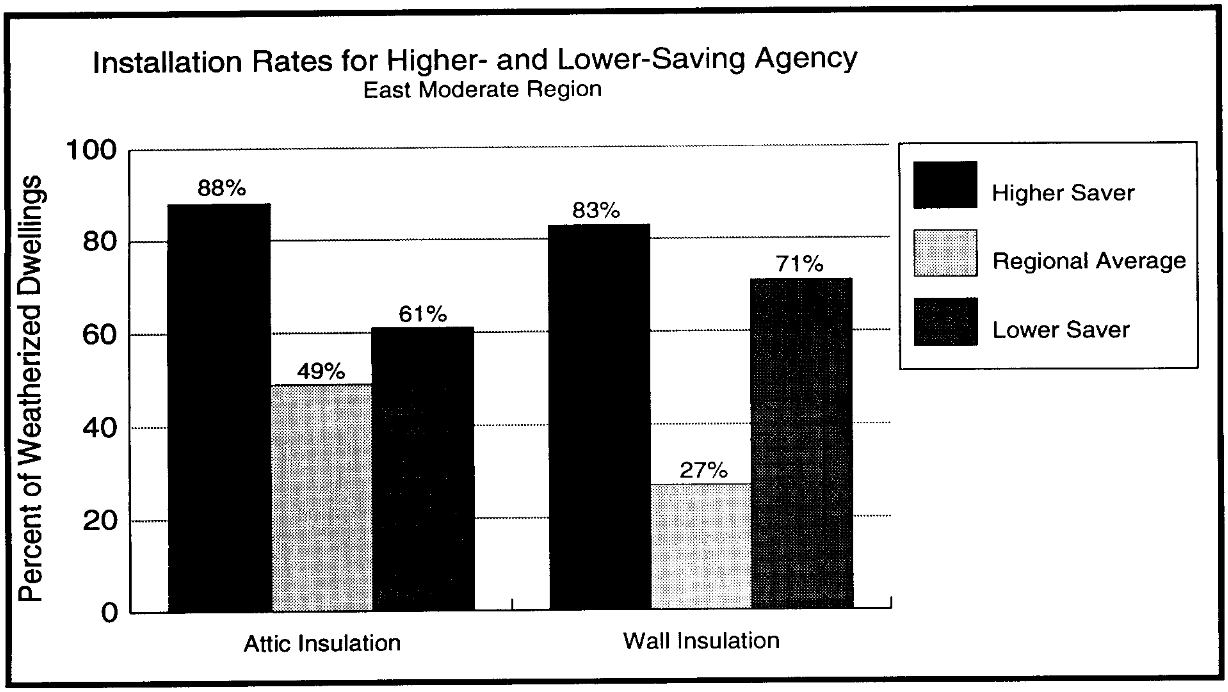

Fig. 5.6 Comparisons of Weatherization Measure Installation Rates for Higher- and Lower-Saver in the Moderate East Region

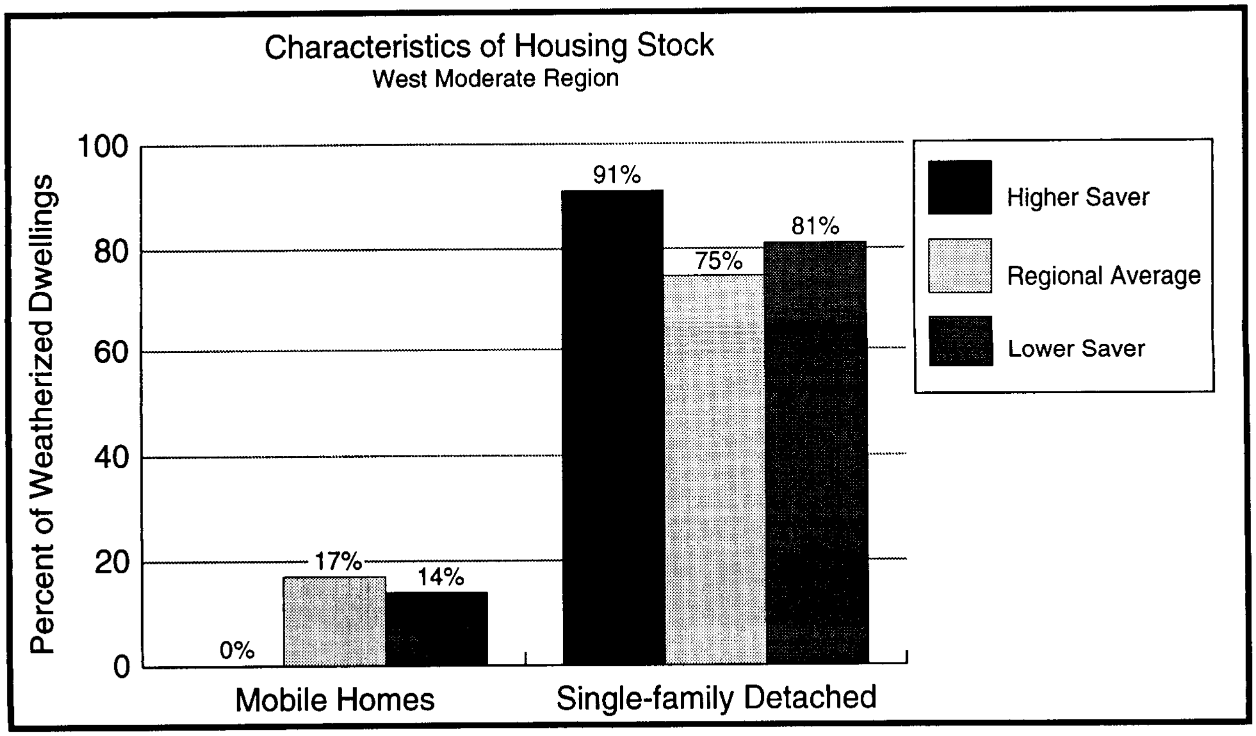

Fig. 5.7 Comparisons of Dwellings Types for Higher- and Lower-Saver in Moderate West Region

the lower saver (Fig. 5.7). The higher-saving agency's homes were older and larger and used about 319 ccf/year more gas before weatherization. In both agencies a large majority of homes had central heat.

The higher saver installed attic insulation in most of the homes it weatherized, while the lower saver did not (Fig. 5.8). The R-values for attic insulation were at R-30 or higher for 64% of the dwellings weatherized by the higher saver, but were at this level for only 6% of those weatherized by the lower saver. Both agencies, however, installed wall insulation in about one-third of the homes that they weatherized. In this region, the lower saver installed floor insulation and storm windows more frequently than the higher saver (Appendix G). The higher saver installed more water-heater measures and did more heating system tune-ups. The higher saver replaced the heating system in about 4% of the homes it weatherized, while the lower saver did not replace any of the heating systems (Fig. 5.8).

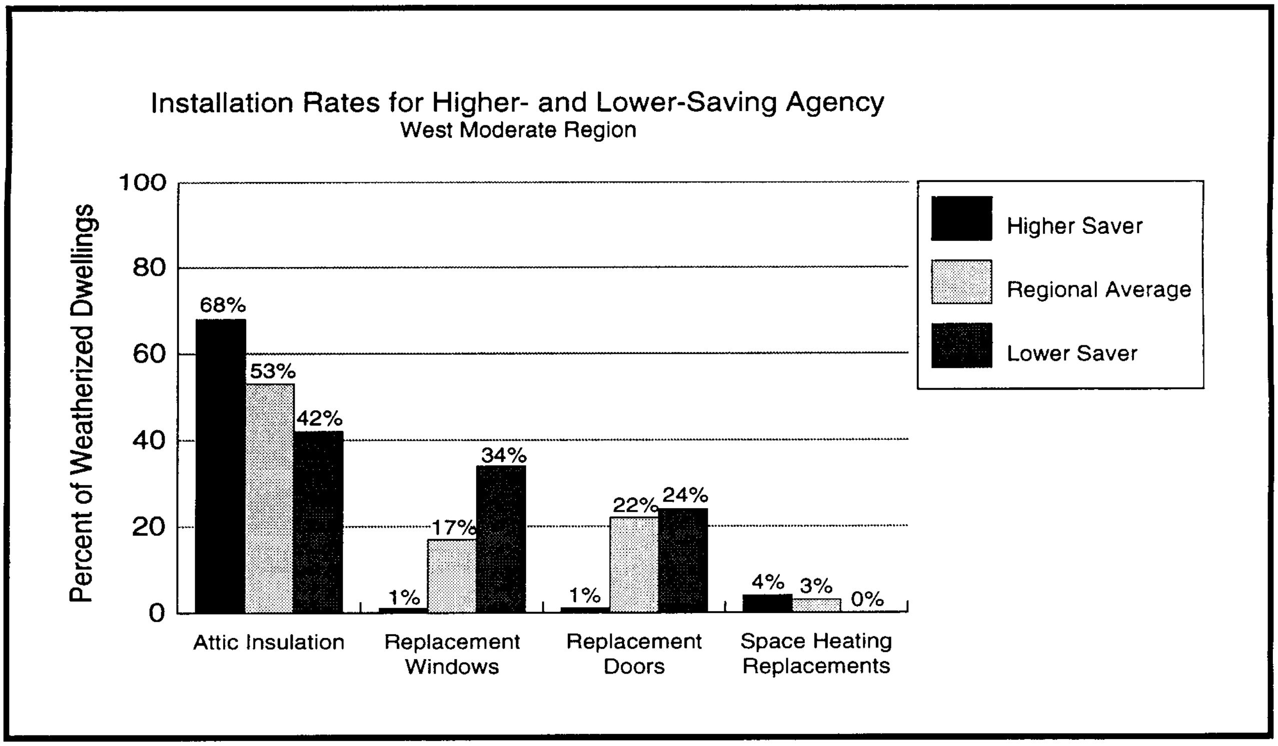

Fig. 5.8 Comparisons of Weatherization Measure Installation Rates for Higher- and Lower-Saver in the Moderate West Region

The higher saver installed replacement windows in only 1% of its weatherized homes, while the lower saver installed them in 34%. The higher saver also installed replacement doors in only 1% of its homes, while the lower saver installed them in 24%. The higher saver had somewhat higher rates for structural repairs. Both agencies used a priority list to select measures. The higher saver did air sealing with a blower door in nearly all of the homes it weatherized, while the lower saver rarely did air sealing with a blower door. Their average expenditures per home were similar.

In summary, the superior savings of this higher-saving agency appear due to:

- weatherizing dwellings with higher energy use before weatherization;
- installing attic insulation in more dwellings;
- replacing more heating systems;
- installing more water-heating measures;
- doing more air sealing with blower doors; and
- investing more of its resources in high-saving measures and less in replacement windows and doors.

5.5 HOT EAST REGION

One suitable pair of agencies was available for the hot east region. This pair was located in adjacent states. In this case, as is shown in Fig. 5.9, the higher saver served more mobile homes than the lower saver. The average age of their homes was similar, but the lower saver's homes were about 200 square feet larger. In this pair of agencies, in contrast to the typical pattern, the lower saver's dwellings consumed, on average, about 50% more gas before weatherization than the higher saver's dwellings. In addition, the agencies had very different patterns of supplemental fuel use. In the high-saving agency none of the dwellings used supplemental fuels, while in the low-saving agency all of them did (Appendix G).

The rates of installing certain weatherization measures were quite different for the higher and lower saver. First-time attic insulation was installed much more frequently by the higher saver (Fig. 5.10). The R-values for attic insulation were at R-30 or higher for 62% of the dwellings weatherized by the higher saver and for only 22% of those weatherized by the lower saver. In addition, in this pair, the treated homes in the higher-saving agency had higher R-values (R-21) than those in the lower-saving agency (R-10). This was the only pair of agencies that had a significant difference in the R-values of their treated group of homes (Appendix G). In all of the other pairs, R-values for the treated homes were about the same. Neither of these agencies installed any wall insulation, although the higher saver installed somewhat more floor insulation.

In this pair, the higher saver completed structural repairs such as roof and door repairs, and the replacement or reglazing of windows much less frequently than the lower saver (Fig. 5.10). These findings suggest that the higher saver is putting more resources into measures that substantially improve energy efficiency, while the lower saver is putting more resources into measures that improve structural conditions, but have less impact on energy efficiency.

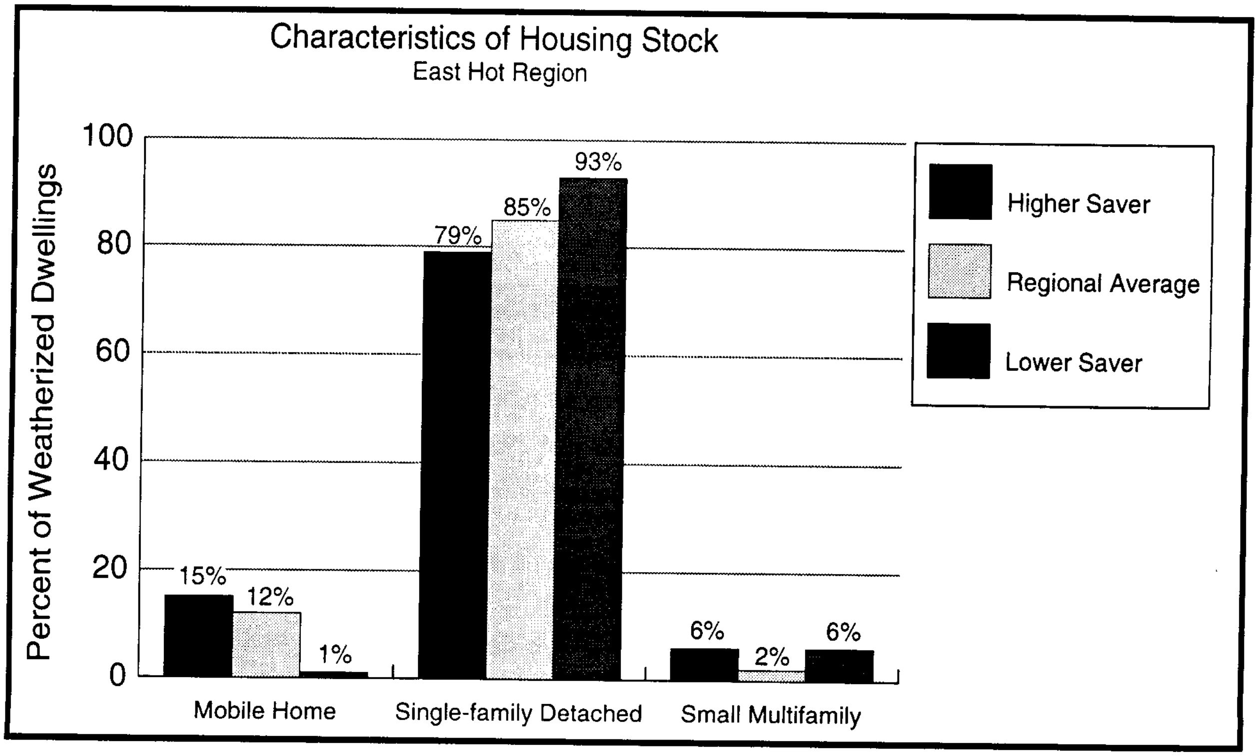

Fig. 5.9 Comparisons of Dwelling Types for Higher- and Lower-Saver in Hot East Region

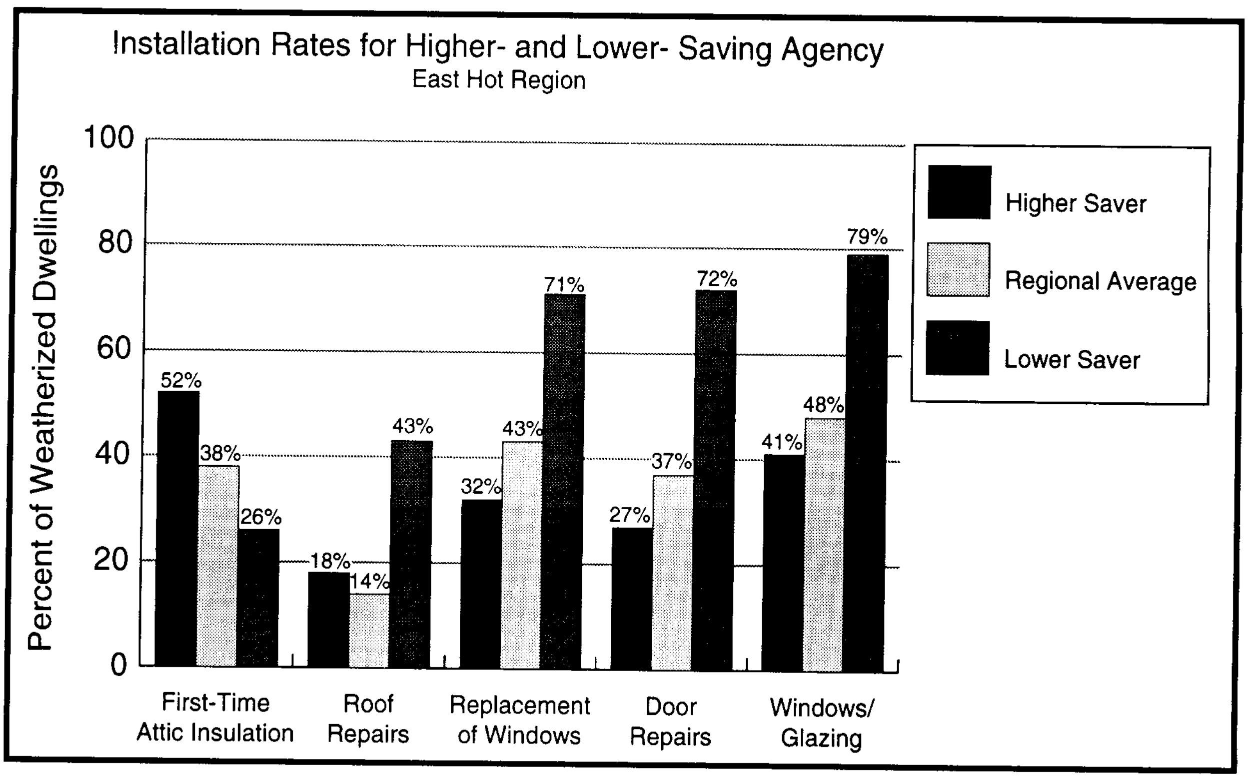

Fig. 5.10 Comparisons of Weatherization Measure Installation Rates for Higher- and Lower-Saver in the Hot East Region

Both of these agencies use priority lists to select measures. Neither does any space heating work, and neither uses blower doors or other advanced diagnostics. Neither has access to leveraged funds. The lower saver spends an average of about $200 more per house, and a much higher percentage of its total expenditures is spent on structural repairs and windows and doors.

In summary, the superior savings of this higher-saving agency appear due to:

- installing attic insulation in more dwellings;
- installing thicker attic insulation;
- installing more storm windows and fewer replacement windows, and
- investing a higher proportion of its resources in high-saving measures and less in structural repairs.

5.6 HOT WEST REGION

One suitable pair of agencies, which was located in the same state, was available for the hot west region. This pair of agencies served similar types of housing. In both agencies the average age of the dwellings was about 35 years, but the homes weatherized by the higher saver had more square footage and used about 200 ccf/year more before weatherization. In the high-saving agency 40% of the dwellings used supplemental fuels, while in the low-saving agency 75% of them did (Appendix G).

In all of the pairs of agencies, except this one, the higher saver installed attic insulation more frequently than the lower saver (Appendix G). Here, the higher saver installed much less attic insulation (9% of dwellings) than the lower saver (58%). Nevertheless, the percentage of homes in the two agencies that had R-values for attic insulation that were at R-30 or higher was about the same: 60% of the dwellings weatherized by the higher saver and 57% of those weatherized by the lower saver. This suggests that the lower saver may have installed more attic insulation here because more of its dwellings needed it.[9] The higher saver did air sealing with blower doors more frequently, installed more water heater tank wraps and pipe insulation, and installed more storm windows (Appendix G). Window film/shades were installed much more often by the higher saver (Fig. 5.11). The higher saver also

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9 In all of the pairs, including this one, the higher saver had a higher percentage of homes with attic insulation that was at R-30 or above (Appendix G). Since this is the only pair in which the lower saver had a higher installation rate for attic insulation, it seems logical to assume that it had more homes that needed attic insulation. R-values were calculated for the control group of homes in each agency but, unfortunately, the sample sizes were too small to produce reliable results. Only two control homes served by the higher saver had measurements that could be used to calculate an R-value. These two homes had a lower mean R-value than the control homes in the lower-saving agency, which does not support the idea that the lower saver's homes had a greater need for insulation. In general, the control homes in higher-saving agencies had lower mean R-values than the control homes in the lower-saving agencies. These results are not statistically significant, however, because the number of control homes with measurements was always 10 or less. Measurements from such a small number of homes cannot give an accurate estimate of the level of attic insulation that is present in all of the eligible housing stock served by an agency.

installed fans in 27% of the dwellings, while the lower saver did not install any fans. The installation of these cooling measures probably reduced electricity usage, but since this analysis examined only gas savings it could not be detected. The higher saver replaced about 9% of the heating systems, while the lower saver installed no new heating systems. Both agencies did tune-ups on a majority of the heating systems. Neither agency installed any wall insulation.

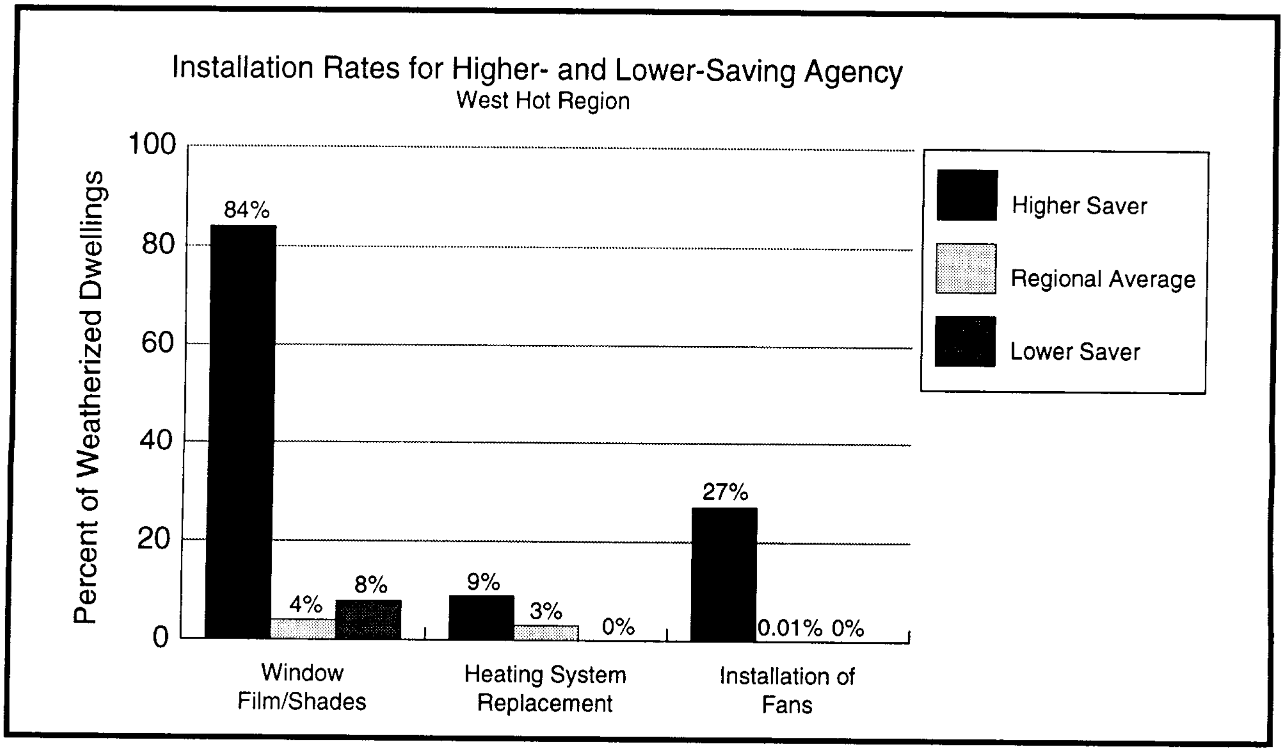

Fig. 5.11 Comparisons of Heating/Cooling Measure Installation Rates for Higher- and Lower-Saver in the Hot West Region

Both agencies used a priority list to select measures in PY 1989. Today, the higher saver uses an integrated audit. On average, the lower saver reported spending about $200 more per house. However, the higher saver referred many of its clients to housing rehabilitation programs, which raised the total investment (including both DOE and non-DOE funds) in many homes. Both agencies did blower door testing on 40-50% of the dwellings weatherized.

In summary, the superior savings of this higher saver appear due to:

- weatherizing dwellings with higher energy use before weatherization;
- installing more water-heater measures;
- replacing more furnaces ; and
- doing more air sealing with blower doors.

5.7 SUMMARY AND CONCLUSIONS

Several factors typically distinguish higher- from lower-saving agencies. Higher savers weatherize fewer mobile homes, and more small multifamily dwellings. In addition, the homes weatherized by higher savers are larger, older, and use more energy. Their normalized annual pre-weatherization consumption is higher, as is their average energy intensity measured in Btu/square foot/HDD.

The measures that are installed more frequently by several higher savers include:

- attic insulation,
- wall insulation,
- water heater measures, and
- heating system replacements.

The association of these measures with high savings is strong in the aggregate analysis that compares six higher-saving agencies to six lower-saving agencies. In the pair by pair comparisons, however, the typical associations are not seen in every case (Appendix G). The presence of exceptions to the typical pattern suggests that no one factor is always necessary to produce good results. Nevertheless, the typical patterns are usually present. In four out of the five pairs compared, for example, the higher-saver installed attic insulation more frequently than the lower saver. Only one comparison, in the hot west region, showed that the lower saver installed attic insulation more often. Wall insulation was installed at higher rates by the higher saver in two of the five paired comparisons. In one region the installation rates of the higher and lower saver were nearly equal, and in two regions neither the higher nor the lower saver installed any wall insulation. Water-heater measures were installed at significantly higher rates by the higher saver in one region and at slightly higher rates in two regions. In three of the regional comparisons heating system replacements were installed at higher rates by the higher saver, while in two regions neither agency installed heating system replacements (Appendix G).

In general, the lower savers install more window and door replacements. In four of the five regions, the lower saver installed more replacement windows and replacement doors than the higher saver. In the moderate east region, however, the higher saver installed more replacement windows and doors (Appendix G). In general, the lower savers also tended to install more floor insulation.

Storm window installation rates show a mixed picture. In the two hot regions the higher saver installed significantly more storm windows, and in the cold and the moderate west regions the lower saver installed significantly more. In the moderate east region, both the higher and the lower saver installed storm windows in a small percentage of homes. Thus, there is no consistent association between rates of installation of storm windows and agency energy savings. The heating system tune-up is another measure that is sometimes done more by higher savers and sometimes more by lower savers.

The findings reviewed above are consistent with phase one results, which also demonstrated a close association between high savings and the installation of attic insulation, wall insulation, water-heating measures, and heating system replacements. There was little evidence in our analysis that different climate regions consistently showed different patterns of measure effectiveness.[10]

The results for the hot region may have been influenced by the strikingly different patterns of supplemental fuel use. In the hot east region, none of the dwellings weatherized by the high-saving agency used supplemental fuels, while in the low-saving agency all of them did (Appendix G). Similarly, in the hot west region 40% of the dwellings weatherized by the high-saving agency used supplemental fuels, while 75% of the dwellings weatherized by the low-saving agency used them. Phase one results show that homes using supplemental fuels tend to have lower savings than those that do not use supplemental fuels.

Although one would expect to find an association between high savings and the use of advanced audits, this issue could not be addressed by the paired comparisons of the higher and lower savers. In most of the regions, the higher and lower savers both used priority lists, and in the one region where the higher saver used an advanced audit the lower saver did too. This similarity among the pairs probably reflects the fact that state policies have a strong influence on audit procedures. Thus, our paired comparison approach is not a suitable way of identifying the effects of advanced audits. Experimental studies, such as the North Carolina Field Test of an advanced audit (Sharp, 1993), are a better approach to demonstrating the benefits of these procedures.

Blower door use is more common among the higher savers (Appendix G). In three of the pairs, the higher saver did air sealing with blower doors in a significantly higher percentage of its weatherized homes. In phase one, the benefits of blower door usage were not apparent. In these paired comparisons, however, the higher savers clearly used blower doors more frequently than the lower savers.

Almost all of the higher savers used leveraged funds 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 savers did not leverage their resources, and relied exclusively on DOE funds.

10 In the hot west region the higher saver did install more cooling measures (window films and fans). This agency was the only one out of the 12 discussed in this chapter that installed any cooling measures. Because only gas savings are examined here the impact of any reductions in air conditioning demand due to the cooling measures could not be measured. In both of the hot regions, more storm windows were installed by the higher savers. In the cold and moderate regions, in contrast, the lower savers installed more storm windows. This suggests the possibility of regional differences in the effectiveness of storm windows (Appendix G). Further research is needed to determine if there are any distinct regional patterns.

6. OCCUPANT PERCEPTIONS OF NONENERGY BENEFITS

As part of the occupant survey, occupants of weatherized and control homes were asked to rate their dwellings in terms of comfort, draftiness, safety, and heating expenses (Appendix C). 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 draftiness of the dwelling). For each question a before and after rating (on a seven-point scale) was obtained from occupants of the homes. For the weatherized homes, the before period was defined as the winter before their home was weatherized, and the after period as the two winters after. For the control homes the before period was the winter of 1988-89, and the after period was the winters of 1990-91 and 1991-92.

6.1 WEATHERIZED VS. CONTROL

On every rating scale, occupants of the weatherized dwellings reported a significant and positive change between the before and after weatherization time periods. The control group, on the other hand, reported no change in any of the ratings (Fig. 6.1). 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 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. For each of the ratings, the amount of change for the weatherized group was compared to the amount of change in the control group. All of the differences were highly significant ($p \leq 0.001$).

6.2 HIGH- VS. LOW-SAVING DWELLINGS

Both the high- and low-saving dwellings reported significant and positive changes on each of the five rating scales (Fig. 6.2). Thus, both groups experienced improvements in the comfort and safety of their homes, and believed their homes became less drafty and their heating bills more affordable after weatherization. Both groups also reported an improvement in their own health. Although both groups reported improvements after weatherization, the pre-weatherization ratings were slightly more positive among the occupants of low-saving dwellings. The occupants of low-saving dwellings rated their pre-weatherization homes as more comfortable, safer, less drafty, and their heating bills as more affordable than the occupants of high-saving dwellings. They also reported that their health was slightly better. The post-weatherization ratings, however, were nearly the same for both groups. Thus, the occupants of high-saving dwellings had more room for improvement and reported greater amounts of improvement than the occupants of low-saving dwellings. For each of the ratings, the amount of change in the high-saving dwellings was compared to the amount of change in the low-saving dwellings. All of these differences, except the differences in the amount of change in health, were statistically significant. In particular, the occupants of the high-saving dwellings experienced not only more energy savings but also significantly more nonenergy benefits in terms of improved comfort and safety, and reduced draftiness and heating expenses. Occupants of both the high- and low-saving dwellings reported similar levels of improvement in their health.

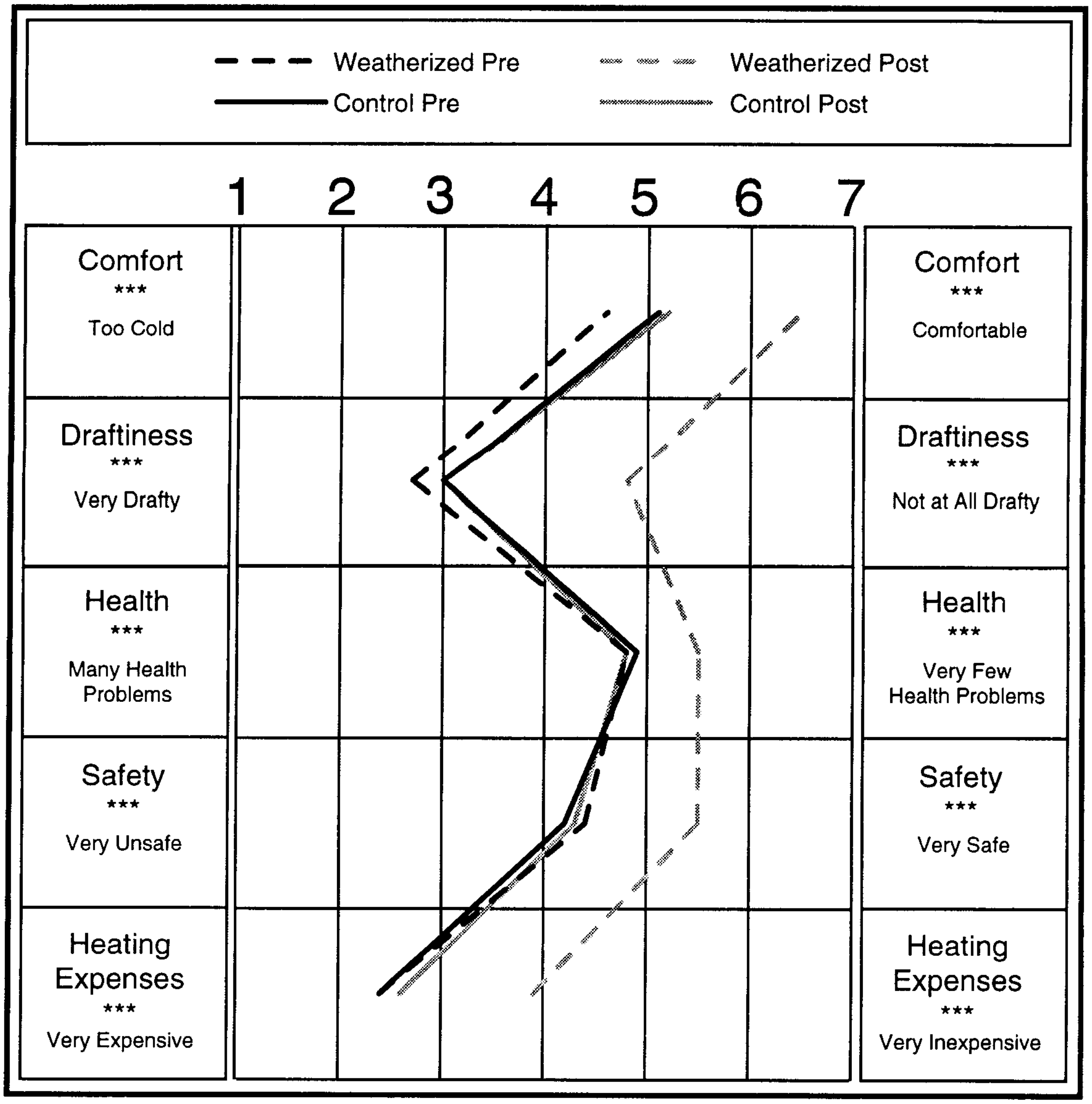

Fig. 6.1 Occupant Perceptions of Nonenergy Benefits of Weatherization in Weatherized and Control Dwellings

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

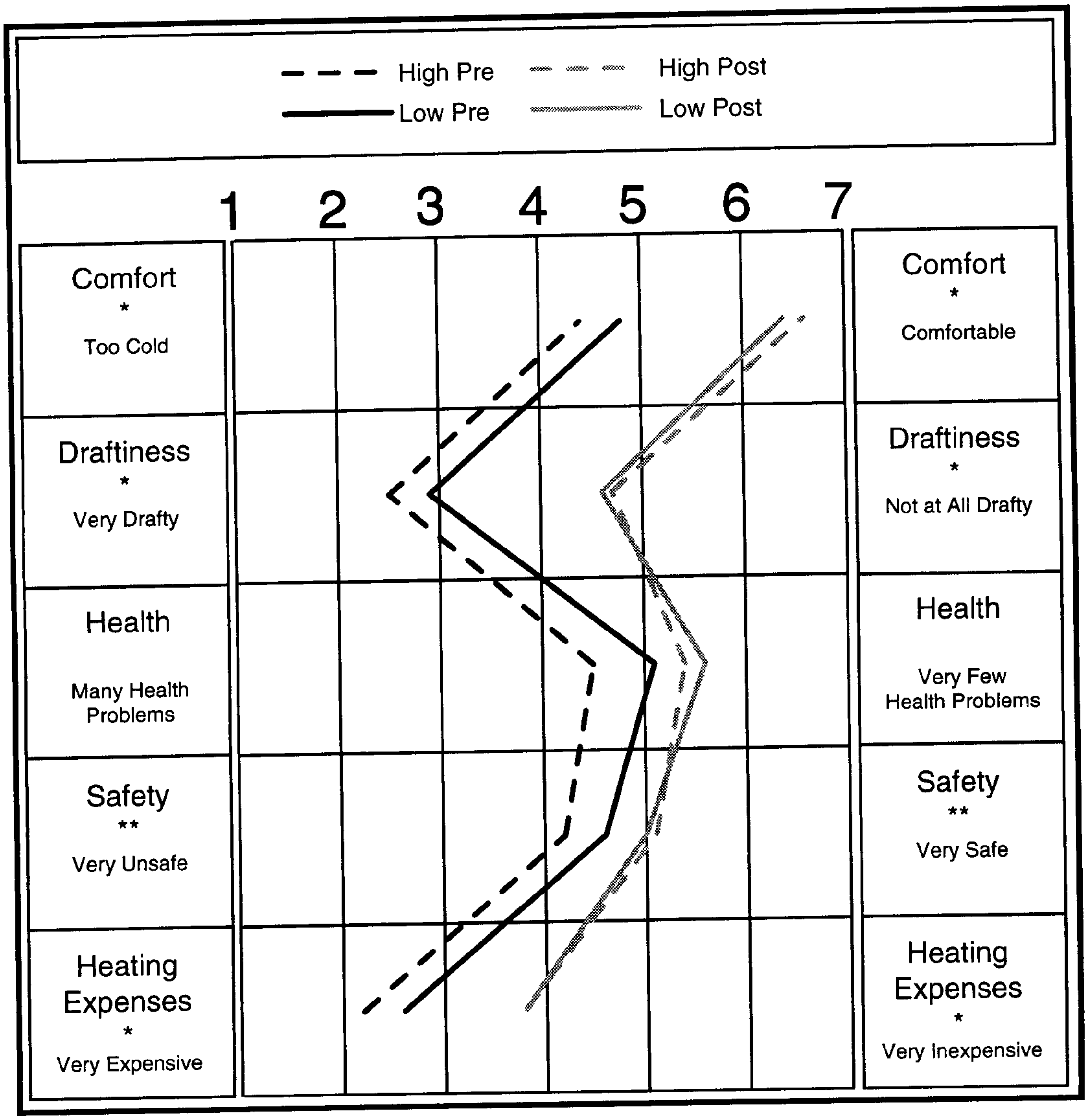

Fig. 6.2 Occupant Perceptions of Nonenergy Benefits of Weatherization in High- and Low-Saving Dwellings.

*, **, and *** indicate that differences between high- and low-saving dwellings are significant at the 0.05, 0.01, and 0.001 levels, respectively.

6.3 HIGHER- VS LOWER-SAVING AGENCIES

On every rating scale the occupants of dwellings weatherized by higher-saving agencies reported a significant and positive change between the before and after weatherization time periods. The occupants of dwellings weatherized by the lower-saving agencies also reported changes in all of the ratings (Fig. 6.3). Thus, both groups experienced improvements in the comfort and safety of their homes, and believed their homes became less drafty, and their heating bills more affordable after weatherization.

Both groups also reported an improvement in their own health. For each of the ratings, the amount of change for the higher-saving agencies was compared to the amount of change in the lower-saving agencies. None of these differences were statistically significant. Thus, the occupants of dwellings weatherized by the higher-saving agencies and by the lower-saving agencies reported about the same overall level of nonenergy benefits.

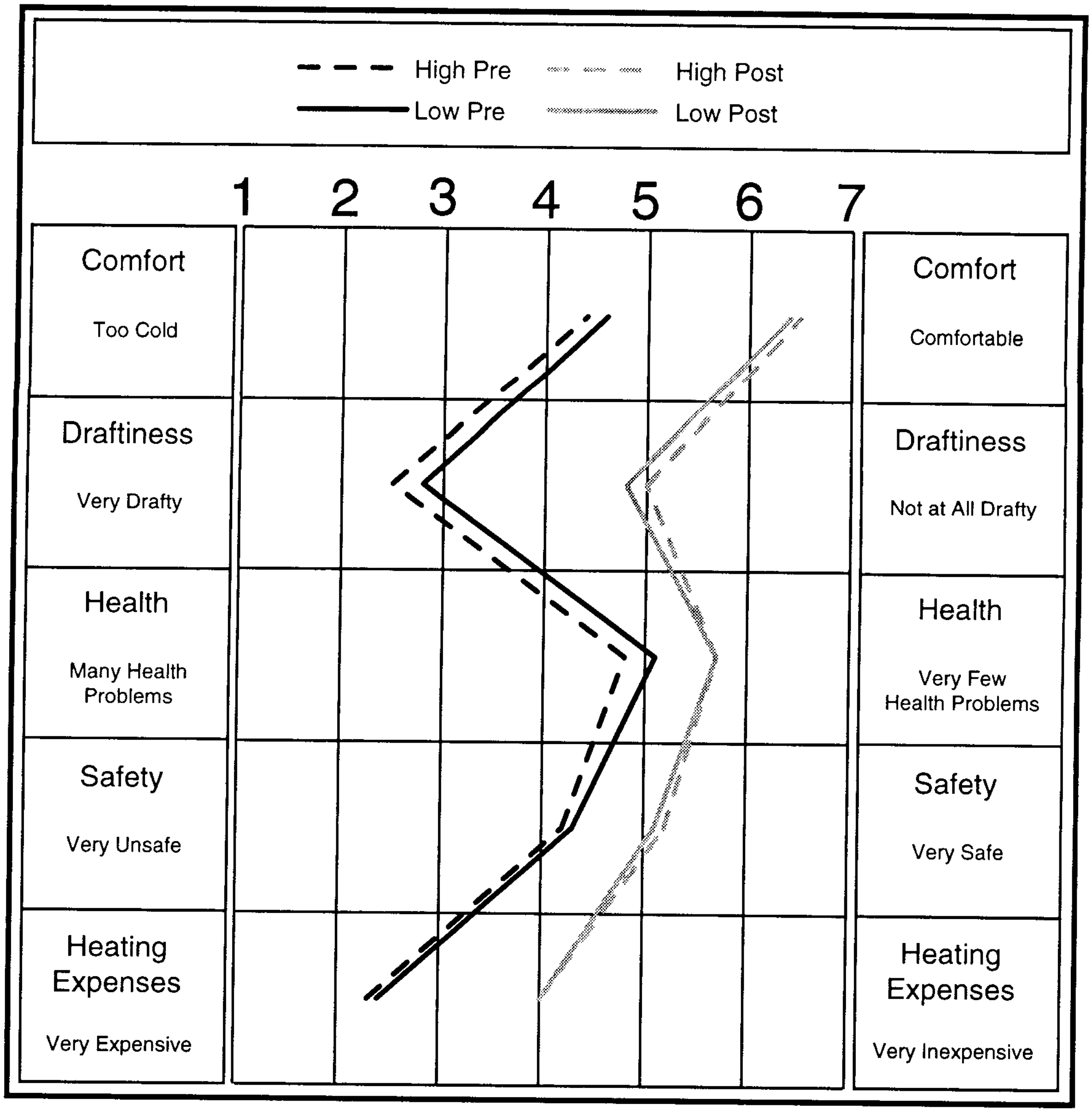

Fig. 6.3 Occupant Perceptions of Nonenergy Benefits of Weatherization in Higher- and Lower-Saving Agencies

*, **, and *** indicate that differences between the dwellings weatherized by the higher- and lower-saving agencies are significant at the 0.05, 0.01, and 0.001 levels, respectively.

7. CONCLUSIONS AND RECOMMENDATIONS

This study was designed to quantify various impacts of weatherization and to lead to a more complete understanding of the factors that produce high or low energy savings in individual homes and in local agencies. In this second phase of the Single-Family Study, detailed on-site data were used to assess energy-efficiency, health, safety, and comfort improvements and to highlight differences between high- and low-saving dwellings and higher- and lower-saving agencies.

The on-site measurements involved a detailed characterization of each dwelling, which included a complete description of the building shell, mechanical systems, and energy-efficiency features, as well as measurements of floor area, window area, volume, and conditioned space. The on-site inspectors also performed blower door tests, CO tests, and heating systems steady-state efficiency tests. An occupant interview was conducted to assess client perceptions of the nonenergy benefits of weatherization and to develop an analysis of how occupant behavior affected energy savings.

The quantification of the impacts of weatherization, and of the differences between high- and low-saving dwellings, and higher- and lower-saving agencies provided insight into the impacts and remaining potential of the following weatherization measures:

- air leakage control,
- health and safety measures,
- insulation,
- heating system and duct measures,
- structural repairs, and
- storm and replacement windows and doors.

In addition, the impacts of variations in weatherization expenditures on the magnitude of energy savings were examined, as were the impacts of variations in the pre-weatherization energy consumption of dwellings. Finally, occupant perceptions of nonenergy benefits were compared for weatherized vs. control groups, high- and low-saving dwellings, and higher-and lower-saving agencies. Major findings in each of these topic areas are summarized below.

7.1 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. As 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, many of them still were not as tight as would be optimal. Approximately 20% of the weatherized homes had air leakage rates that were at or below a threshold beyond which further tightening is generally not recommended. The remaining 80% seem to have more air leakage than is optimal. Experience with blower-door directed air sealing techniques developed in the past few years also indicates that additional cost-effective air leakage reduction is possible in the majority of client homes.

Higher-saving agencies had air leakage rates in their weatherized homes that were about the same as the the average for all weatherized homes. 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 are older and larger than the average dwelling and so may have been much leakier before weatherization. When air leakage is measured in air changes per hour, which takes the size of the dwelling into account and measures relative leakiness, the high-saving dwellings have a lower value than low-saving dwellings. The higher absolute leakiness of high-saving dwellings, however, measured at cfm_{50} , is a better indicator of the amount of heated air being lost, and, therefore, of the size of the opportunity for air leakage reduction.

7.2 HEALTH AND SAFETY

Nationwide, in PY 1989, about 18% of agencies routinely provided health and safety-related services. Some of these services, such as CO testing, and replacing broken glass or defective windows, are a standard part of the Program, supported by DOE funding. Other services, including the installation of smoke alarms and radon testing, are not a standard part of the Program and must be supported with funds from other sources.

In the phase two inspections, weatherized homes were more likely than control homes to have smoke alarms. Weatherized homes also were less likely than the control homes to have broken glass, or to have either windows or sashes that needed replacement. The better condition of the windows in the weatherized homes is especially significant because these phase two inspections took place several years after the homes were weatherized in PY 1989.

During the 1992 phase two inspections, carbon monoxide tests were performed in four locations (at the furnace flue, five feet from the heating system, at the nearest register, and in the living space) in each home. The results indicated that CO levels exceeded safe levels in each location in only a few homes, less than 2% of those inspected. The existence of CO problems in a few homes is not surprising, given that more than two years had passed since weatherization. In the small percentage of homes with dangerous CO levels, detection and correction is critical to the health and safety of the occupants. Corrective action was taken in all the homes in which unsafe levels were measured during the phase two inspections.

Higher-saving agencies do more CO testing (47% of their weatherized dwellings) than lower-saving agencies (17%). High-saving dwellings received CO tests almost twice as frequently as low savers. Because of the low incidence of CO problems, however, there were no statistically significant differences between these groups. Rates of installing smoke alarms, and of repairing broken glass and windows are about the same in the higher- and lower-saving agencies.

7.3 INSULATION

In PY 1989 attic insulation was added in 19.9% of weatherized homes and was installed for the first time in 28.0%. The mean R-value of attic insulation was almost twice as high in the phase two weatherized homes as in the control homes. In addition, nearly three times as many weatherized homes (21% vs 7.8%) had insulation that was at or above recommended R-values for dwellings in their climate region. The weatherized homes also had attic insulation R-values that were above the average for the U. S. housing stock in general. This indicates that dwellings in higher income groups also need higher levels of insulation, and that the Program is improving insulation in weatherized homes to a level that exceeds that found in the average home.

Although the R-values in weatherized homes are significantly higher than those in control homes, the R-values of the attic insulation in weatherized homes are still often below DOE-recommended levels. For example, about 26% of weatherized homes had R-values of less than R-19 and 63% had R-values of less than R-30. R-19 or less is below recommended levels in all climate regions in the U.S and R-30 is below the recommended level for all except the hottest regions. Thus, significant proportions of weatherized homes still have attic insulation with R-values below DOE-recommended levels, which 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. More installation of wall insulation, especially in the hot region, appears to be desirable.

These findings suggest that there is a substantial 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.

7.4 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 are generally old and inefficient. When heating systems are replaced, as they were in 4% of PY 1989 homes, high energy savings typically are produced. 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 saving agencies (Brown et al., 1993b). These findings suggest that the Program would benefit from access to greater resources to accomplish more heating system replacements.

The condition of ducts was poor in over 50% of the phase two weatherized homes. In PY 1989 distribution system work was completed on less than 7% of homes, far below the proportion that needs duct improvements. In the phase two inspections, the incidence of duct problems was the same in the weatherized and control groups. High- and low-saving dwelling and higher-and lower-saving agencies also had the same incidence, perhaps because duct improvements were performed so infrequently. Here again there is an unrealized opportunity to improve the energy efficiency of low-income dwellings.

7.5 STRUCTURAL REPAIRS

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 the total phase two sample, about 15% of homes had holes in walls and about 15% had holes in roofs. In the hot region, nearly 30% of homes had holes in walls and over 30% had holes in roofs. Nationally, repairs to floors, stairs, and porches also were needed in 5% to 20% of both control and weatherized homes, with homes in the hot region having the greatest need for repairs.

In every category of structural problem, the hot region had a higher incidence than the national average. In several categories, dwellings in the hot region were more than twice as likely to have a structural deficiency. The high level of structural problems in the hot region undoubtedly has a negative effect on the ability of agencies there to achieve energy savings comparable to those in other regions 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. In order to meet the need for structural repairs in low-income dwellings, substantial funding for housing rehabilitation must be obtained from leveraged sources. The DOE funds are not meant to be spent on major housing rehabilitation.

7.6 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. Rates of window and door replacements and repairs were lowest in the cold region and highest in the hot region. Storm windows were installed in over one-third of the weatherized homes, nationally, and over one-third of homes received replacement doors.

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%) than for the control homes (49%). In treated homes, that is in those weatherized homes in which the Program installed storm windows in PY 1989, 73% of their window area was covered with storms. 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 were covered.

In general, the higher-saving agencies install fewer window and door replacements and high-saving dwellings are more likely to receive window repairs than window replacements. Patterns of storm window installation rates, however, showed a weaker, or less consistent, association with low 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.

7.7 EXPENDITURES

In general, the more that is invested in weatherizing a dwelling, the greater the savings. Consistent with this linear trend, the high-saving dwellings received significantly larger investments than the low savers. High savers had direct costs of $1,192 (slightly above the national average of $1,050) and materials costs of $602 (approximately equal to the national average of $594). The low savers, in contrast, received an average investment of $714, or about 68% of the national average, and materials costs of only $427. A similar pattern was found for higher- and lower-saving agencies. In addition, both high-saving dwellings and higher-saving agencies invested more in air leakage, insulation, space-heating, and water-heating measures, and relatively less in structural repairs and in windows and doors.

Almost all of the higher-saving agencies used leveraged funds from non-DOE sources 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, and relied exclusively on DOE funding.

7.8 ENERGY CONSUMPTION

In phase one, pre-weatherization consumption was identified as the best predictor of energy savings. In this study, the same finding was demonstrated again. In particular, the high-saving dwellings used about 70% more energy before weatherization than the low-saving dwellings. Before weatherization the high savers also were significantly less energy efficient, consuming 25 Btu/square foot/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 vs. 932 ccf/year). The higher-saving agencies' homes used more energy, in part, because they tended to be larger and older. However, their average energy intensity measured in Btu/square foot/HDD also is 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. Thus, it is clear that weatherizing dwellings that are using more energy consistently produces more energy savings.

7.9 OCCUPANT PERCEPTIONS OF NONENERGY BENEFITS

Occupants of weatherized and control homes were asked to rate the comfort, draftiness, safety, and heating expenses for their homes. 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 draftiness of the dwelling).

On every rating scale the weatherized group reported a highly significant and positive change between the before and after weatherization time periods. 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 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 and safety of their homes, and believed their homes became less drafty and their heating bills more affordable after weatherization. Both groups also reported an improvement in their own health. For each of the ratings, the amount of change in the high-saving dwellings was compared to the amount of change in the low-saving dwellings. All of these differences, except the differences in the amount of change in health, were statistically significant. Thus, the occupants of the high-saving dwellings experienced not only more energy savings but also more nonenergy benefits in terms of improved comfort and safety, and reduced draftiness and heating expenses. Occupants of both the high- and low-saving dwellings reported about the same amount of change in their health.

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. Thus, both groups experienced improvements in the comfort and safety of their homes, and believed their homes became less drafty and their heating bills more affordable after weatherization. Both groups also reported an improvement in their own health. For each of the ratings, the amount of change for the higher-saving agencies was compared to the amount of change in the lower-saving agencies. None of these differences were statistically significant. Thus, the occupants of dwellings weatherized by the higher-saving agencies and by the lower-saving agencies reported about the same level of nonenergy benefits.

7.10 CONCLUSIONS

Overall, this study's findings reinforce the conclusions of the first phase of the Single-Family Study, that attic and wall insulation, water-heater measures, and heating system replacements are the measures most closely associated with high levels of energy savings (Brown et al. 1993a). The Fuel-Oil Study also identified the same measures as correlates of high savings (Ternes and Levins, 1993). In addition, all of these studies pointed to the strong association between high levels of pre-weatherization energy consumption and high savings. Greater efforts to target homes with the highest saving potentials, and to invest more of the available funds in the most effective measures would increase overall Program energy savings.

Nearly every type of measure examined in this report showed significant opportunities for additional energy-efficiency improvements. Opportunities for additional air sealing were present in 80% of client homes. The need for more frequent installations of attic and wall insulation was widespread, and especially important in the hot region. The poor condition of heating systems and ducts in many homes also pointed to opportunities for additional savings. Measures that cost the most to install, such as heating system replacements and wall insulation, are performed more infrequently than less expensive measures. The many unrealized opportunities for efficiency improvements suggest the Program is underfunded relative to the need for efficiency improvements in the low-income housing stock. In addition, regulations that limit the amount spent per dwelling do not allow agencies to achieve the maximum savings in many homes. Without increased funding, all of the available opportunities for energy-efficiency improvements cannot be realized.

Although many important, and cost-effective, energy-efficiency improvements are being implemented by the Program, more funding would make it possible to do much more. Because of the overhead costs involved in setting up work in each home, it would be most cost efficient to capture as many opportunities as possible during the DOE-sponsored installation. In addition, because a home will rarely be revisited at a later date, cost-effective measures which are not installed are likely to be long-term "lost opportunities." Leveraged funds from utilities, and other sources, are an important vehicle for providing more complete and comprehensive weatherization and for minimizing lost opportunities.

Many low-income homes need extensive structural repairs, which must be paid for with leveraged funds. Federal and state housing rehabilitation funds should be accessed to finance repairs whenever possible. In many homes, leveraging of housing rehabilitation funds to supplement DOE funds is an essential step in achieving minimal structural integrity and energy efficiency.

Further research is needed to quantify the energy-savings potential of additional investments. For instance, the results of an advanced home energy audit could be used to identify the cost-effective investments that practitioners currently are unable to install. Alternatively, a demonstration project could compare measured savings in a group of homes that received standard investment levels to a group of homes that received all the investments recommended as cost-effective by an advanced audit. More definitive documentation of this remaining potential would help utilities, and other potential providers of leveraged funds, to make more informed decisions about the cost effectiveness of forming partnerships with the DOE Program.

8. REFERENCES

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APPENDIX A

Example of Information Package Based on Phase One

FUEL CONSUMPTION

Agency: Energy Conservation Association
635 Bryant Street
Denver, Colorado 80202

House ID: 0018

Fuel Type: Gas (in ccf's)

Usage	
	10 26 88 PRE Weatherization
181	11 28 88
209	12 27 88
222	1 25 89
262	2 24 89
172	3 28 89
98	4 26 89
76	5 25 89
57	6 26 89
39	7 26 89
40	8 24 89
54	9 22 89
71	10 23 89
154	11 22 89
	1 24 90 POST Weatherization
207	2 23 90
149	3 26 90
115	4 25 90
89	5 24 90
54	6 25 90
56	7 25 90
34	8 23 90
54	9 24 90
75	10 24 90
116	11 26 90
191	12 26 90
176	1 24 91

2

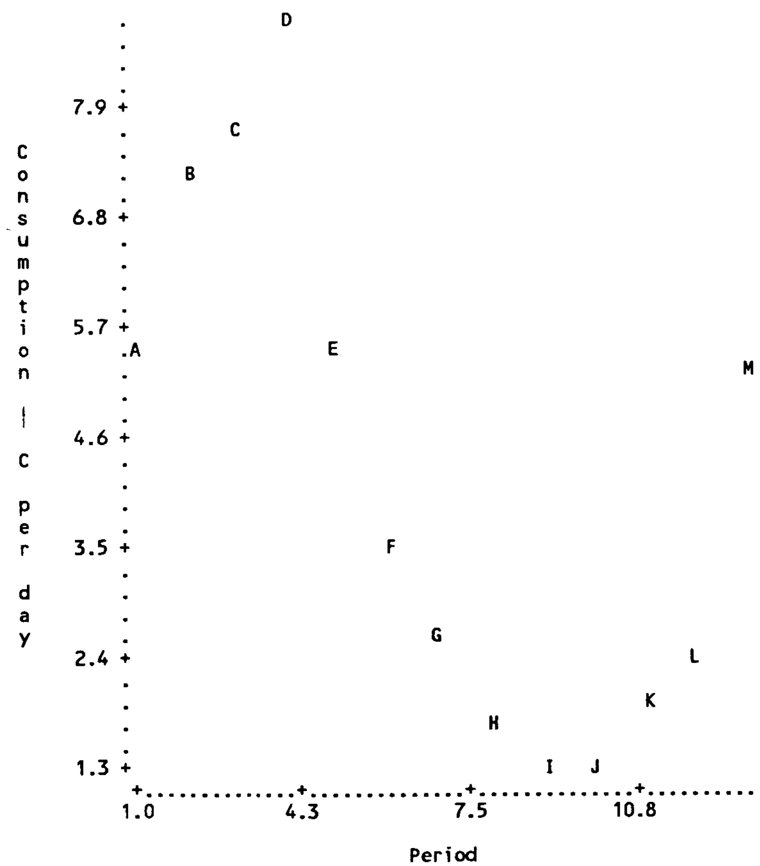
********************* PRISM-Heating Only (HO) **

UNIT ID	PRE OR POST	TIME PERIOD	# PDS	# DAYS	RAW CONS X	RXR	TREF	BASE LEVEL X PER DAY	HEAT SLOPE X PER HDD	HEATING PART X PER YEAR	NAC X PER YEAR
0018	PRE	10/26/88-11/22/89	13	392	1635C	0.988	63.7(2.1)	1.18(0.19)	0.195(0.012)	1079.(62.)	1512.(32.)
0018	POST	01/24/90-01/24/91	12	365	1316C	0.959	62.1(3.9)	1.54(0.26)	0.151(0.019)	774.(83.)	1336.(47.)

PRE-WEATHERIZATION NORMALIZED ANNUAL CONSUMPTION: 1511.71
POST-WEATHERIZATION NORMALIZED ANNUAL CONSUMPTION: 1335.7
NORMALIZED ANNUAL CONSUMPTION SAVINGS: 176.01

```
************************** PRISM-Heating Only (HO) ***************************

ESTIMATION FOR HOUSE 0018 , PERIOD: OCT 26, 1988 TO NOV 22, 1989
                        PREPOST=PRE UNITS=C

             REFERENCE      HEATING    BASE      NORM ANNUAL   R-SQUARE   NUM
             TEMPERATURE    SLOPE      LEVEL     CONSUMPTION              OF OBS

 ESTIMATES:     63.67        0.1948     1.1840     1511.7057    0.9877     13
(STD ERRS)     (2.07)       (0.0117)  (0.1936)     (31.8082)
  (CV%)        (----)       (  6.0%)  ( 16.3%)     (   2.1%)

HEATING PART OF NAC:      1079.2548 (62.4722)     % OF NAC:  71.4
  (CV%)                             (    5.8%)

TECHNICAL CODES:  J                               NUMBER OF ITERATIONS:   4

*****************************************************************************
```

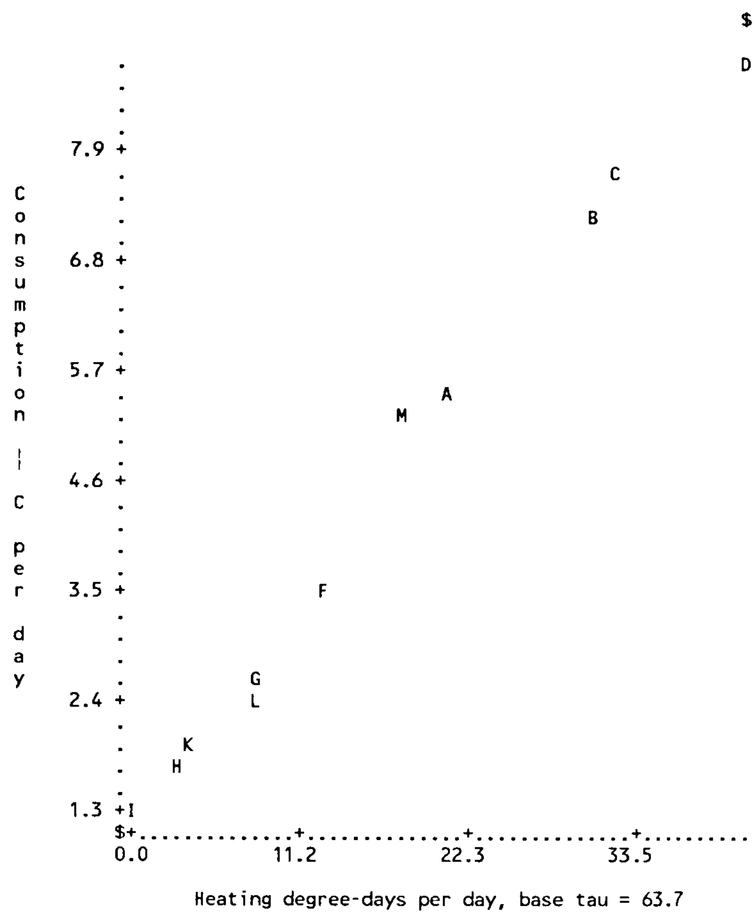
House: 0018 PRE



PERIODS:

```
A OCT 26,1988 to NOV 27,1988
B NOV 28,1988 to DEC 26,1988
C DEC 27,1988 to JAN 24,1989
D JAN 25,1989 to FEB 23,1989
E FEB 24,1989 to MAR 27,1989
F MAR 28,1989 to APR 25,1989
G APR 26,1989 to MAY 24,1989
H MAY 25,1989 to JUN 25,1989
I JUN 26,1989 to JUL 25,1989
J JUL 26,1989 to AUG 23,1989
K AUG 24,1989 to SEP 21,1989
L SEP 22,1989 to OCT 22,1989
M OCT 23,1989 to NOV 21,1989
```

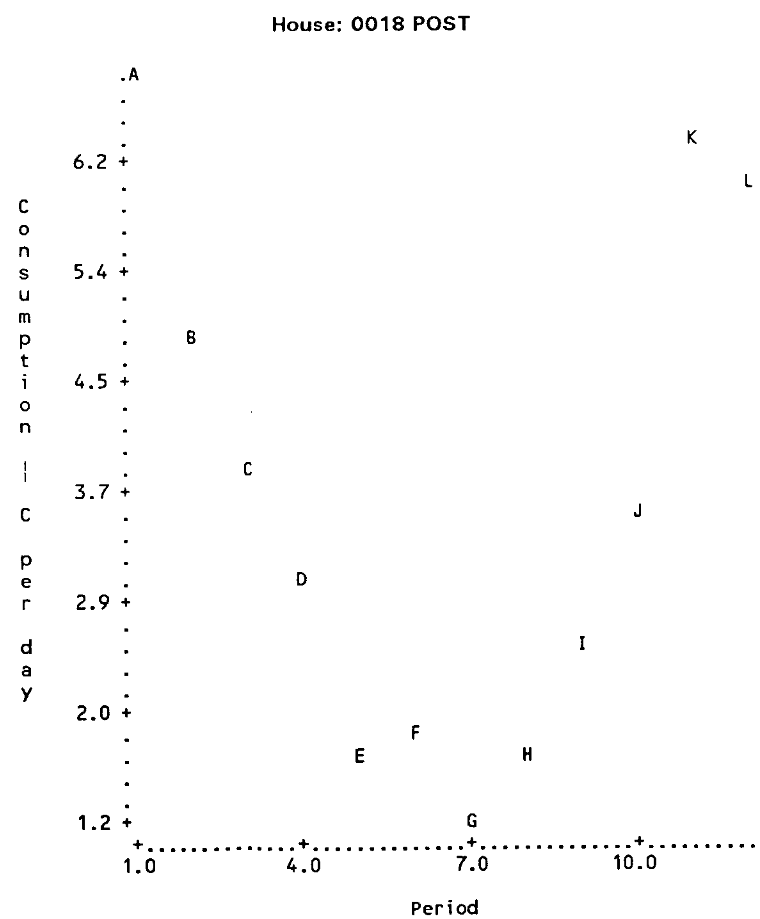
House:0018 PRE ,alpha = 1.18,beta = 0.19,R2 = 0.9877



PERIODS:

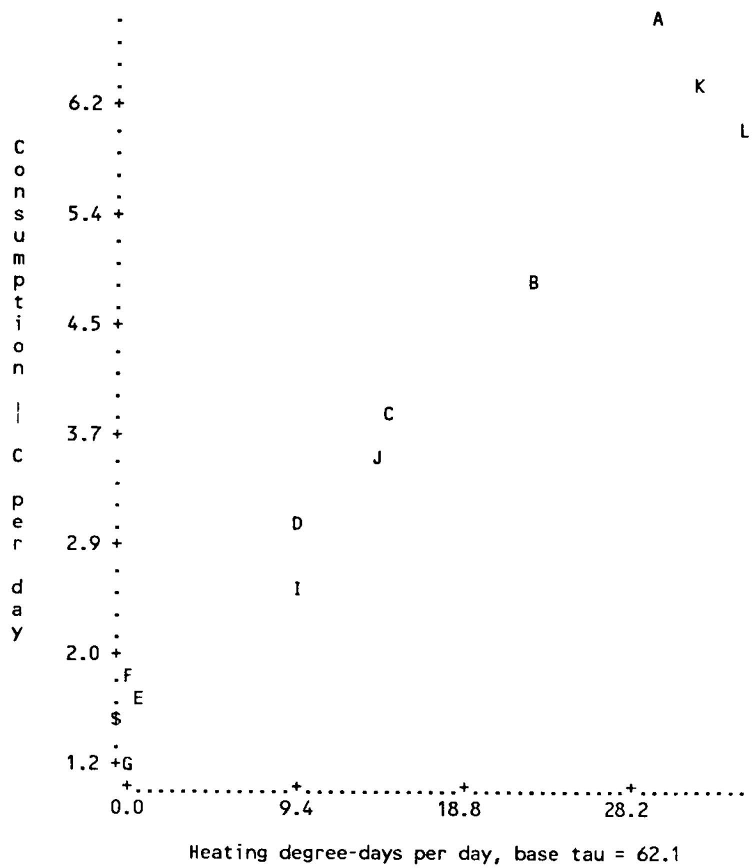
A OCT 26,1988 to NOV 27,1988
B NOV 28,1988 to DEC 26,1988
C DEC 27,1988 to JAN 24,1989
D JAN 25,1989 to FEB 23,1989
FEB 24,1989 to MAR 27,1989
F MAR 28,1989 to APR 25,1989
G APR 26,1989 to MAY 24,1989
H MAY 25,1989 to JUN 25,1989
I JUN 26,1989 to JUL 25,1989
JUL 26,1989 to AUG 23,1989
K AUG 24,1989 to SEP 21,1989
L SEP 22,1989 to OCT 22,1989
M OCT 23,1989 to NOV 21,1989

```
************************** PRISM-Heating Only (HO) ***************************

ESTIMATION FOR HOUSE 0018 , PERIOD: JAN 24, 1990 TO JAN 24, 1991
                     PREPOST=POST UNITS=C

            REFERENCE      HEATING    BASE       NORM ANNUAL   R-SQUARE   NUM
            TEMPERATURE    SLOPE      LEVEL      CONSUMPTION              OF OBS

 ESTIMATES:    62.07        0.1506    1.5387      1335.7010    0.9586     12
(STD ERRS)     (3.90)      (0.0190)  (0.2589)     (47.3514)
  (CV%)        (----)      ( 12.6%)  ( 16.8%)     (    3.5%)

HEATING PART OF NAC:       773.6774 (83.2418)    % OF NAC:  57.9
  (CV%)                             (  10.8%)

TECHNICAL CODES:                                 NUMBER OF ITERATIONS:   2

******************************************************************************
```




```
PERIODS:

A JAN 24,1990 to FEB 22,1990
B FEB 23,1990 to MAR 25,1990
C MAR 26,1990 to APR 24,1990
D APR 25,1990 to MAY 23,1990
E MAY 24,1990 to JUN 24,1990
F JUN 25,1990 to JUL 24,1990
G JUL 25,1990 to AUG 22,1990
H AUG 23,1990 to SEP 23,1990
I SEP 24,1990 to OCT 23,1990
J OCT 24,1990 to NOV 25,1990
K NOV 26,1990 to DEC 25,1990
L DEC 26,1990 to JAN 23,1991
```

House:0018 POST ,alpha = 1.54,beta = 0.15,R2 = 0.9586



PERIODS:

A JAN 24,1990 to FEB 22,1990
B FEB 23,1990 to MAR 25,1990
C MAR 26,1990 to APR 24,1990
D APR 25,1990 to MAY 23,1990
E MAY 24,1990 to JUN 24,1990
F JUN 25,1990 to JUL 24,1990
G JUL 25,1990 to AUG 22,1990
AUG 23,1990 to SEP 23,1990
I SEP 24,1990 to OCT 23,1990
J OCT 24,1990 to NOV 25,1990
K NOV 26,1990 to DEC 25,1990
L DEC 26,1990 to JAN 23,1991

DWELLING CHARACTERISTICS AND EQUIPMENT AS RECORDED ON OR NEAR 12 /89

HOUSE ID: 18

- DATE OF WEATHERIZATION: 12 /89
- DWELLING TYPE: SF-DETACHED
- CONDITIONED AREA OF DWELLING: 1776 SQUARE FEET
- OWNER OR RENTER: OWNER OCCUPIED
- MAIN HEATING FUEL: GAS
- PRESENCE OF SECONDARY FUEL: NO
- HEATING SYSTEM TYPE: CENTRAL
- AGE OF DWELLING: UNKNOWN
- PRESENCE OF CENTRAL AIR CONDITIONING: NOT REPORTED
- PRESENCE OF WINDOW/WALL AIR UNITS: NOT REPORTED

OCCUPANT CHARACTERISTICS AS RECORDED ON OR NEAR 12 /89

- TOTAL NUMBER OF DWELLING OCCUPANTS: 2
- NUMBER OF ELDERLY OCCUPANTS: 0
- NUMBER OF HANDICAPPED OCCUPANTS: 1

WEATHERIZATION MEASURES INSTALLED

INSULATION

- ATTIC INSULATION (ADDED TO EXISTING INSULATION) : IN-HOUSE

AIR LEAKAGE CONTROL

- GENERAL CAULKING AND WEATHERSTRIPPING : IN-HOUSE
- AIR SEALING, EMPHASIZING BYPASSES WITH BLOWER DOOR TESTING : IN-HOUSE

WATER HEATING SYSTEM

- WATER HEATER TANK INSULATION : IN-HOUSE
- LOW FLOW SHOWER HEADS : IN-HOUSE
- TEMPERATURE REDUCTION : IN-HOUSE

STRUCTURAL REPAIRS (FULL OR PARTIAL)

- ATTIC VENTILATION : CONTRACTOR
- DOORS : IN-HOUSE
- WINDOWS/GLAZING : IN-HOUSE

SPACE HEATING SYSTEM

- CLEAN AND TUNE-UP : IN-HOUSE
- SAFETY PROBLEM FIXED : IN-HOUSE
- REPAIRS : IN-HOUSE

OTHER HEALTH AND SAFETY REPAIRS OR IMPROVEMENTS

- CARBON MONOXIDE TESTING : IN-HOUSE

SERVICE DELIVERY PROCEDURES

- ENVELOPE MEASURES WERE SELECTED USING A PRIORITY OR PRESCRIBED LIST OF MEASURES
- ENVELOPE MEASURES WERE SELECTED USING A DECISION APPROACH OR SCORING (CALCULATION) DEVELOPED FOR EACH HOUSE
- ENVELOPE MEASURES WERE SELECTED BASED ON AN ANALYSIS OF ENERGY SAVINGS PER $ INVESTED
- SPACE-HEATING SYSTEM MEASURES WERE SELECTED BASED ON PHYSICAL CHARACTERISTICS OR A STANDARD APPROACH
- SPACE-HEATING SYSTEM MEASURES WERE SELECTED USING A DECISION APPROACH OR SCORING (CALCULATIONS BASED ON OPERATING PERFORMANCE
- SPACE-HEATING SYSTEM MEASURES WERE SELECTED BASED ON AN ANALYSIS OF ENERGY SAVINGS PER $ INVESTED
- OTHER MEASURE SELECTION PROCEDURES
- BLOWER DOOR TESTING WAS USED TO FIND LEAKAGE AREAS FOR SEALING
- BLOWER DOOR TESTING TO MEASURE AIR LEAKAGE RATES
- A HEATING SYSTEM SAFETY INSPECTION WAS CONDUCTED

BREAKDOWN OF MATERIALS COST

	CREW-BASED MATERIALS COST IN $	CONTRACTOR-BASED MATERIALS COST IN $
INSULATION		
ATTIC	137	0
WALL	0	0
OTHER	0	0
AIR LEAKAGE CONTROL	140	0
WATER HEATING SYSTEM REPLACEME	.	0
STRUCTURAL REPAIRS	.	20
WINDOWS AND DOORS	0	0
SPACE HEATING SYSTEM		
RETROFIT	34	0
REPLACEMENT	0	0
SPACE COOLING		
RETROFIT	0	0
REPLACEMENT	0	0
OTHER COSTS	.	0
TOTAL	312	20

CREW BASED INSTALLATION COSTS

NUMBER OF CREW HOURS: 26

AVERAGE HOURLY RATE :$ 8.50 MULTIPLY

TOTAL CREW COST :$ 221.

CONTRACTOR-BASED INSTALLATION COSTS

TOTAL INSTALLED COST:$ 169.

FUNDING SOURCE

PERCENT FUNDS SPENT ON THIS HOUSE FROM DOE WAP: 87 %
IF NON-DOE FUNDS WERE USED, WERE THEY USED ACCORDING TO DOE GUIDELINES ?Y

APPENDIX B

House Characteristics Survey Variables with Distributions and Means of Weatherized Dwellings

Auditor: ______________

Date: ______________

SINGLE-FAMILY STUDY HOUSE CHARACTERISTICS SURVEY

Control: ☐ Y=288
Weatherized: ☐ N=477

Average heating degree days MN=6090.46 MD=6320

Fuel units: (ccf or kWh) CCF=92.2% kWh=7.8%

Heated space MN=1162.81 MD=1056 sq ft

GENERAL

House type: ☐

House Type		
SFD	single-family detached	= 67.74%
SFA	single-family attached	= 11.11%
MFS	small (2-4 units) multifamily	= 14.10%
MH	manufactured or mobile home	= 6.84%
MHA	mobile home with addition	= 0.21%

The following systems are shared with other housing units:

Space-heating system	☐	Yes = 0.84%
Space-cooling system	☐	Yes = 0.63%
Water-heating system	☐	Yes = 1.68%

If SFA, number of attached housing units: MN=1.39 MD=1

AIR CONDITIONERS

Unit type	Nameplate Information: Input (watts)	Voltage (volts)	Current (amps)	Rated Efficiency EER	Rated Output (Btu/h)	Age (years)
	MN=1636.1 MD=1308	MN=133.1 MD=115	MN=11.4 MD=12	MN=7.2 MD=7.5	MN=12,936 MD=11,000	MN=9.6 MD=10

Window Air Conditioner removed during heating season ☐ Yes = 4.82%

Air Conditioner Type
- CAC central air conditiner = 14.7%
- CHP central heat pump = 0%
- WAC window air conditioner = 62.8%
- WMAC Wallmount air conditioner = 3.8%
- WHP window heat pump = 0%
- EC evaporative cooler = 18.6%
- X other __________ = 0%

THERMOSTATS

Thermostat type ____

Thermostat voltage code ____

Thermostat type:
- M manual = 88.3%
- A analog setback = 4.6%
- E electronic setback = 3.45%
- X other = 0.23%
- N none__________ = 3.45%

Thermostat voltage
- L low voltage (24 V) = 88.9%
- H 110/120 volt = 1.3%
- M milivolt = 7.8%
- G gas expansion bul = 1.3%
- X other __________ = 0.78%

		Yes
Thermostat dysfunctional	☐	2.10%
Thermostat has no calibration	☐	1.70%
Thermostat loose on wall	☐	2.10%
Thermostat not level	☐	2.90%

Thermostat calls for heat MN=2.31 MD=2 °F

Higher or Lower than actual temperature
High = 56.4%
Low = 43.6%

Anticipator setting MN=0.51 MD=0.5 amps

Solenoid amperage rating MN=1.27 MD=0.42 amps

Solenoid valve actual draw MN=0.66 MD=0.4 amps

FLOOR AREAS AND VOLUMES

Sketch plans: **1st floor** **2nd floor**

Floor	Total area	Intentionally heated area	Unintentionally heated area	Air-conditioned area	Height	Volume (of heated area)
Basement	MN=767 sqft MD=759 sqft	MN=558 sqft MD=602 sqft	MN=663 sqft MD=672 sqft	MN=180 sqft MD=0 sqft	MN=7.6 ft MD=7.5 ft	MN=5149cft MD=5238cft
First floor	MN=922 sqft MD=885 sqft	MN=894 sqft MD=873 sqft	MN=89 sqft MD=36 sqft	MN=570 sqft MD=532 sqft	MN=8.2 ft MD=8 ft	MN=7294cft MD=7160cft
Second floor	MN=643 sqft MD=599 sqft	MN=614 sqft MD=578 sqft	MN=255 sqft MD=36 sqft	MN=191 sqft MD=45 sqft	MN=8.0 ft MD=8 ft	MN=5015cft MD=4668cft
All other floors	MN=674 sqft MD=470 sqft	MN=255 sqft MD=234 sqft	MN=397 sqft MD=121 sqft	MN=0 sqft MD=0 sqft	MN=8.0 ft MD=8 ft	MN=3452cft MD=2919cft
Total	MN=1514sqft MD=1401sqft	MN=1201sqft MD=1055sqft	MN=447sqft MD=354sqft	MN=566sqft MD=432sqft		MN=10341cft MD=9360cft

(use for heated volume calculations)

Number of intentionally heated stories: MN=1.41 MD=1 (1, 1.5, 2, 2.5, 3, 3.5, 4 or more)

Notes: ______________________________

FOUNDATION SPACES

		Bsmt/crawl Ceiling		Foundation Perimeter			Wall height		Wall insulation	
Type	Space Status	Ceiling area	Insulation thickness	Ttl lgh(ft)	% expsd	% insltd	Total	% above ground	Type	Thickness
		MN=828.4 MD=800	MN=1.2 in MD=0 in	MN=106.7 MD=112	MN=68.6 MD=91	MN=27.2 MD=0	MN=5.8 ft MD=7 ft	MN=40.9% MD=30.5%		MN=1.8 in MD=0 in

Foundation type
B basement = 57.5%
C crawlspace = 29.2%
C-B crawlspace open to basement = 3.6%
US uninsulated slab = 8.9%
IS insulated slab = 0.8%

Foundation space status
NH not heated = 44.4%
IH intentionally heated = 15.9%
UH unintentionally heated = 39.8%

Wall insulation type
BC blown cellulose = 1.5%
BF blown fiberglass = 0.5%
FB fiberglass batt = 14.6%
RB rigid board or foam = 1.9%
BRW blown rock wool = 0%
RWB rock wool batt = 0%
WFB wood fiber batt = 0%
X other__________ = 0.5%
N none = 81%

ATTICS

Insulation type (Heated)
BC blown cellulose=42.1%
BF blown fiberglass=2.6%
FB fiberglass batt=36.8%
RB rigid board or foam=0%
BRW blown rock wool=0%
RWB rock wool batt=1.3%
WFB wood fiber batt=0%
V vermiculite=0%
X other ____________=0%
N none=17.1%

Unheated Attic type
F floored=13.3%
U unfloored=73.8%
L flat roof=12.9%

Insulation type (Unheated)
BC blown cellulose=47.8%
BF blown fiberglass=18.9%
FB fiberglass batt=20.8%
RB rigid board or foam 1%
BRW blown rock wool=2.6%
RWB rock wool batt=0.2%
WFB wood fiber batt=0.2%
V vermiculite=0.5%
X other ____________=1.2%
N none=6.7%

HEATED ATTIC AREAS (Within the Thermal Envelope)				UNHEATED ATTIC AREAS (outside envelope)			
		Insulation				Insulation	
	Area	Type	Thickness	Attic type	Floor area	Type	Thckns
Collar beam	MN=375sqft		MN=5.6in		MN=735sqft		MN=7.3in
Kneewall to exterior	MD=283sqft		MD=6in		MD=737sqft		MD=7in
Kneewall to storage							
Roof rafter							
Gable End							
Kneewall floor							

Vent type (see graphic)
G gable = 36.4%
E eave = 10%
L lourvre strip = 9.4%
P perferations = 0.8%
BV button vents = 3.3%
RJ roof jack = 7.4%
M mushroom = 22.1%
R ridge = 2.5%
T turbine = 2.2%
PV power vent = 1.0%
WHF whole house fans = 0%
X other ___________ = 3.7%
N none = 1.2%

Attic vents present: ☐

Types:								
High or low:	high	low	high	low	high	low	high	low
Number each:	MN = 2.96; MD = 2.0							
Total net free vnt area	MN = 241.5"; MD = 200.0"							

EXTERIOR ELEVATIONS Sketch each view

Front

Orientation: N NE E SE S SW W NW
(circle appropriate orientation)

Left side

Orientation: N NE E SE S SW W NW
(circle appropriate orientation)

Rear

Orientation: N NE E SE S SW W NW
(circle appropriate orientation)

Right side

Orientation: N NE E SE S SW W NW
(circle appropriate orientation)

Notes:

____

____

WALL DATA

Wall exposure	Exterior type	Wall type	Gross wall area		Insulated sheathing	Insulation Type	Insulation Thickness
			MN = 866.1 MD = 795	sq ft	Yes = 6.1%		MN =3.3 in MD = 3.5 in
				sq ft	☐		
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in
				sq ft	☐		in

Wall exposure
O outside = 82.1%
B buffered space = 13.5%
(unconditioned porch, garage, vacant bldg.etc.)
AC attached conditioned space=4.4%
(e,g. heated adjoining neighbor)

Insulation type
BC blown cellulose = 28.5%
BF blown fiberglass = 3.3%
FB fiberglass batt = 25.2%
RB rigid board or foam = 0.7%
BRW blown rockwool = 0.1%
RWB rock wool batt = 0%
WFB wood fiber batt = 0%
X other _________ = 1.2%
N none = 0.7%

Exterior type
WT same as wall type material = 6.8%
(adobe, block, masonry etc)
WO wood or masonite = 25.2%
WS wood shingle = 8.2%
AL aluminum, steel = 18.9%
V Vinyl = 7.3%
ST stucco = 6.8%
BR brick or stone = 12.4%
AS asphalt shingle = 5.9%
RA rolled asphalt = 0.2%
AT asbestos tile = 3.2%
C cellulostic board = 1.9%
(fake brick etc)
X other _________ = 2.6%
N none = 0.8%

Wall type
PF platform frame = 68.5%
BF balloon frame = 17.7%
BL block or ceramic = 0.9%
A adobe = 0.3%
ST solid stone or masonry=7.0%
HM hollow masonry = 1.8%
(e.g. multi wythe brick)
FP firred out plaster=2.1%
over masonry
L log = 0%
P plank = 0.6%
X other _________ = 0.9%

EXTERIOR CHIMNEY INSPECTION

	Space Heat		Hot water	
	Shared chi chimney ☐		if separate	
Chimney type:		Yes		Yes
Chimney not lined	☐	17.60%	☐	4.20%
Chimney extends < 2 ft above roof	☐	13.60%	☐	4.20%
Clearance at chimney top < 10 ft	☐	5.70%	☐	2.30%
Trees etc near chimney	☐	1.50%	☐	0.21%
Chimney unsound	☐	2.50%	☐	1.30%
Chimney not capped	☐	16.10%	☐	2.30%
# of unused chimneys:	MN = 0.32 MD = 0			

Space Heat Chimney type
B brick = 55.5%
Bl block = 5.36%
SP single walled pipe=16.4%
IP insulated pipe=20.9%
MF multiple flue=1.9%

Hot Water Chimney type
B brick = 24.0%
Bl block = 1.04%
SP single walled pipe=38.5%
IP insulated pipe=35.4%
MF multiple flue=1.04%

WINDOWS AND DOORS

Window summary (required) (For intentionally heated area only)

Glazing type	Frame type	Storm window	Sky light	Area
			Yes=1.5%	sq ft
			☐ MN = 123.8	sq ft
			☐ MD = 108	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft
			☐	sq ft

Window Glazing Type
SP single pane = 83.9%
DP double pane = 14.6%
TP Triple pane = 0$
GB glass block = 1.0%
TE temporary (cardboard, plastic, etc.) = 0.5%
LE Low-E (may also be single or double pane: e.g.:" LE/DP" = 0%

% window area facing 30° of true south without blockage ______ % MN = 18.2% MD = 20%

Frame Type
W wood=66.6%
S steel=2.5%
A Aluminum=26.6%
V vinyl=3.4%
X other________=0.5%
N none=0.5%

Storm Window
W wood =11.1%
S steel=0.5%
A Aluminum=51.0%
V vinyl=3.0%
X other________=1.8%
N none=32.6%

EXTERIOR DOORS

Door #	Door type	Storm door	Vesti-bule	Lites
Door 1		Yes=55.2%	Yes=21.2%	Yes=41.5%
Door 2		☐	☐	☐
Door 3		☐	☐	☐
Door 4		☐	☐	☐
Door 5		☐	☐	☐

Door type
RP Raised panel wood door=28.5%
HC Hollow core wood door=15.3%
SC Solid core wood door=40.9%
I Insulated metal door=10.0%
SG Sliding glass door =4.3% (include dimensions under window summary above)
B Bulkhead door =1.1%

MISCELLANEOUS HEALTH AND SAFETY CHECKS

ELECTRICAL SYSTEM CHECK

Wire types seen in attic and basement:		Yes
Knob and tube	☐	8.40%
Fabric	☐	22.60%
BX	☐	19.50%
Romex	☐	51.20%
Conduit	☐	20.10%
Aluminum	☐	0.42%
Wiremold	☐	1.50%
Extensive use of extension cords	☐	6.70%
Exposed bare wiring	☐	6.10%
Other electrical hazards ______________		4.60%

MOISTURE CHECK

		Yes
Standing water in basement	☐	4.80%
Signs of basement water	☐	12.60%
Peeling paint exterior	☐	6.50%
Peeling paint interior	☐	12.00%
Interior mold	☐	6.70%
Rafter & stud ghosting	☐	2.30%
Rotted wood	☐	7.80%
Signs of roof leakage	☐	17.00%
Signs of condensation in attic	☐	2.10%
Missing or failed gutter system	☐	13.00%
Unvented dryer	☐	7.80%
No bathroom vents or wondows	☐	6.10%
Other moisture problems ______________		5.50%

HAZARDOUS MATERIALS

		Yes
Septic conditions	☐	2.90%
Combustion byproducts	☐	1.70%
VOC's	☐	4.60%
Asbestos	☐	12.40%
Dust	☐	10.90%
Mold & mildew	☐	7.10%
Smokers	☐	22.40%
Animal waste	☐	6.10%
Vermin	☐	2.90%
Other toxic hazards ________________		2.50%

STRUCTURAL PROBLEMS

		Yes
Floors	☐	7.60%
Foundation	☐	3.40%
Stairs	☐	6.10%
Walls	☐	4.10%
Roof	☐	5.50%
Porch	☐	4.60%
Holes in walls	☐	14.70%
Holes in ceilings	☐	15.50%
Broken out glass	☐	6.90%
Sashes need replacement	☐	4.00%
Windows need replacement	☐	8.00%
Other structural problems _____		3.80%

CLUTTER

		Yes
Attic	☐	4.60%
Basement	☐	19.50%
Living space	☐	15.50%
Yard	☐	3.60%
Other related problems ______		2.70%

FIRE HAZARDS

		Yes
Electrical	☐	4.40%
Space heaters	☐	8.40%
VOC's	☐	3.40%
Other combustibles	☐	1.10%
Lack of access	☐	1.90%
Lack of smoke alarms	☐	32.10%
Signs of furnace flame roll-out		2.70%
Signs of water heater flame roll-		81.50%
Other fire hazards __________		4.60%

Notes and explainations ____

____

____

SPACE-HEATING SYSTEMS

	Primary System
System type	
Fuel	
Original fuel if converted	
Nameplate rating	MN=109,822; MD=105,000
Input Btu	MN=98,793; MD=100,000
Output Btu	MN=84,553; MD=80,000
System Age	MN=16.5; MD=15
Location	

Fuel
NG natural gas=91.0%
P propane = 0%
O oil = 0.2%
K kerosene = 0%
E electricity = 8.2%
W wood = 0.7%
C coal = 0%
S solar = 0%
X other = 0%

Location
NH non-heated space = 10.6%
IH intentionally heated space = 47%
UH unintentionally heated space = 42.4%
UNH unintentionally not heated space=0%

	Primary System	Yes
Fuel Leaks	☐	5.6(
No vent damper	☐	11.90%
Electrical cutoff switch missing	☐	10.60%
Insecure wiring	☐	3.70%
Combustible materials near flue	☐	2.60%
Asbestos insulation on furnace or boiler		4.80%
Pilot type		

Pilot type:
S standing pilot=70.5%
E electronicly ignited pilot=22.6%
I intermittant ignition device=6.1%
X other=0.5%
N none________=0.3%

System Types
Central Systems
1 forced air furnace=63%
2 gravity furnace=2.7%
3 one pipe steam boiler=3.1%
4 two pipe steam boiler=0.2%
5 pumped hot water boiler with radiators/convectors=7.1%
6 convective hot water boiler with radiators/convectors=0.4%
7 hot water boiler for slab heating=
8 heat pump=0%
In-space heaters
Fossil Fueled:
9 free standing convective room heater=8.4%
10 forced air wall furnace=1.6%
11 gravity wall furnace=4.4%
12 forced air floor furnace=0.2%
13 gravity floor furnace=1.6%
14 vaporizing pot heater (oil and kerosene)=0%
15 portable kerosene=0%
Electric:
16 wall=0.2%
17 floor=0.4%
18 baseboard=4.2%
19 ceiling radiant (imbedded)=0.9%
20 wall or floor radiant (imbedded)=0%
21 portable (cord-connected) radient=0.9%
22 portable (cord-connected) fan assisted=0%
23 window heat pump=0%
Other
24 wood or coal stove=0.2%
25 fireplace=0%
26 stove top or oven=0%
27 passive solar=0%
28 active solar=0%
29 other ________=0%
30 none=0%

INTERIOR FLUE INSPECTION

		Space Heat	Hot Water
Shared chimney		Yes = 39.9%	
Shared flue		Yes = 25.2%	
Unit not vented to the exterior	Yes	14.30%	15%
Structurally unsound		16.10%	15.20%
Leaks exist		3.50%	2.40%
No flue liner present		10.60%	8.00%
Thick debris present		1.50%	0.90%
Vent pipe has negative or no slope		19.30%	18.20%
No barometric damper, draft hood or system equivalent		2.80%	1.50%
Combustible materials near flue		3.70%	2.40%

DISTRIBUTION SYSTEMS

ALL SYSTEMS:

Location	Intentionally heated area	Unintentionally heated area	Un-heated area
Distribution system location	☐ 33.2%	☐ 28.7%	☐ 38.1%
Insulated	☐ 18.7%	☐	☐

Type of insulation [ ]

Friable asbestos insulation on distribution system [Yes=7.0%]

Insulation type
RF rigid preformed fiberglass=0%
FB fiberglass house batts=15.8%
FD fiberglass ductwrap=13.8%
F foam=2.6%
A asbestos=18.9%
X other ________=3.1%
N none=45.9%

HYDRONIC SYSTEM	☐	Yes=8.5%	Yes
Gravity system	☐		0.20%
Pump-driven	☐		7.60%
Conversion from gravity system	☐		0.43%
Outdoor temperature reset/cutoff	☐		0%
Boiler operating temperature	°F		
High limit control	°F / psi		
Zoned system	☐		5.21%
Number of zones:	[ ]		MN=1.46; MD=1
Zoned with zone valves	☐		0.90%
Zoned with multiple pumps	☐		0.90%
Radiators	☐		3.50%
Baseboards	☐		4.30%
Slab	☐		0%
Ceiling	☐		0%
Leaks in distribution system	☐		0.20%
Blocked/covered radiators/convectors	☐		0.70%

STEAM SYSTEM	Yes=2.6%	Yes
One pipe system	☐	2.40%
Two pipe system	☐	0.40%
Thermostatic radiator valves	☐	0%
Steam leaks	☐	0.20%
Blocked or covered radiators/convectors	☐	0.20%

ELECTRIC RESISTANCE HEAT	Yes=3.9%
Number of Thermostat/Controls	MN=2.04; MD=0
Number of Calibrated Thermostats	MN=1.07; MD=0
Linear ft of Electric Baseboard	MN=11.44; MD=0

HOT AIR SYSTEM Yes=66.8% Yes

Heat exchanger cracks observed	☐	0.40%
Flue gas odor noticed in house	☐	0.90%
Furnace fan speed	High / Medium / Low	H = 39.1%; M = 190.5%; L = 7.8%
Furnace temperature controls		
High limit	°F	MN = 190.5; MD = 200
Fan on	°F	MN = 128.0; MD = 130
Fan off	°F	MN =98.7; MD = 100
Fan size	Yes cfm hp	MN = 0.3; MD = .33
Fan dirty	11.50%	hp = 100%
Belt loose	3.30%	
Bearings noisy	1.30%	
Integral humidifier present	9.30%	
Humidifier dysfunctional	6.50%	
Air filter type		
Location of air filter		
Condition of air filters		
Filter wrong size	2.40%	
Filter slot open	3.00%	
General condition of ducts		
In-line dampers present	18.40%	

Filter type
F fiberglass(replaceable)=69.7%
W washable=23.5%
E electronic=0.4%

Location of air filters
H Fan housing=72.4%
E external slot=25.7%
R remote (return air register)=2.0%

Condition of ducts
S sealed=15.2%
T tight=45.1%
L leaky=35.3%
V very leaky=3.3%
D disconnected=0.8%
O open=0.4%
R restricted=0%

Condition of air filters
N none=6.9%
C clean,=51.2%
DU dusty, =17.9%
D dirty, =17.9%
P plugged=6.1%

Furnace distribution system sketch:

Duct type
- R round
- O oval
- RE rectangular
- F flex
- P panned
- B building cavity
- PP platform plenum

Duct Material
- A aluminum
- G galvanized
- D ductboard
- W wood
- P plywood
- PL plastic
- S sheetrock
- X other

Damper settings
- (O) open
- (C) closed
- (P) partly closed

Duct integrety key
- (D) disconnect
- (O) open
- (L) leak
- (R) restriction
- (B) blockage

Location
- NH non-heated space
- IH intentionally heated space
- UH unintentionally heated space
- UNH unintentionally not heated space

Notes:

___

___

Supply ducts

Duct Type	Duct Mtrl	Location	Space status	Condition	Insulation type	Insulation thickness	Cross section (in sq in)	Total Length	Total Register size (sq in)
						MN=0.48 in	MN=46.7	MN=16.9 ft	MN=78.1
						MD=0 in	MD=32	MD=12 ft	MD=60
						in		ft	
						in		ft	
						in		ft	
						in		ft	
						in		ft	
						in		ft	
						in		ft	
						in		ft	
						in		ft	
								Total:	MN=374.1 MD=304

Duct type
R round=67.0%
O oval=0%
RE rectangular=30.4%
F flex=1.8%
P panned =0.6%
B building cavity=0.19%
PP platform plenum=0.1%

Duct Material
A aluminum=1.1%
G galvanized=95.3%
D ductboard=0%
W wood=0%
P plywood0.3%
PL plastic1.8%
S sheetrock=0.1%
X other=1.3%

Duct location
B basement=75.1%
C crawlspace-10.9%
A attic=6.0%
G garage=0%
L living space=3.5%
W wall cavities=4.1%
F floor cavities=0.5%

Space status
NH non-heated space=25.4%
IH intentionally heated space=24.3%
UH unintentionally heated space=50.3%
UNH unintentionally not heated space=0%

Condition
S sealed
T tight=41.1%
L leaky=46.8%
V very **leaky**=3.6%
D disconnected=0.6%
O open=0.4%
R restricted=0%
B blockage=0%

Duct Insulation Type
DB ductboard=0.1%
FB fiberglass house batts=7.1%
FD fiberglass ductwrap=9.1%
IF interior fiberglass=0%
F foam=0%
A Asbestos=7.6%
X other _________=0.9%
N none=75.2%

Return Duct Summary

Duct Type	Mtrl	Location	Space status	Condition	Insulation type	Insulation thickness	Minimum Cross section (sq in)	Total Length	Total Register size (sq in)
						MN = 0.2 in	MN=115.7	MN=16.9 ft	MN=78.1
						MD = 0 in	MD=80	MD=12 ft	MD=60
						in		ft	
						in		ft	
						in		ft	
						in		ft	

Total cross section of return air system at its most restricted point: ______ sq in

Total: MN=336.9 MD=288

DOMESTIC WATER-HEATING SYSTEM

Type: [ ]
Fuel: [ ]
Location: [ ] Yes
Age [MN=8.5; MD=8]

Fuel Leaks	2.10%
Water leaks at tank	1.50%
Water line leaks	1.30%
Wiring insecure	0%
Pressure relief valve	1.70%

Water Heater Type
SA stand alone system=99.2%
T tankless [integrated with space-heating system=0.4%
SST seperate insulated storage tank attached to boiler=0%
I instant tankless=0%
X other ______________=0.2%
N none=0.2%

Water heater Location
NH non-heated space=20.2%
IH intentionally heated space=35.9%
UH unintentionally heated space=43.9%
UNH unintentionally not heated space=0%

Fuel
NG natural gas=82%
P propane =0%
O oil =0.2%
K kerosene=0%
E electricity =17.6%
W wood =0%
C coal =0%
S solar =0%
X other________=0.2%

		Yes
No external blanket insulation used		25.80%
Blanket improperly installed or falling off		6.50%
Type of factory insulation:	foam	10.80%
	fiberglass	89.20%

Thickness of factory insulation [ ] in. [MN=1.3; MD=1]

Temperature setting [MN=134.6; MD=135] °F [Hot=32.2 Warm=59.5 Low=8.4]
(record highest setting for electrically heated systems)

Water temperature measured at nearest tap [MN=128.6; MD=130]

Water pipes insulated [Yes=40.3%] [MN=41.4%; MD=20] % of total expose length
Pipe Insulation type [ ]

Pipe Insulation Type
RF rigid preformed fiberglass=17.7%
FB fiberglass house batts=2.8%
FD fiberglass ductwrap=5.9%
F foam=54.3%
A Asbestos=0.4%
X other ________=0.7%
None=18.3%

HOT WATER SYSTEM DRAFT (for Natural gas and propane units only)

Outdoor temperature MN=46; MD=43 °F

Test	Conditions					Measurements			
	Exhaust fans & clothes dryer	Door from water heater zone to House	Furnace Burner	Air Handler		Δ P Water Heater Zone to Outside	Water Heater Draft in.w.c. or Pa	Water Heater CO	Time to Establish Draft at Water Heater
Pre	off	open	off	off	Water	MN=0 MD=0	MN=-.22 MD=-.01		
1	on	open	off	off	off	MN=0 MD=0	MN=-.06 MD=0		
2	on	closed	off	off	off	MN=0 MD=0	MN=-.11 MD=0		
immediately after firing	on	worst case:open or closed	off	off	off	MN=0 MD=0	MN=-.42 MD=0	MN=12.8 MD=6	MN=.6 MD=0
	Water heater flame roll-out expe				on	☐			
30 sec.	on	same	off	off			MN=-.33 MD=-.005	MN=15.4 MD=7	
1 minute	on	same	off	off	on		MN=-.37 MD=0		
2 minutes	on	same	off	off	on		MN=-.49 MD=-.01		
3 minutes	on	same	off	off	on	MN=0 MD=0	MN=-.54 MD=-.01	MN=9.4 MD=4	

Firing rate from label Btu/hr on MN=36,450; MD=36,000

Cubic feet from meter in 36 seconds: MN=0.9; MD=0.4

HEATING SYSTEM TESTS

Pre-Test (All combustion systems)

Conditions: Yes

Exhaust fans and clothes dryer **off** ☐ 42.80%

Gas fired water heaters **off** ☐ 45.30%

Furnace burner **off** ☐ 47.20%

Air handler **off** ☐ 43.40%

[Pa] Δ P Heating system zone to exterior [MN=1.13; MD=0.01]

Exhaust fans and clothes dryer **on** ☐ 0%

Door to heating system zone in worst case position (from hot water test)

☐ open or 76.50%

☐ closed 23.50%

Measure:

[°F] Outdoor temperature [MN=43.1; MD=40]

[Pa] Δ P Heating system zone to exterior [MN=0.1; MD=0]

[wc] Draft at heating system flue [MN=0; MD=0]

[ppm] Ambient CO [MN=2.3; MD=1.5]

Initial Start up Test

Furnace burner on **on** ☐ 41.30%

☐ Experience furnace flame roll-oı 7.10%

30 seconds after firing

[%] Oxygen at heating system flue [MN=11.56;]

[wc] Draft at heating system flue [MN=0; MD=0]

1 minute after firing

[%] Oxygen at heating system flue (Watch for change when fan comes on) [MN=11.19;]

[wc] Draft at heating system flue [MN=0; MD=0]

Air Handler Fan-On Tests (Furnace systems only):

As furnace fan come **(may be earlier or later than this in timed sequence)**

[%] Oxygen at furnace flue [MN=11.3; MD=11.4]

[Pa] Δ P Heating system zone to exterior [MN=0.3; MD=0]

[wc] Draft at furnace flue [MN=0; MD=.007]

Furnace spillage record (All comb ustion furnaces and boilers)

[MN=0.7 MD=0] [min] Time for heating system to stop spilling (establish draft)

(if longer than 3 minutes shut down and correct)

Worst case test

Re-establish worst case depressurization (with furnace air handler on)

Reverse door between space heating room and house (if closed, open it; if open, close it)

[MN=-0.42 MD=0] Open [Pa] Δ P Heating system zone to exterior

[MN=-0.35; MD=0] Closed [Pa] Δ P Heating system zone to exterior

Final worst case condition ☐ Open [87.8%] ☐ Closed [11.16%]

Water heater spillage check (under worst case conditions)

Furnace air handler **on** ☐ 26.6%

Water heater **refired** ☐ 31.9%

MN=1.5 MD=0	min	Time for water heater to stop spilling (establish draft)

High Limit Shut Down

If furnace or boiler reaches high limit temperature and shuts off before reaching steady state

MN=367.6; MD=360	°F	Maximum stack temperature reached
MN=201.2; MD=195	°F	Maximum plenum or boiler temperature reached

Steady-State Efficiency test

Test equipment identification number ☐

Water heater **off** ☐ 34.20%

Exhaust fans and clothes dryer **off** ☐ 32.10%

Furnace **at steady state:** ☐

MN=0; MD=.003	wc	Draft at furnace flue
MN=10.5; MD=10.5	%	Oxygen at furnace flue (for 02-based systems)
MN=4.6; MD=4.2	%	CO2 at furnace flue (for CO2-based test systems))
MN=394; MD=390	°F	Furnace stack temperature
MN=68.7; MD=68	°F	Room Temp (if not subtracted from furnace temperature)
MN=354; MD=350	°F	Net stack temperature
MN=75.9; MD=76.5	.%	Steady state efficiency

Gas firing rate measurement (All natural gas units)

Record firing rate from label		Btu/hr	MN=99,508; MD=100,000
Count cubic feet at meter in 36 seconds:			MN=1.94; MD=1.03

Carbon Monoxide tests (All combustion furnaces)

MN=18.0; MD=4	ppm	CO at furnace flue
MN=2.6; MD=2	ppm	CO five feet from space heating system
MN=2.4; MD=1	ppm	CO at nearest register
MN=2.3; MD=1	ppm	CO in living space

Yes	8.60%	☐	Gas stove top on ?
	6.10%	☐	Gas oven on ?
	3.60%	☐	Kerosine space heater on ?
	1.90%	☐	Other possible source of CO ____________________

Register temperature check (All hot air systems)

Temperature at:

MN=140.9; MD=140	°F	Supply plenum as close to heat exchanger as possible
MN=79.3; MD=75	°F	Down stream of filter - closest to furnace plenum as possible
MN=130.2 MD=130	°F	Close supply register
MN=119.8; MD=120	°F	Far supply register
MN=78.2; MD=75	°F	Close return register
MN=75.8; MD=74	°F	Far return register

Filter-Removed Steady State Test (For hot air systems with clogged, removable filters:)

Filter **removed** ☐ 8.00%

Temperature at:

MN=145.6; MD=151	°F	Supply plenum as close to heat exchanger as possible
MN=85.4; MD=78	°F	Down stream of filter - in fan compartment

If there is a significant change in ΔT, do a revised steady state test:

MN=.01; MD=.01	wc	Draft at furnace flue
MN=10.6; MD=10	%	Oxygen at furnace flue (for 02-based systems)
MN=3.8; MD=3.8	%	CO2 at furnace flue (for CO2-based test systems))
MN=387.7; MD=360	°F	Furnace stack temperature
MN=72.1; MD=70.5	°F	Room Temperature (if not subtracted from furnace temperature)
MN=341.6; MD=307.5	°F	Net stack temperature
MN=76.3; MD=77.8	.%	New steady state efficiency

Filter **replaced** ☐ 7.10%

Room depressurization test (for closed-door rooms without return air regsters)

MN=0.36; MD=0	Pa	Δ P house to main bedroom
MN=0.57; MD=0	Pa	Δ P house to exterior
Door closed in other room		Room I.D.
MN=0.37; MD=0	Pa	Δ P house to main bedroom
MN=0.41; MD=0	Pa	Δ P house to exterior
Door closed in other room		Room I.D.
MN=0.26; MD=0.01	Pa	Δ P house to main bedroom
MN=0.05; MD=0	Pa	Δ P house to exterior
Door closed in other room		Room I.D.
MN=-0.16; MD=0.01	Pa	Δ P house to main bedroom
MN=-0.17; MD=0	Pa	Δ P house to exterior
Door closed in other room		Room I.D.
	Pa	Δ P house to main bedroom
	Pa	Δ P house to exterior

All houses:

Do blower door tests and duct protocol

BLOWER-DOOR TEST DATA SHEET:
MINNEAPOLIS BLOWER DOOR -- Type 3 Test equipment i.d. number: ______________

Unusual procedures to prepare house for test: ______________

Indoor temperature Start	Indoor temperature Finish	Outdoor temp.	Average wind speed	Maximum wind gust	Local shielding class	Number of stories	House Volume (from p. 2)
MN=72.1 MD=72	MN=70.1 MD=71	MN=46.3 MD=40	MN=3.9 MD=3	MN=7.7 MD=5		MN=1.4 MD=1	MN=10233 MD=9108

Basement door: open | closed | Other conditions:

Goal	House pressure	Fan Pressure	Fan Configuration (circle one): Open	Ring A	Ring B	Flow rate (cfm)
10 Pa	MN=5.9 MD=.3	MN=770 MD=45	Open 39.5%	A 40.3%	B 6.2%	MN=1921 MD=1827
15 Pa	MN=9.9 MD=15	MN=744 MD=55	Open 49.%	A 45.2%	B 5.7%	MN=2090 MD=1979
20 Pa	MN=13.7 MD=20	MN=473 MD=55	Open 39.2%	A 47.2%	B 13.6%	MN=1796 MD=1549
25 Pa	MN=17.1 MD=25	MN=464 MD=68	Open 41.7%	A 46.6%	B 11.7%	MN=1986 MD=1695
30 Pa	MN=20.5 MD=30	MN=506 MD=75	Open 45.8%	A 44.6%	B 9.5%	MN=2111 MD=1843
35 Pa	MN=23.6 MD=35	MN=518 MD=81	Open 47.5%	A 44.4%	B 8.1%	MN=2276 MD=1975
40 Pa	MN=26.8 MD=40	MN=545 MD=90	Open 49.4%	A 43.1%	B 7.5%	MN=2462 MD=2178
45 Pa	MN=30 MD=45	MN=578 MD=99	Open 50.8%	A 44.1%	B 5.1%	MN=2533 MD=2254
50 Pa	MN=36.7 MD=50	MN=366 MD=90	Open 50.%	A 45.6%	B 4.4%	MN=2648 MD=2400
60 Pa	MN=44.8 MD=60	MN=182 MD=95	Open 51.2%	A 45.6%	B 3.2%	MN=2722 MD=2500

Describe house air leakage characteristics ______________

List leakage sites in perceived order of magnitude (# 1 being gr 7______________
1______________ 4______________ 8______________
2______________ 5______________ 9______________
3______________ 6______________

Use Lines 1-6 of Duct Protocol sheet to record one-point blower door measurements.

APPENDIX C

Occupant Surveys

Final version
10/19/92

Interviewer______________________

Date of Interview_________________

SINGLE-FAMILY STUDY OCCUPANT QUESTIONNAIRE: **WEATHERIZED HOME**

A. Identification

INTERVIEWER INSTRUCTIONS:

Complete Questions A1, A2, and A5 using data from the local weatherization agency before starting the interview.

A1. Dwelling Unit Identifier __ __ __ __ __

A2. Name of WAP Applicant ______________________________

A3. Name of local WAP Agency ______________________________

SCREENER:

The purpose of this screening section is to locate a suitable respondent. This screening should be done by telephone before the site visit, if possible.

ASK TO SPEAK TO THE APPLICANT NAMED IN QUESTION A2. IF AVAILABLE, READ THE FOLLOWING :

Your home was weatherized as a participant in the Weatherization Assistance Program. As a follow up to that we would like to conduct an interview to learn more about how that weatherization may have affected your energy use and ask your opinions regarding the value of weatherization. Will you be available on (date and time of the site visit) to answer these questions?

IF THE APPLICANT NAMED IN QUESTION A2 IS NOT AVAILABLE, CONTINUE WITH THE FOLLOWING:

Your home was weatherized as a participant in the Weatherization Assistance Program. As a follow up to that we would like to conduct an interview to learn more about how that weatherization may have affected your energy use and ask your opinions regarding the value of weatherization. I'd like to speak to a person over 18 years of age who is knowledgeable about energy use. Would you be able to answer these questions? Will you be available on (date and time of the site visit) to answer these questions?

(IF YES, RECORD THIS PERSON'S NAME IN QUESTION A4. IF NO, IDENTIFY SUITABLE RESPONDENT AND CONFIRM THEIR AVAILABILITY ON THE DATE AND TIME OF THE SITE VISIT AND RECORD THEIR NAME IN A4.)

INTERVIEWER INSTRUCTIONS:

IF RESPONDENT IS HESITANT: Your answers to these questions will provide valuable information to the Department of Energy. The interview will take approximately 30 minutes.

INTERVIEWER INSTRUCTIONS:

BEGIN THE ON-SITE INTERVIEW HERE.

Ask to speak to the person previously identified in the telephone screening (QUESTION A4). If that person is not available try to identify another suitable respondent. If no suitable respondent can be identified leave the exhibits and explain that the interview will be conducted by telephone at a later date.

A4. Name of respondent____

Relation to WAP applicant____
[ ] RESPONDENT IS SAME AS WAP APPLICANT

INTRODUCTION

Your home was weatherized as a participant in the Weatherization Assistance Program. As a follow up to that we would like to conduct an interview to learn more about how that weatherization may have affected your energy use and ask your opinions regarding the value of weatherization. First, I would like to confirm the date of the weatherization work.

A5. Date of WAP weatherization work ____

A6. In what year was this home built? Just your estimate.*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985	[ ] 1990
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986	[ ] 1991
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987	[ ] 1992
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988	
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989	

A7. In what year did your family move into this home?*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985	[ ] 1990
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986	[ ] 1991
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987	[ ] 1992
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988	
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989	

IF "1987" OR LATER ON QUESTION A7, ASK:

A8. During which month did you move in?*

[ ] January	[ ] May	[ ] September
[ ] February	[ ] June	[ ] October
[ ] March	[ ] July	[ ] November
[ ] April	[ ] August	[ ] December

INTERVIEWER INSTRUCTIONS:

If respondent moved into the home after March of 1989, do not ask him/her the before questions in Sections B through G.

B. Major Heating Fuel

Next, I will ask some questions about the fuels you used to heat your home during the winters before and after weatherization on (READ DATES FROM QUESTION A5). *Throughout the survey, when I ask about the winter **before** weatherization, I mean the winter of 1988-1989. The winters **after** weatherization include the winters of 1990-1991, and of 1991-1992.*

INTERVIEWER INSTRUCTIONS:

Hand Exhibit Booklet to the respondent and ask him/her to look at Exhibit B. Discuss the time line and ask the respondent to identify any personal events that coincide with the winter before and the two winters after weatherization.

INTERVIEWER INSTRUCTIONS:

If two or more heating fuels are used, the **main heating fuel** is the one that provides most of the heat for the home. The main heating fuel may not necessarily be the one used for the central heating system.

B1. Please look at Exhibit B1. What was the **one main heating fuel** used for heating your home during the winter **before** weatherization?*

	B1 Main Fuel (Mark only one)	B2 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood...........	[ ]	[ ]
Bottled gas (LPG or Propane)........	[ ]	[ ]
Fuel oil.......................	[ ]	[ ]
Kerosene or coal oil...............	[ ]	[ ]
Electricity....................	[ ]	[ ]
Coal or coke....................	[ ]	[ ]
Wood.......................	[ ]	[ ]
Solar collectors..................	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED...............	[ ]	[ ]
DON'T KNOW................	[ ]	[ ]

2. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the winter **before** weatherization was (FUEL FROM QUESTION B1). What **other** fuels were used to heat your home during the winter before weatherization -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B2. IF NONE, MARK "NO FUELS USED")*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B2, ASK:

B3. Going back to your **main heating fuel** used during the winter **before** weatherization--(FUEL FROM QUESTION B1) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

[ ] All or almost all (95% or more)
[ ] About three-fourths (67-94%)
[ ] Closer to half (66% or less)
[ ] DON'T KNOW/REMEMBER

Now, I will ask similar questions about the fuels you used during the winters ***after*** *weatherization. The winters* ***after*** *weatherization include the winters of 1990-1991, and of 1991-1992.*

B4. Please look at Exhibit B1 again. What was the **one main heating fuel** used for heating your home during the winters **after** weatherization?*

	B4 Main Fuel (Mark only one)	B5 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED.	[ ]	[ ]
DON'T KNOW.	[ ]	[ ]

B5. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the winters **after** weatherization, was (FUEL FROM QUESTION B4). What **other** fuels were used to heat your home during the winters after weatherization -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B5. IF NONE, MARK "NO FUELS USED".)*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B5, ASK:

B6. Going back to your **main heating fuel** used during the winters **after** weatherization --(FUEL FROM QUESTION B4) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

- [ ] All or almost all (95% or more)
- [ ] About three-fourths (67-94%)
- [ ] Closer to half (66% or less)
- [ ] DON'T KNOW/REMEMBER

B7a. Please look at Exhibit B7. During the winter **before** the weatherization work was done, did you use any of the following to **help** heat your home? (USE COLUMN B7a TO CHECK AS MANY AS WERE USED.)

(B7a) BEFORE		(B7b) AFTER
[ ]	Wood/coal stove.	[ ]
[ ]	Fireplace.	[ ]
[ ]	Cooking stove/range/oven.	[ ]
[ ]	Non-portable room heater burning gas, oil, or kerosene.	[ ]
[ ]	Portable kerosene heater.	[ ]
[ ]	Non-portable electric heater	[ ]
[ ]	Electric portable heater (cord-connected).	[ ]
[ ]	Other (specify):______________________________. . .	[ ]
[ ]	NONE.	[ ]

B7b. Please look at Exhibit B7 again. During the winters **after** the weatherization work was done, did you use any of the following to **help** heat your home? (USE COLUMN B7b TO CHECK AS MANY AS WERE USED.)

INTERVIEWER INSTRUCTIONS:

Confirm that responses to B7a do not contradict responses to B1 and B2. Confirm that responses to B7b do not contradict responses to B4 and B5. Probe the respondent if the responses contradict.

ASK QUESTION B8 ONLY FOR EACH ITEM IN QUESTION B7 USED BOTH BEFORE AND AFTER WEATHERIZATION:

B8. Please turn to Exhibit B8. Please tell me how often you used the following to help heat your home during the winters **after** the weatherization work was done, as compared to the winter **before** the weatherization work was done. Did you use it less, about the same, or more **after** weatherization as compared to **before** weatherization? (CIRCLE ONE NUMBER IN EACH LINE ASKED.)

	Used Less After	Used About The Same	Used More After
1. Wood/coal stove	1	2	3
2. Fireplace	1	2	3
3. Cooking stove/range/oven	1	2	3
4. Non-portable room heater burning gas, oil, or kerosene	1	2	3
5. Portable kerosene heater	1	2	3
6. Non-portable electric heater	1	2	3
7. Electric portable heater (cord-connected)	1	2	3
8. Other (________________)	1	2	3

C. Demographics

Now I have some questions about the people who live here and about your housing costs.

C1. Please tell me how many people living in your home during the winter **before** weatherization were . . . (READ EACH ITEM).

Under the age of 5 ________________

Between 5 and 17 years old ________________

Between 18 and 64 years old ________________

65 years old or older ________________

TALLY -- so that is (READ NUMBER) in total? ______________________
ENTER CORRECT TOTAL HERE

C2. You have told me that there were (READ TOTAL NUMBER FROM QUESTION C1) people living in your home during the winter **before** weatherization. How many people were living in your home during each of the winters **after** weatherization?

____________________ NUMBER OF RESIDENTS IN THE WINTER OF 1990-91

____________________ NUMBER OF RESIDENTS IN THE WINTER OF 1991-92

C3. Were any of the people living in your home during the winter **before** weatherization handicapped? By handicapped, I mean a permanent condition. I do not mean a temporary condition, such as a short-term illness. (EYEGLASSES ARE NOT CONSIDERED A HANDICAP). (IF YES, ASK HOW MANY.)

____________________ NUMBER HANDICAPPED

C4. Do you or members of your household own your home, or rent?*

[ ] Own (buying)
[ ] Rent
[ ] Occupied without payment of rent (SKIP TO SECTION D)

FROM QUESTION C4, IF HOUSEHOLD OWNS OR PAYS RENT, ASK:

C5. Please tell me which category best describes the monthly rent or mortgage payment the household pays for your home. Is it . . .? Stop me when I reach the category. (READ CATEGORIES.)

[ ] less than $200 per month
[ ] $201 - 300 per month
[ ] $301 - 400 per month
[ ] $401 - 500 per month
[ ] $501 - 600 per month
[ ] $601 - 700 per month
[ ] $701 - 800 per month
[ ] $801 - 900 per month
[ ] more than $900 per month
[ ] OWNED, MORTGAGE PAID OFF (SKIP TO SECTION D)
[ ] DON'T KNOW

C6. Does this payment include: (READ ITEMS AND PROBE FOR "YES" OR "NO".)

	Yes	No	DON'T KNOW
1. electricity.	[ ]	[ ]	[ ]
2. natural gas.	[ ]	[ ]	[ ]

D. Conditioned Living Space

My next question is about the number of different types of rooms in your home. Remember that when I ask about the winter **before** weatherization, I mean the winter of 1988-1989. When I ask about the winters **after** weatherization, I mean the winters of 1990-1991, and of 1991-1992. Weatherization work was done to your home on (READ DATES FROM QUESTION A5).

INTERVIEWER INSTRUCTIONS:

For one-bedroom efficiency or studio apartment, record "0 bedrooms" and number of bathrooms and other rooms.

Full Bathroom -- sink with running water **and** flush toilet **and** bathtub or shower.

Half Bathroom -- toilet **or** bathtub **or** shower

D1. How many of each of the following rooms does this home have? (ASK EACH ITEM AND RECORD NUMBER FOR EACH.)*

	D1 Total Number	D2A Number heated during the winter **before** weatherization	D2B Number heated during the winters **after** weatherization
Bedroom?.	________	________	________
Full bathrooms?.	________	________	________
Half bathrooms?.	________	________	________
All other rooms:.	________	________	________

(Do not count laundry rooms, foyers or unfinished storage space. Only count porches if they are enclosed and used year-round.)

D2. (FOR EACH TYPE OF ROOM THE RESPONDENT HAS IN THE HOME, ASK D2A, THEN D2B. A HEATED ROOM IS ONE THAT IS WARM ENOUGH TO BE USED.)

D2a. Of the (READ NUMBER OF ROOMS AND TYPE OF ROOM), how many were heated during the winter **before** weatherization (RECORD ABOVE ON COLUMN D2A.)

D2b. And how many (READ TYPE OF ROOM) were heated during the winters **after** weatherization? (RECORD ABOVE ON COLUMN D2B.)

E. Thermostat Management

I would now like to ask you some questions about the temperature at which you kept your home.

INTERVIEWER INSTRUCTIONS:

Remember, we are interested in the respondent's perceptions. Ask the respondent for their opinion; avoid checking the thermostat for the actual settings.

If respondent keeps different sections of the home at different temperatures, we want to know the temperature in the part of the house where the people are. If, for example, the heat is turned off upstairs during the day because the family is downstairs, we want the downstairs temperature.

We would like to know the actual temperature of the home. If the respondent doesn't know the temperature, but does know the thermostat setting, record the thermostat setting. Otherwise, probe for best estimate.

E1a. During the winter **before** weatherization, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E1B)
[ ] Changed the temperature (GO TO QUESTION E1C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E1A, ASK:

E1b. **Before** weatherization, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(GO TO QUESTION E2A)

IF CHANGED THE TEMPERATURE ON QUESTION E1A, ASK:

E1c. **Before** weatherization, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E1d. **Before** weatherization, at what temperature did you **usually** keep your home during the day **when no one was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E1e. **Before** weatherization, at what temperature did you **usually** keep your home **during sleeping hours**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(ASK EVERYONE:)

E2a. During the winters **after** weatherization, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E2B)
[ ] Changed the temperature (GO TO QUESTION E2C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E2A, ASK:

E2b. **After** weatherization, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(GO TO SECTION F)

IF CHANGED THE TEMPERATURE ON QUESTION E2A, ASK:

E2c. **After** weatherization, at what temperature did you **usually** keep your home during the day **when someone was at home?***

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2d. **After** weatherization, at what temperature did you **usually** keep your home during the day **when no one was at home?***

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2e. **After** weatherization, at what temperature did you **usually** keep your home **during sleeping hours?***

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

F. Events Affecting Energy Use

The next questions are about events which may have affected your energy use during the winters, before and after weatherization.

F1a. During the winter **before** your home was weatherized, was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued**........ your gas or electric service?	[ ]	[ ]

IF "YES" TO EITHER PART OF QUESTION F1A, ASK:

F1b. Thinking about these times that you went without heat, during the winter **before** weatherization, how many separate times were there?

Total times: ________

F1c. Altogether, how many hours or days were you without heat?
Total hours without heat: ________ OR Total days without heat: ________

F2a. During the winters **after** your home was weatherized was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued**........	[ ]	[ ]

your gas or electric service?

IF "YES" TO ANY PART OF QUESTION F2A, ASK:

F2b. Thinking about these times that you went without heat, during the winters **after** weatherization, how many separate times were there?

Total times: __________

F2c. Altogether, how many hours or days were you without heat?

Total hours without heat: __________ OR Total days without heat: __________

F3. Except for the weatherization of your home on (READ DATES FROM QUESTION A5), was there any home repair, major house renovation, or damage to your house that would affect energy use done between January 1987 and September 1992?

[ ] Yes
[ ] No
[ ] DON'T KNOW

IF YES ON QUESTION F3, ASK:

F4. Please describe the home repair, renovation, or damage. (RECORD VERBATIM BELOW.)

		MONTH/YEAR
(1)	______________________________	__________
	______________________________	__________
(2)	______________________________	__________
	______________________________	__________
(3)	______________________________	__________
	______________________________	__________

F5. In which month/year was the work or damage done? (RECORD UNDER COLUMN FOR MONTH/YEAR ABOVE.)

G. Impacts on Health, Safety, Comfort, Affordability

My next questions ask for your opinion about how weatherization affected the health, safety, comfort, and value of your home.

G1a. First I have some questions about the temperature of your home. Please look at Scale G1. Using a scale of 1 to 7, where 1 is too cold, 4 is comfortable, and 7 is too hot, how would you rate the temperature in your home during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1A, ASK:

G1b. Why couldn't you keep your home the temperature you preferred during the winter **before** weatherization? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem, such as broken windows, or holes in walls
[ ] Other (please specify)________________________

____

[ ] NOT SURE

G1c. Using the same scale (REPEAT SCALE IF NECESSARY) how would you rate the temperature in your home during the winters **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1C, ASK:

G1d. Why couldn't you keep your home the temperature you preferred during the winters **after** weatherization? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem such as broken windows, or holes in walls
[ ] Other (please specify)________________________
__ [ ] NOT SURE

G2. Now I have some questions about the draftiness of your house. Please look at Scale G2. Using a scale of 1 to 7, where 1 is very drafty, 4 is somewhat drafty, and 7 is not at all drafty, how would you rate the draftiness of your home during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the draftiness in your home during the winters **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

G3. Next I have some questions about how changes in the operation of your heating system or the temperature of your home may have affected your health. Please look at Scale G3. Using a scale of 1 to 7, where 1 is many health problems, 4 is some health problems, and 7 is very few health problems, how would you rate the health of household members during the winter **before** weatherization? By health I mean illnesses (such as colds, flus, allergies, frequent headaches, frequent nausea, or arthritis), which may be affected by temperature or heating system problems.

BEFORE

1	2	3	4	5	6	7	8
many health problems			some health problems			very few health problems	DON'T REMEMBER

Using the same scale (REPEAT SCALE IS NECESSARY), how would you rate the health of household members during the winters **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
many health problems			some health problems			very few health problems	DON'T REMEMBER

G4. Now I have some questions about the safety of your home. Please look at Scale G4. Using a scale of 1 to 7, where 1 is very unsafe, 4 is acceptable, and 7 is very safe, how would you rate the safety of your home during the winter **before** weatherization? By safety, I mean absence of hazards. Some examples of hazards in the home are faulty electrical, heating, or plumbing systems; combustible materials or other fire hazards; unstable porches or broken doors; or the absence of safety precautions such as bolt locks or smoke detectors.

BEFORE

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the safety of your home during the winters **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

G5. Next I have some questions about your heating bills. Please look at Scale G5. Using a scale of 1 to 7, where 1 is very expensive, 4 is acceptable, and 7 is very inexpensive, how would you rate the cost of your heating bills during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the cost of your heating bills during the winters **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

END
On behalf on the U.S. Department of Energy, I would like to thank you for your time and patience today. The information that you have shared with us will be helpful in our study.

*These items are modified versions of questions taken from the 1990 Residential Energy Consumption Survey (RECS) conducted by the Energy Information Administration.

INTERVIEWER INSTRUCTIONS:

Check to make sure each question has been answered and that verbatim responses are clear and legible.

EXHIBIT B1

GAS FROM UNDERGROUND PIPES SERVING THE NEIGHBORHOOD

BOTTLED GAS (LPG OR PROPANE)

FUEL OIL

KEROSENE OR COAL OIL

ELECTRICITY

COAL OR COKE

WOOD

SOLAR COLLECTORS

OTHER

EXHIBIT B7

WOOD/COAL STOVE

FIREPLACE

COOKING STOVE/RANGE/OVEN

NON-PORTABLE ROOM HEATER BURNING GAS, OIL, OR KEROSENE

PORTABLE KEROSENE HEATER

NON-PORTABLE ELECTRIC HEATER

ELECTRIC PORTABLE HEATER (CORD-CONNECTED)

OTHER

EXHIBIT B8

USED LESS AFTER WEATHERIZATION

USED ABOUT THE SAME AFTER WEATHERIZATION

USED MORE AFTER WEATHERIZATION

SCALE G1
Temperature

1	2	3	4	5	6	7
too cold			comfortable			too hot

SCALE G2
Draftiness

1	2	3	4	5	6	7
very drafty			somewhat drafty			not at all drafty

SCALE G3
Health

1	2	3	4	5	6	7
many health problems			some health problems			very few health problems

SCALE G4
Safety

1	2	3	4	5	6	7
very unsafe			acceptable			very safe

SCALE G5
Heating Costs

1	2	3	4	5	6	7
very expensive			acceptable			very inexpensive

Final version
10/19/92

Interviewer________________________

Date of Interview__________________

SINGLE-FAMILY STUDY OCCUPANT QUESTIONNAIRE: **CONTROL HOME**

A. Identification

INTERVIEWER INSTRUCTIONS:

Complete Questions A1 and A2 using data from the local weatherization agency before starting the interview.

A1. Dwelling Unit Identifier ___ ___ ___ ___ ___

A2. Name of WAP Applicant ____

A3. Name of local WAP Agency ______________________________________

SCREENER:

The purpose of this screening section is to locate a suitable respondent. This screening should be done by telephone before the site visit, if possible.

ASK TO SPEAK TO THE APPLICANT NAMED IN QUESTION A2. IF AVAILABLE, READ THE FOLLOWING:

Your home will be weatherized soon as a participant in the Weatherization Assistance Program. We would like to conduct an interview to learn more about your energy use. Will you be available on (date and time of the site visit) to answer these questions?

IF THE APPLICANT NAMED IN QUESTION A2 IS NOT AVAILABLE, CONTINUE WITH THE FOLLOWING:

Your home will be weatherized soon as a participant in the Weatherization Assistance Program. We would like to conduct an interview to learn more about your energy use. I'd like to speak to a person over 18 years of age who is knowledgeable about energy use in your home. Would you be able to answer these questions? Will you be available on (date and time of the site visit) to answer these questions?

(IF YES, RECORD THIS PERSON'S NAME IN QUESTION A4. IF NO, IDENTIFY SUITABLE RESPONDENT AND CONFIRM THEIR AVAILABILITY ON THE DATE AND TIME OF THE SITE VISIT AND RECORD THEIR NAME IN A4.)

INTERVIEWER INSTRUCTIONS:

IF RESPONDENT IS HESITANT: Your answers to these questions will provide valuable information to the Department of Energy. The interview will take approximately 30 minutes.

INTERVIEWER INSTRUCTIONS:

BEGIN THE ON-SITE INTERVIEW HERE.

Ask to speak to the person previously identified in the telephone screening (QUESTION A4). If that person is not available try to identify another suitable respondent. If no suitable respondent can be identified leave the exhibits and explain that the interview will be conducted by telephone at a later date.

A4. Name of respondent____________________________________

Relation to WAP applicant____________________________________

[ ] RESPONDENT IS SAME AS WAP APPLICANT

A5. In what year was this home built? Just your estimate.*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985	[ ] 1990
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986	[ ] 1991
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987	[ ] 1992
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988	
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989	

A6. In what year did your family move into this home?*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985	[ ] 1990
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986	[ ] 1991
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987	[ ] 1992
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988	
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989	

IF "1987" OR LATER ON QUESTION A6, ASK:

A7. During which month did you move in?*

[ ] January	[ ] May	[ ] September
[ ] February	[ ] June	[ ] October
[ ] March	[ ] July	[ ] November
[ ] April	[ ] August	[ ] December

INTERVIEWER INSTRUCTIONS:

If respondent moved in after the winter of 1988-89, do not ask the questions about that winter in Sections B through G.

B. Major Heating Fuel

Next, I will ask some questions about the fuels you used to heat your home during the winter of 1988-89 and the winters of 1990-91 and 1991-92. We are asking about these time periods because other houses being studied were weatherized during the time between the winter of 1988-89 and the winters of 1990-91 and 1991-92.

INTERVIEWER INSTRUCTIONS:

HAND EXHIBIT BOOKLET TO THE RESPONDENT and ask him/her to look at Exhibit B. Discuss the time line and ask the respondent to identify any personal events that coincide with the winter of 1988-89 and the winters of 1990-91 and 1991-92.

INTERVIEWER INSTRUCTIONS:

If two or more heating fuels are used, the **main heating fuel** is the one that provides most of the heat for the home. The main heating fuel may not necessarily be the one used for the central heating system.

B1. Please look at Exhibit B1. What was the **one main heating fuel** used for heating your home during the winter of 1988-89?*

	B1 Main Fuel (Mark only one)	B2 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED.	[ ]	[ ]
DON'T KNOW.	[ ]	[ ]

B2. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the winter of 1988-89 was (FUEL FROM QUESTION B1). What **other** fuels were used to heat your home during the winter of 1988-89 -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B2. IF NONE, MARK "NO FUELS USED")*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B2, ASK:

B3. Going back to your **main heating fuel** used during the winter of 1988-89--(FUEL FROM QUESTION B1) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

[ ] All or almost all (95% or more)
[ ] About three-fourths (67-94%)
[ ] Closer to half (66% or less)
[ ] DON'T KNOW/REMEMBER

Now, I will ask similar questions about the fuels you used during the last two winters.

B4. Please look at Exhibit B1 again. What was the **one main heating fuel** used for heating your home during the last two winters?*

	B4 Main Fuel (Mark only one)	B5 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED.	[ ]	[ ]
DON'T KNOW.	[ ]	[ ]

B5. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the last two winters, was (FUEL FROM QUESTION B4). What **other** fuels were used to heat your home during the last two winters -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B5. IF NONE, MARK "NO FUELS USED")*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B5, ASK:

B6. Going back to your **main heating fuel** used during the last two winters -- (FUEL FROM QUESTION B4) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

[ ] All or almost all (95% or more)
[ ] About three-fourths (67-94%)
[ ] Closer to half (66% or less)
[ ] DON'T KNOW/REMEMBER

B7a. Please look at Exhibit B7. During the winter of 1988-89, did you use any of the following to **help** heat your home? (USE COLUMN B7a TO CHECK AS MANY AS WERE USED.)

(B7a) 1988-89		(B7b) Last 2 Winters
[ ]	Wood/coal stove.	[ ]
[ ]	Fireplace.	[ ]
[ ]	Cooking stove/range/oven.	[ ]
[ ]	Non-portable room heater burning gas, oil, or kerosene.	[ ]
[ ]	Portable kerosene heater.	[ ]
[ ]	Non-portable electric heater	[ ]
[ ]	Electric portable heater (cord-connected).	[ ]
[ ]	Other (specify):______________________________. . .	[ ]
[ ]	NONE.	[ ]

B7b. Please look at Exhibit B7 again. During the last two winters, did you use any of the following to **help** heat your home? (USE COLUMN B7b TO CHECK AS MANY AS WERE USED.)

INTERVIEWER INSTRUCTIONS:

Confirm that responses to B7a do not contradict responses to B1 and B2. Confirm that responses to B7b do not contradict responses to B4 and B5. Probe the respondent if the responses contradict.

ASK QUESTION B8 ONLY FOR EACH ITEM IN QUESTION B7 USED BOTH IN THE WINTER OF 1988-89 AND THE WINTERS OF 1990-91 AND 1991-92:

B8. Please turn to Exhibit B8. Please tell me how often you used the following to help heat your home during the last two winters, as compared to the winter of 1988-89. Did you use it less, about the same, or more during the last two winters as compared to the winter of 1988-89? (CIRCLE ONE NUMBER IN EACH LINE ASKED.)

	Used Less in 1990-92	Used About The Same	Used More in 1990-92
1. Wood/coal stove	1	2	3
2. Fireplace	1	2	3
3. Cooking stove/range/oven	1	2	3
4. Non-portable room heater burning gas, oil, or kerosene	1	2	3
5. Portable kerosene heater	1	2	3
6. Non-portable electric heater	1	2	3
7. Electric portable heater (cord-connected)	1	2	3
8. Other (________________)	1	2	3

C. Demographics

Now I have some questions about the people who live here and about your housing costs.

C1. Please tell me how many people living in your home during the winter of 1988-89 were . . . (READ EACH ITEM).

Under the age of 5 ________________

Between 5 and 17 years old ________________

Between 18 and 64 years old ________________

65 years old or older ________________

TALLY -- so that is (READ NUMBER) in total? ________________
ENTER CORRECT TOTAL HERE

C2. You have told me that there were (READ TOTAL NUMBER FROM QUESTION C1) people living in your home during the winter of 1988-89. How many people were living in your home during the winters of 1990-91 and 1991-92?

____
NUMBER OF RESIDENTS IN THE WINTER OF 1990-91

____
NUMBER OF RESIDENTS IN THE WINTER OF 1991-92

C3. Were any of the people living in your home during the winter of 1988-89 handicapped? By handicapped, I mean a permanent condition. I do not mean a temporary condition, such as a short-term illness. (EYEGLASSES ARE NOT CONSIDERED A HANDICAP. IF YES, ASK HOW MANY.)

____
NUMBER HANDICAPPED

C4. Do you or members of your household own your home, or rent?*

[ ] Own (buying)
[ ] Rent
[ ] Occupied without payment of rent (SKIP TO SECTION D)

FROM QUESTION C4, IF HOUSEHOLD OWNS OR PAYS RENT, ASK:

C5. Please tell me which category best describes the monthly rent or mortgage payment the household pays for your home. Is it . . .? Stop me when I reach the category. (READ CATEGORIES.)

[ ] less than $200 per month
[ ] $201 - 300 per month
[ ] $301 - 400 per month
[ ] $401 - 500 per month
[ ] $501 - 600 per month
[ ] $601 - 700 per month
[ ] $701 - 800 per month
[ ] $801 - 900 per month
[ ] more than $900 per month

[ ] OWNED, MORTGAGE PAID OFF (SKIP TO SECTION D)
[ ] DON'T KNOW

C6. Does this payment include: (READ ITEMS AND PROBE FOR "YES" OR "NO".)

	Yes	No	DON'T KNOW
1. electricity.	[ ]	[ ]	[ ]
2. natural gas.	[ ]	[ ]	[ ]

D. Conditioned Living Space

My next question is about the number of different types of rooms in your home.

INTERVIEWER INSTRUCTIONS:

For one-bedroom efficiency or studio apartment, record "0 bedrooms" and number of bathrooms and other rooms.

Full Bathroom -- sink with running water **and** flush toilet **and** bathtub or shower.

Half Bathroom -- toilet **or** bathtub **or** shower

D1. How many of each of the following rooms does this home have? (ASK EACH ITEM AND RECORD NUMBER FOR EACH.)*

	D1 Total Number	D2A Number heated during the winter of 1988-89	D2B Number heated during the last two winters
Bedrooms?	________	________	________
Full bathrooms?.	________	________	________
Half bathrooms?	________	________	________
All other rooms:.	________	________	________

(Do not count laundry rooms, foyers or unfinished storage space. Only count porches if they are enclosed and used year-round.)

D2. (FOR EACH TYPE OF ROOM THE RESPONDENT HAS IN THE HOME, ASK D2A, THEN D2B. A HEATED ROOM IS ONE THAT IS WARM ENOUGH TO BE USED.)

D2a. Of the (READ NUMBER OF ROOMS AND TYPE OF ROOM), how many were heated during the winter of 1988-89 (RECORD ABOVE ON COLUMN D2A.)

D2b. And how many (READ TYPE OF ROOM) were heated during the winters of 1990-91 and 1991-92? (RECORD ABOVE ON COLUMN D2B.)

E. Thermostat Management

I would now like to ask you some questions about the temperature at which you kept your home.

INTERVIEWER INSTRUCTIONS:

Remember, we are interested in the respondent's perceptions. Ask the respondent for their opinion; avoid checking the thermostat for the actual settings.

If respondent keeps different sections of the home at different temperatures, we want to know the temperature in the part of the house where the people are. If, for example, the heat is turned off upstairs during the day because the family is downstairs, we want the downstairs temperature.

We would like to know the actual temperature of the home. If the respondent doesn't know the temperature, but does know the thermostat setting, record the thermostat setting. Otherwise, probe for best estimate.

E1a. During the winter of 1988-89, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E1B)
[ ] Changed the temperature (GO TO QUESTION E1C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E1A, ASK:

E1b. During the winter of 1988-89, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: _________
[ ] HEAT TURNED OFF

(GO TO QUESTION E2A)

IF CHANGED THE TEMPERATURE ON QUESTION E1A, ASK:

E1c. During the winter of 1988-89, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: _________
[ ] HEAT TURNED OFF

E1d. During the winter of 1988-89, at what temperature did you **usually** keep your home during the day **when no one was at home**?*

Degrees Fahrenheit: _________
[ ] HEAT TURNED OFF

E1e. During the winter of 1988-89, at what temperature did you **usually** keep your home **during sleeping hours**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(ASK EVERYONE:)

E2a. During the winters of 1990-91 and 1991-92, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E2B)
[ ] Changed the temperature (GO TO QUESTION E2C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E2A, ASK:

E2b. During the last two winters, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(GO TO SECTION F)

IF CHANGED THE TEMPERATURE ON QUESTION E2A, ASK:

E2c. During the last two winters, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2d. During the last two winters, at what temperature did you **usually** keep your home during the day **when no one was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2e. During the last two winters, at what temperature did you **usually** keep your home **during sleeping hours**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

F. Events Affecting Energy Use

The next questions are about events which may have affected your energy use during the winter of 1988-89 and during the last two winters.

F1a. During the winter of 1988-89, was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued** . . . . your gas or electric service?	[ ]	[ ]

IF "YES" TO EITHER PART OF QUESTION F1A, ASK:

F1b. Thinking about these times that you went without heat, during the winter of 1988-89, how many separate times were there?

Total times: __________

F1c. Altogether, how many hours or days were you without heat?

Total hours without heat: __________ OR Total days without heat: __________

F2a. During the last two winters was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued** . . . . your gas or electric service?	[ ]	[ ]

IF "YES" TO ANY PART OF QUESTION F2A, ASK:

F2b. Thinking about these times that you went without heat, during the last two winters, how many separate times were there?

Total times: __________

F2c. Altogether, how many hours or days were you without heat?

Total hours without heat: __________ OR Total days without heat: __________

F3. Was there any home repair, major house renovation, or damage to your home that would affect energy use between January 1987 and September 1992?

[ ] Yes
[ ] No
[ ] DON'T KNOW

IF YES ON QUESTION F3, ASK:

F4. Please describe the home repair, renovation, or damage. (RECORD VERBATIM BELOW.)

		MONTH/YEAR
(1)	______________________________	__________
	______________________________	__________
(2)	______________________________	__________
	______________________________	__________
(3)	______________________________	__________
	______________________________	__________

F5. In which month/year was the work or damage done? (RECORD UNDER COLUMN FOR MONTH/YEAR ABOVE.)

G. Impacts on Health, Safety, Comfort, Affordability

My next questions ask for your opinion about whether the health, safety, and comfort of your home has changed during the last few years.

G1a. First I have some questions about the temperature of your home. Please look at Scale G1. Using a scale of 1 to 7, where 1 is too cold, 4 is comfortable, and 7 is too hot, how would you rate the temperature in your home during the winter of 1988-89?

1988-89							
1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1A, ASK:

G1b. Why couldn't you keep your home the temperature you preferred during the winter of 1988-89? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem, such as broken windows, or holes in walls
[ ] Other (please specify)________________________________
[ ] NOT SURE

G1c. Using the same scale (REPEAT SCALE IF NECESSARY) how would you rate the temperature in your home during the last two winters?

Last 2 Winters							
1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1C, ASK:

G1d. Why couldn't you keep your home the temperature you preferred during the last two winters? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem such as broken windows, or holes in walls
[ ] Other (please specify)________________________________
____
[ ] NOT SURE

G2. Now I have some questions about the draftiness of your house. Please look at Scale G2. Using a scale of 1 to 7, where 1 is very drafty, 4 is somewhat drafty, and 7 is not at all drafty, how would you rate the draftiness of your home during the winter of 1988-89?

1988-89							
1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the draftiness in your home during the last two winters?

Last 2 Winters							
1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

G3. Next I have some questions about how the operation of your heating system or the temperature of your home may have affected your health. Please look at Scale G3. Using a scale of 1 to 7, where 1 is many health problems, 4 is some health problems, and 7 is very few health problems, how would you rate the health of household members during the winter of 1988-89? By health I mean illnesses (such as colds, flus, allergies, frequent headaches, frequent nausea, or arthritis), which may be affected by temperature or heating system problems.

1988-89							
1	2	3	4	5	6	7	8
many health problems			some health problems			very few health problems	DON'T REMEMBER

Using the same scale (REPEAT SCALE IS NECESSARY), how would you rate the health of household members during the last two winters?

Last 2 Winters							
1	2	3	4	5	6	7	8
many health problems			some health problems			very few health problems	DON'T REMEMBER

G4. Now I have some questions about the safety of your home. Please look at Scale G4. Using a scale of 1 to 7, where 1 is very unsafe, 4 is acceptable, and 7 is very safe, how would you rate the safety of your home during the winter of 1988-89? By safety, I mean absence of hazards. Some examples of hazards in the home are faulty electrical, heating, or plumbing systems; combustible materials or other fire hazards; unstable porches or broken doors; or the absence of safety precautions such as bolt locks or smoke detectors.

1988-89							
1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the safety of your home during the last two winters?

Last 2 Winters							
1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

G5. Next I have some questions about your heating bills. Please look at Scale G5. Using a scale of 1 to 7, where 1 is very expensive, 4 is acceptable, and 7 is very inexpensive, how would you rate the cost of your heating bills during the winter of 1988-89?

1988-89							
1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the cost of your heating bills during the last two winters?

Last 2 Winters							
1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

END

On behalf on the U.S. Department of Energy, I would like to thank you for your time and patience today. The information that you have shared with us will be helpful in our study.

*These items are modified versions of questions taken from the 1990 Residential Energy Consumption Survey (RECS) conducted by the Energy Information Administration.

INTERVIEWER INSTRUCTIONS:
Check to make sure each question has been answered and that verbatim responses are clear and legible.

EXHIBIT B1

GAS FROM UNDERGROUND PIPES SERVING THE NEIGHBORHOOD

BOTTLED GAS (LPG OR PROPANE)

FUEL OIL

KEROSENE OR COAL OIL

ELECTRICITY

COAL OR COKE

WOOD

SOLAR COLLECTORS

OTHER

EXHIBIT B7

WOOD/COAL STOVE

FIREPLACE

COOKING STOVE/RANGE/OVEN

NON-PORTABLE ROOM HEATER BURNING GAS, OIL, OR KEROSENE

PORTABLE KEROSENE HEATER

NON-PORTABLE ELECTRIC HEATER

ELECTRIC PORTABLE HEATER (CORD-CONNECTED)

OTHER

EXHIBIT B8

USED LESS DURING LAST TWO WINTERS

USED ABOUT THE SAME DURING LAST TWO WINTERS

USED MORE DURING LAST TWO WINTERS

SCALE G1
Temperature

1	2	3	4	5	6	7
too cold			comfortable			too hot

SCALE G2
Draftiness

1	2	3	4	5	6	7
very drafty			somewhat drafty			not at all drafty

SCALE G3
Health

1	2	3	4	5	6	7
many health problems			some health problems			very few health problems

SCALE G4
Safety

1	2	3	4	5	6	7
very unsafe			acceptable			very safe

SCALE G5
Heating Costs

1	2	3	4	5	6	7
very expensive			acceptable			very <u>in</u>expensive

APPENDIX D

Comparison of Phase One and Phase Two Samples

Appendix D

Comparison of Mean Values for Phase I and Phase II Samples of Weatherized Dwellings

	Phase I n = 3,873	Phase II n = 431
Pre-weatherization Normalized Annual Consumption (ccf)	1,348	1,235
Post-weatherization Normalized Annual Consumption (NAC)	1,212	1,080
Change in NAC	136	154
Percentage of mobile homes	18%	7%
Percentage of single-family detached	63%	72%
Percentage of single-family attached	3%	5%
Percentage of small multi-family	14%	15%
Percentage of owner-occupied	65%	65%
Number of occupants	2.0	2.7
Percentage with an elderly occupant	31%	38%
Percentage with central heat	73%	78%
Percentage with air conditioning	29%	31%
Age of dwelling	39	45
Square footage	1,125	1,098
Percentage receiving first-time attic insulation	26%	26%
Percentage receiving wall insulation	20%	27%
Percentage receiving space heating replacements	3%	4%
Total spent on materials (1989$)	$568	$492
Total spent on materials and labor (1989%)	$1,024	$914
Percentage in cold region	31%	24%
Percentage in moderate region	48%	53%
Percentage in hot region	21%	23%

*** Statistically significant difference at $p \leq 0.001$
** Statistically significant difference at $p \leq 0.01$
* Statistically significant difference at $p \leq 0.05$

APPENDIX E

Comparison of Weatherized and Control Samples

APPENDIX E

CHARACTERISTICS OF THE WEATHERIZED AND CONTROL SAMPLES

Because most of the physical characteristics measured (such as the floor area, volume, age, appliance saturations, number of floors, housing type, heating fuels, types of heating systems) are unaffected by weatherization, we expected to find few differences between weatherized and control groups. This expectation was supported by the data analysis. The weatherized and control groups had no statistically significant differences for most of the dwelling characteristics examined.

T-tests were run on 250 numeric variables to identify any statistically significant differences between the mean values for the control homes vs the weatherized homes. In the same manner, chi-square tests were run on about 250 categorical variables (such as housing type, insulation type, or fuel type) to identify any statistically significant differences in the control vs the weatherized homes. Out of over 500 variables tested, 63 were identified as showing significant differences (22 of the numeric and 41 of the categorical). The important differences are discussed below. A complete listing of variables that were shown to be significantly different (by the t-test or chi-square results) for the weatherized and control groups is presented in Appendix F.

The most important differences between the weatherized and control groups in housing characteristics unaffected by weatherization were in the distributions of housing type and fuel type. The sample of weatherized homes included lower proportions of single-family detached dwellings and of mobile homes than the control sample. The weatherized sample also had higher proportions of small multifamily units (Fig. E.1). The weatherized sample included higher proportions of homes that used natural gas as their primary heating fuel, and lower proportions that used electricity, and other fuels (Fig. E.2).[1] Other differences that were statistically significant included differences in the type of exterior wall and the type and location of ducts (Appendix F).

[1] The local agencies were instructed to include only gas or electrically heated homes in the control group recruited for this study. In some cases, dwellings heated with other fuels were included, perhaps because of the difficulty of recruiting enough study participants. The higher proportion of mobile homes in the control group may reflect the greater convenience of recruiting several study participants from the same mobile home park.

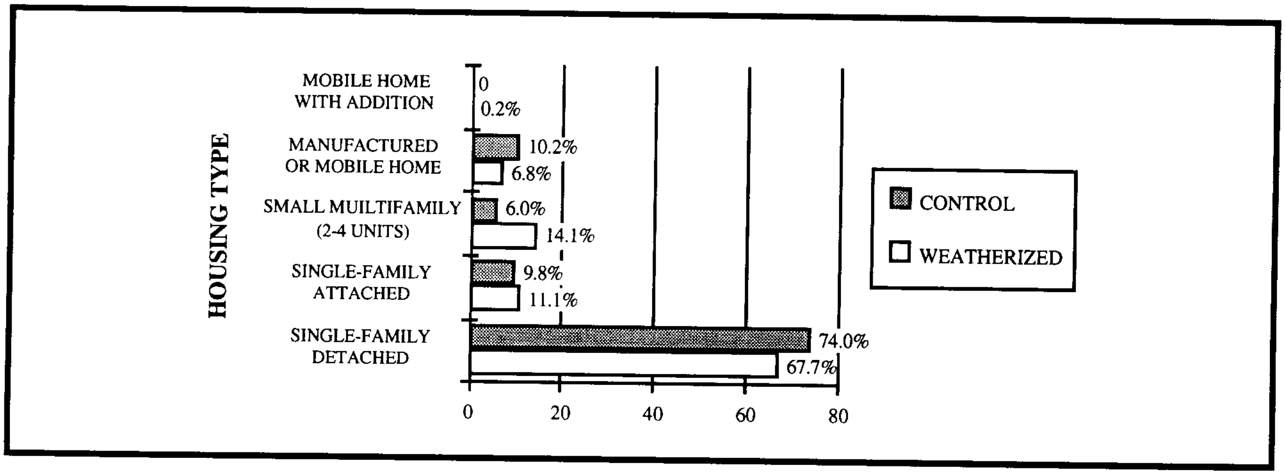


Fig. E.1 Distribution of Housing Types for Weatherized vs. Control Dwellings

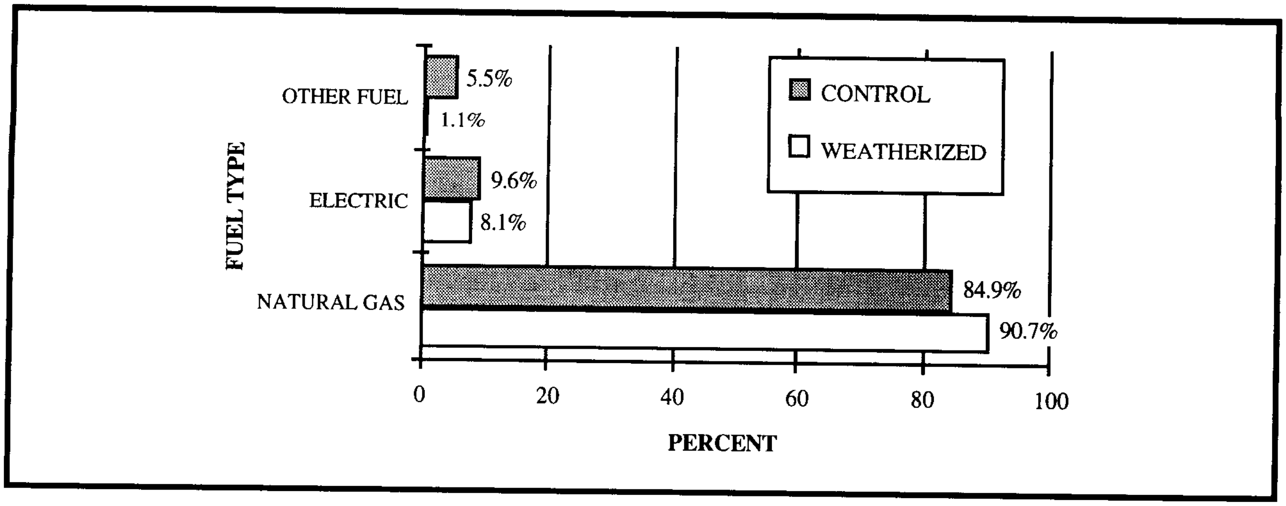


Fig. E.2 Distribution of Fuel Type of Primary Heating System for Weatherized vs. Control Dwellings

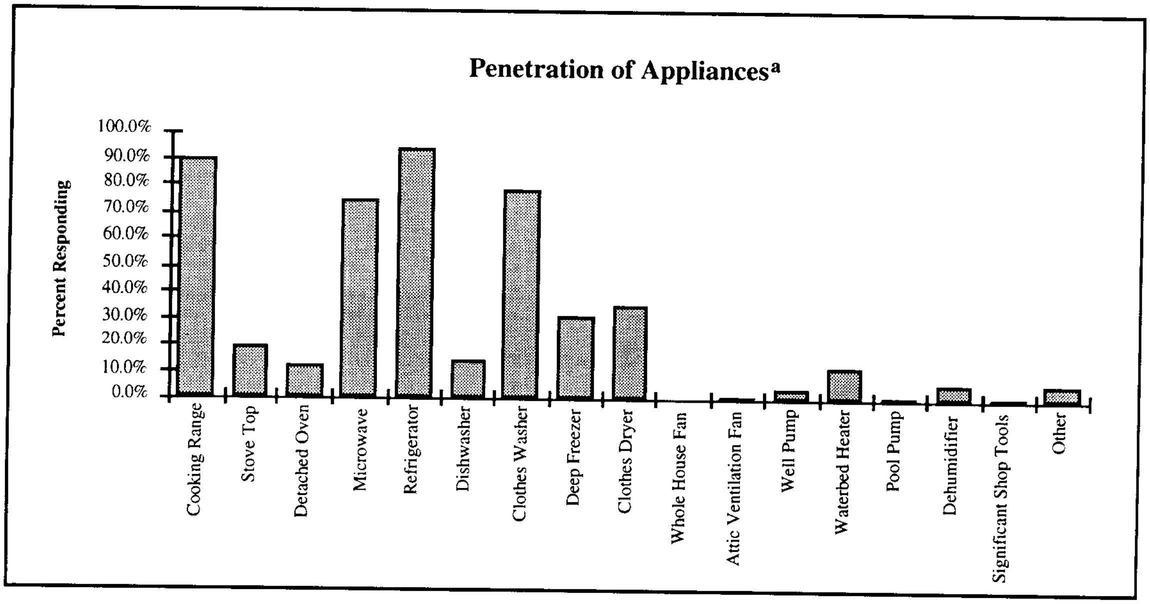
Although there were a few statistically significant differences in the housing stock occupied by the weatherized and control groups, the two samples were nearly identical in most respects (Table E.1). For example, there were no statistically significant differences in their square footage, volume, heated areas, age, number of residents, and appliance saturations (including refrigerators, clothes washers, clothes dryers, microwaves, and air conditioning). Appliance saturations were so similar between the two groups that they were combined to show overall appliance saturations in the housing stock (Fig. E.3). As Fig. E.3, shows over 90% of homes have cooking ranges and refrigerators. Over 70% have microwaves and clothes washers, and about one-third have freezers and clothes dryers. All other appliances are in a small percentage of homes.

Table E.1 Weatherized and Control Houses are Similar[a] on Most Variables

	Weatherized	Control
One-story dwelling (%)	62	64
Mean number residents	2.7	3.1
Mean number of electric appliances	4.46	4.65
Age of house (years)	44	48
Central heat only (%)	71	74
Age of air conditioner (years)	9.6	9.8
Age of water heater (years)	8.5	7.7
Age of heating system (years)	17	18
Square footage	1,513	1,622
Percent with no heat	4.9	4.6
Volume (cubic feet)	10,341	10,656
Percent with no air conditioning	68	62
Intentionally heated area (% of total area)	77	75

[a] The slight differences in the variables shown in this table are not statistically significant at $p \leq 0.05$. Of 250 numeric variables for which t-tests were run, only 22 showed significant differences (Appendix F). Most of these were variables, such as thickness of insulation, that are affected by weatherization.

As shown in Fig. E.4 through Fig. E.10, the control and weatherized groups were very similar in most respects. The majority of both groups occupied one-story dwellings (Fig. E.4). A large majority of both groups had hot air distribution systems (Fig. E.5), natural gas water heaters (Fig. E.6), and stand alone water heating systems (Fig. E.7). Patterns of location of the water heaters were nearly identical (Fig. E.8). Distributions of their square footage (Fig. E.9), and heated areas (Fig. E.10) were similar. Given the large number of variables that were compared, the few statistically significant differences in the housing stock characteristics that were observed could have occurred by chance. Thus, the goal of selecting samples of weatherized and control homes drawn from the same housing stock seems to have been achieved.



[a] There were no significant differences in the appliance saturations for weatherized and control dwellings, so the two groups are combined in this figure.

Fig. E.3 Appliance Saturations in all Phase Two Dwellings

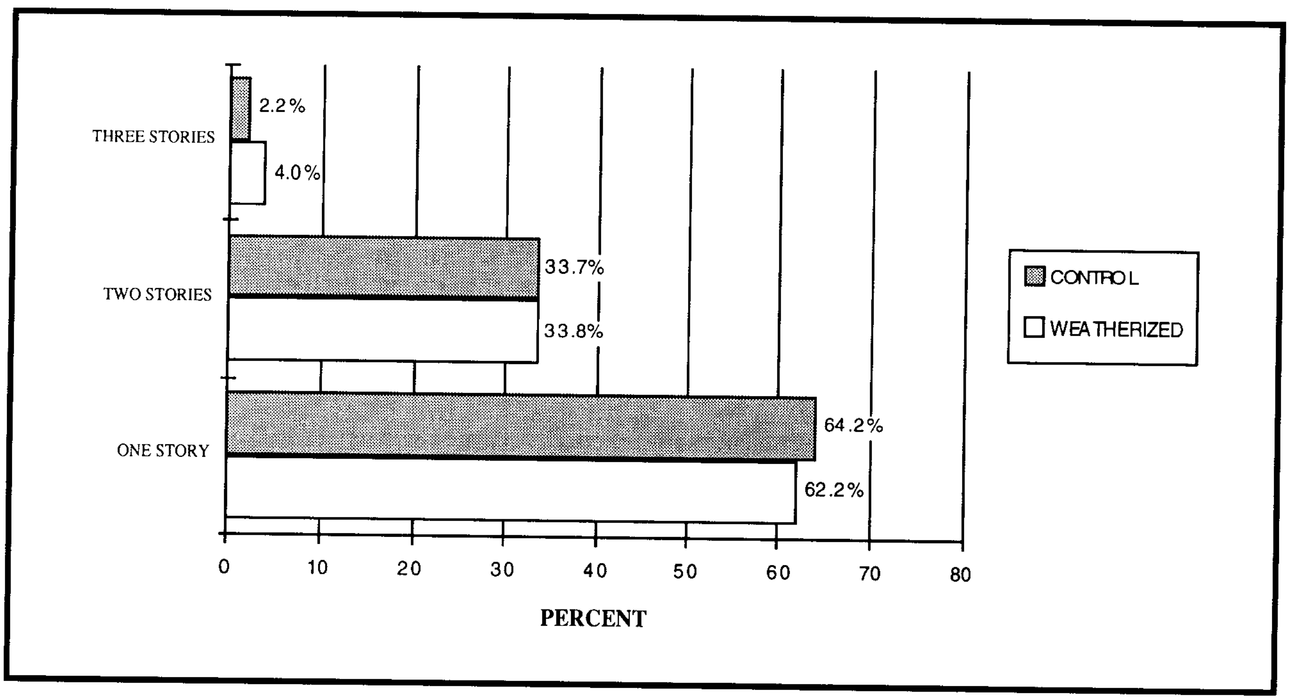


Fig. E.4 Number of Stories in Weatherized vs. Control Dwellings

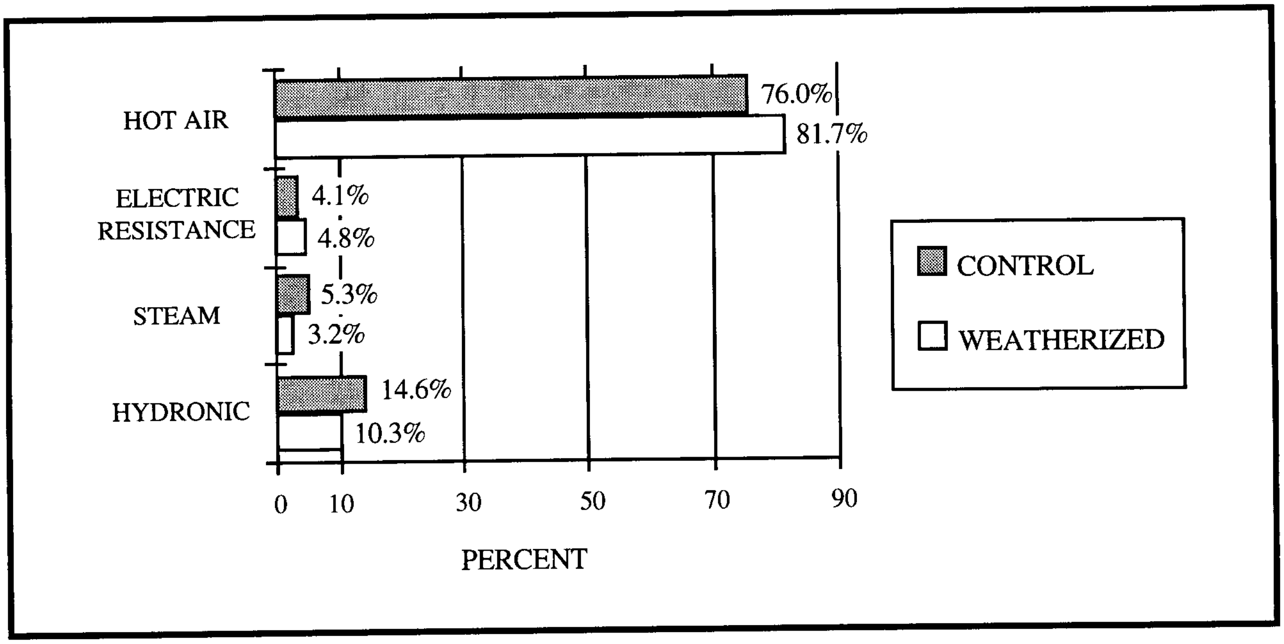


Fig. E.5 Type of Distribution System for Primary Heating System in Weatherized vs. Control Dwellings

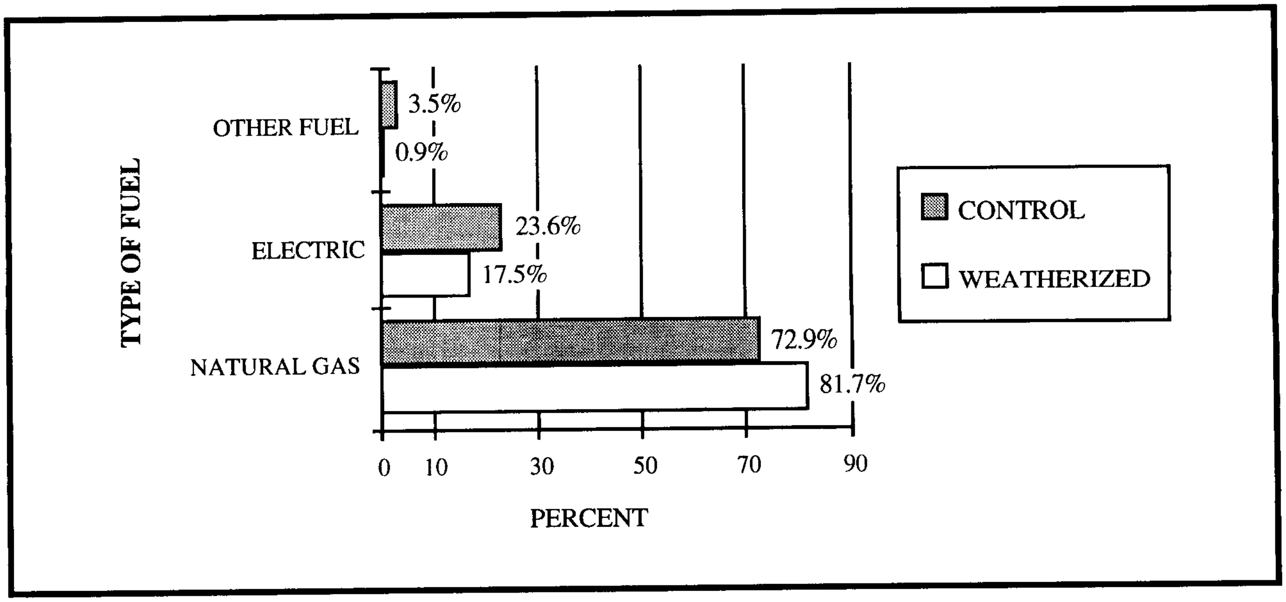


Fig. E.6 Distribution of Water Heater Fuel Type for Weatherized vs. Control Dwellings

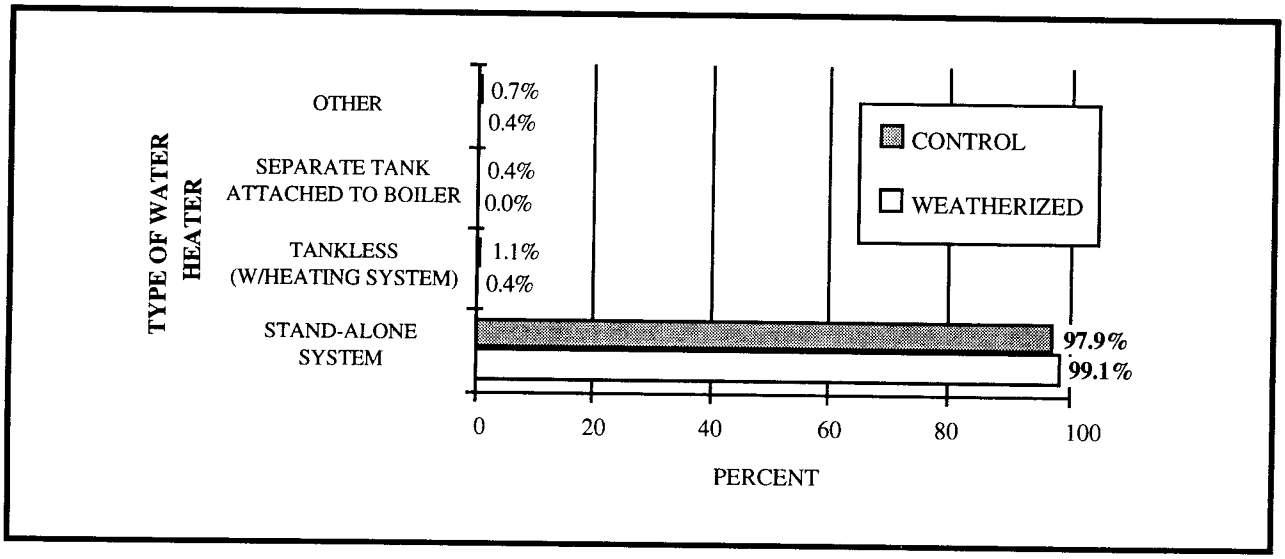


Fig. E.7 Distribution of Water Heater Types in Weatherized vs. Control Dwellings

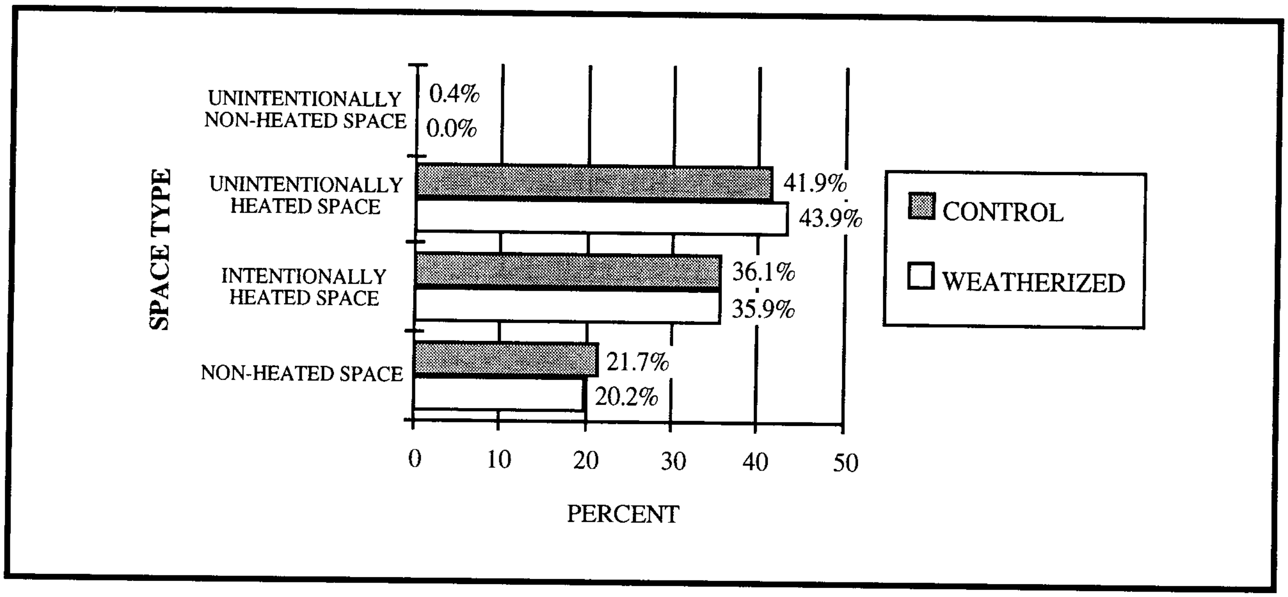


Fig. E.8 Distribution of Water Heater Locations in Weatherized vs. Control Dwellings

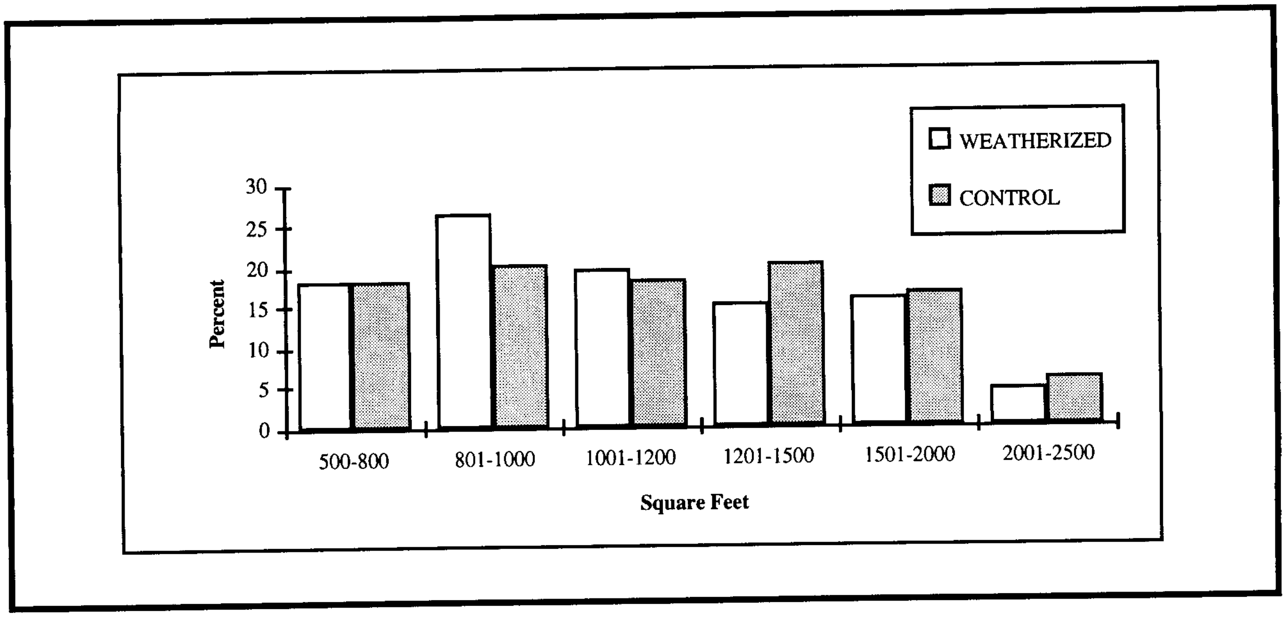


Fig. E.9 Distribution of Total Area in Weatherized vs. Control Dwellings

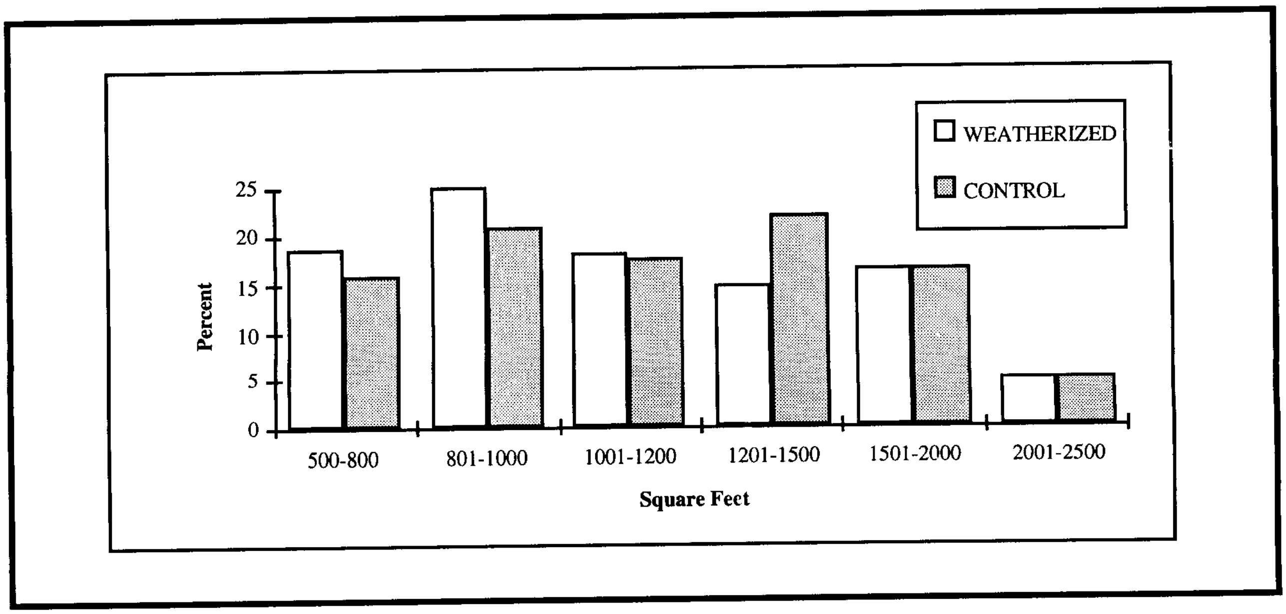


Fig. E.10 Distribution of Intentionally Heated Area for Weatherized vs. Control Dwellings

APPENDIX F

Variables that Differ between Weatherized and Control Groups

Table F.1 Differences between the Weatherized and Control Groups in Variables that Weatherization Does not Affect by Region[a]

	CE	CW	ME	MW	HE	HW
House Type			√	√		
Primary Heating System Fuel Type	√	√		√		
Primary Heating System Pilot Type	National only					
Water Heating System Fuel Type						√
Type of Attic in Unheated Attic Area, Roof Rafter			√			
Type of Exterior Wall		√	√	√		√
Location of Ducts	√		√	√		
Percent of Foundation Wall Height Above Ground				√		

Legend of Regions		
CE	-	Cold East
CW	-	Cold West
ME	-	Moderate East
MW	-	Moderate West
HE	-	Hot East
HW	-	Hot West

a The variables in the table showed statistically significant differences between the weatherized and control groups with either a t-test ($P \leq 0.05$) or a chi-square test at the national level. Some of them also differed at the regional level as indicated by the check marks in the table. None of these variables would be expected to be affected by weatherization.

Table F.2 Differences between the Weatherized and Control Groups in Variables that may be Affected by Weatherization by Region[b]

	CE	CW	ME	MW	HE	HW
Insulation Thickness of Heated Attic Area, Collar Beam	√					
Insulation Thickness of Unheated Attic Area, Collar Beam	√		√	√	√	
Insulation Thickness of Unheated Attic Area, Roof Rafter			√			
Insulation Thickness of Heated Attic Area, Kneewall Floor	National only					
Thickness of Foundation Wall Insulation			√			
Supply Duct Insulation Thickness (inches)	√	√	√			
Supply Duct Cross Section (square inches)	√		√			
Insulated Water Pipes, % of Total Exposed Length			√			√
Percent of Foundation Perimeter Insulated	√	√		√		
Insulation Type in Unheated Attic Area, Collar Beam	√		√	√		
Insulation Type in Unheated Attic Area, Kneewall to Exterior	√	√				
Insulation Type in Heated Attic Area, Roof Rafter	√					
Insulation Type in Unheated Attic Area, Roof Rafter			√	√		
Insulation Type in Heated Attic Area, Kneewall Floor	√	√				
Insulation Type on Exterior Walls	√	√	√	√	√	√
Storm Windows Present			√			
Water Temperature Measured at Nearest Tap (Deg. F)				√		
(Cont'd on next page)						

Legend of Regions		
CE	-	Cold East
CW	-	Cold West
ME	-	Moderate East
MW	-	Moderate West
HE	-	Hot East
HW	-	Hot West

[b] The variables in the table showed statistically significant differences between the weatherized and control groups with either a t-test ($P \leq 0.05$) or a chi-square test at the national level. Some of them also differed at the regional level as indicated by the check marks in the table. All of the variables in this table could be affected by weatherization.

Table F.2 Differences between the Weatherized and Control Groups in Variables that may be Affected by Weatherization by Region[b] (cont'd)

	CE	CW	ME	MW	HE	HW
Water Heating System Safety Check - External Blanket Off	National only					
Water Heating System Temperature Setting	National only					
Water Heating System Pipes Insulated	√		√	√		
Water Heating System Pipe Insulation Type				√		
Water Heater Spillage Check - Furnace Air Handler On			√			
Water Heater Spillage Check - Water Heater Refired			√			
Supplemental Data - General Impression of House	√			√		
Supplemental Data - No ECM Recommended	√			√		
Supplemental Data - Bypasses				√		
Types of Attic Vents Present	√		√			
Foundation Wall Insulation Type			√	√		
Exterior Door Type	√		√	√	√	√
Exterior Door - Storm Door Present	National only					
Space Status of Ducts			√			
Condition of Ducts	√		√			
Type of Insulation on Ducts	√		√			
Condition of Return Ducts			√			
(Cont'd on next page)						

Legend of Regions		
CE	-	Cold East
CW	-	Cold West
ME	-	Moderate East
MW	-	Moderate West
HE	-	Hot East
HW	-	Hot West

b The variables in the table showed statistically significant differences between the weatherized and control groups with either a t-test ($P \leq 0.05$) or a chi-square test at the national level. Some of them also differed at the regional level as indicated by the check marks in the table. All of the variables in this table could be affected by weatherization.

Table F.2 Differences between the Weatherized and Control Groups in Variables that may be Affected by Weatherization by Region[b] (cont'd)

	CE	CW	ME	MW	HE	HW
Type of Ducts	√	√	√			
Type of Duct Material			√			
Health & Safety Checks - Structural - Broken Out Glass	National only					
Health & Safety Checks - Structural - Sashes Need Replacement	National only					
Primary Heating System Safety Check - No Vent Damper	National only					
Hydronic Distribution Systems - Radiators	National only					
Hydronic Distribution Systems - Leaks in System	National only					
Hot Air Distribution Systems - Noisy Bearings				√		
Hot Air Distribution Systems - Air Filter Type	National only					
Furnace Temperature Controls, High Limit (Deg F)	√					
Total Number of Attic Vents Present		√				
Percent of Foundation Perimeter Exposed			√			
Air Leakage, Blower Door Test Flow Rate @cfm_{50}		√		√		

Legend of Regions		
CE	-	Cold East
CW	-	Cold West
ME	-	Moderate East
MW	-	Moderate West
HE	-	Hot East
HW	-	Hot West

[b] The variables in the table showed statistically significant differences between the weatherized and control groups with either a t-test ($P \leq 0.05$) or a chi-square test at the national level. Some of them also differed at the regional level as indicated by the check marks in the table. None of these variables would be expected to be affected by weatherization.

APPENDIX G

Characteristics of Dwellings Weatherized by Higher- vs. Lower-Saving Agencies, by Region

Characteristics of Dwellings Weatherized by Higher- vs. Lower-Saving Agencies, by Region

	Cold		Moderate East		Moderate West		Hot East		Hot West	
	High	Low	High	Low	High	Low	High	Low	High	Low
Pre-NAC (ccf/year)	1,605***	764	1,653*	1,229	1,475**	1,156	759**	1,200	624**	415
Post-NAC (ccf/year)	1,284*	726	1,109	1,042	1,140	1,052	631**	1,124	524*	400
Change in NAC	321***	38	544*	187	335*	104	128	76	100	15
Heating Degree Days	6,848	5,802	6,352	5,686	6,014	5,465	3,021	3,207	1,474	1,606
Pre-Weatherization Btu/sq. ft./HDD	21*	15	19*	13	19	21	27	27	40	32
Post-Weatherization Btu/sq. ft./HDD	16	14	13	13	16	21	24	25	34	29
% Mobile Homes	0***	52	10	6	0*	14	15***	1	1	0
% Single-family Detached	22**	40	90	89	91	81	79*	93	88	92
% Single-family Attached	2	0	0	0	0	0	0	0	3	0
% Small Multifamily	75***	7	0	5	9	5	6	6	3	8
% with Central Heat	100***	80	97	99	98***	83	59***	14	73	66
% Using Supplemental Fuels	3***	24	20	13	11*	0	0***	100	40**	75
Age of Dwelling	75***	27	74	67	75	15	34*	42	35	37
Square Footage of Dwelling	1,591***	932	1,250	1,328	1,218***	805	964*	1,161	1,195**	877
% Receiving any Insulation Measures	90***	40	94	95	85*	67	64**	29	33**	83
% Receiving Attic Insulation	73***	16	88	61	68	42	56*	26	21***	83
% Receiving First Time Attic Insulation	72***	2	64	51	23	39	52**	26	9***	58

*** Statistically significant difference at $p \leq 0.001$
** Statistically significant difference at $p \leq 0.01$
* Statistically significant difference at $p \leq 0.05$

Characteristics of Dwellings Weatherized by Higher- vs. Lower-Saving Agencies, by Region (cont'd)

	Cold		Moderate East		Moderate West		Hot East		Hot West	
	High	Low	High	Low	High	Low	High	Low	High	Low
% Receiving Wall Insulation	41***	12	83	71	31	29	0	0	0	0
% Receiving Floor Insulation	1***	21	5***	52	4**	33	16*	3	0	0
% Receiving Any Air Leakage Measures	92	98	96	100	100	100	96	96	100	100
% Receiving Air Sealing with Blower Door	0	2	25***	2	88***	3	0	0	12*	0
% Receiving any Water Heater Measures	84	74	100	96	99*	88	0	1	72	92
% Receiving Water Heater Tank Wrap	80***	0	81	59	62	67	0	1	48*	8
% Receiving Water Heater Pipe Wrap	81***	49	94	95	85	73	0	0	45*	8
% Receiving any Structural Repair	84	81	100	98	93**	76	88	95	94	100
% Receiving Replacement Windows	0.5***	20	35***	0	1***	34	32***	71	3	16
% Receiving Replacement Doors	4***	37	34	20	1***	24	72	84	52	66
% Receiving Storm Windows	0***	63	2	5	0*	12	76***	24	27*	0
% Receiving any Space Heating Measures	47**	26	15***	89	92***	55	0	0	85	58
% Receiving Tune-ups	20*	2	8***	75	88***	55	0	0	60	50
% Receiving Heating System Replacements	26***	2	0	0	4*	0	0	0	9	0

*** Statistically significant difference at $p \leq 0.001$
** Statistically significant difference at $p \leq 0.01$
* Statistically significant difference at $p \leq 0.05$

Characteristics of Dwellings Weatherized by Higher- vs. Lower-Saving Agencies, by Region (cont'd)

	Cold		Moderate East		Moderate West		Hot East		Hot West	
	High	Low	High	Low	High	Low	High	Low	High	Low
Mean Steady-state Efficiency of Central Gas Heating Systems	76	71	77	77	79	77	82	80	72	68
Mean Attic Insulation R-values for:										
Weatherized dwellings	24.3	23.3	32.1	31.3`	21.1	33.2	21.5	10.7	21.8	23.1
Treated dwellings	21.3	28.8	30.4	28.8	24.3	25.1	20.9	10.1	25.4	27.9
% of Weatherized Dwellings with Attic Insulation R-values that are above R-30 in:										
Weatherized dwellings	33.3 (n=9)	12.5 (n=8)	58.3 (n=12)	50.0 (n-14)	64.3 (n=14)	6.3 (n=16)	23.1 (n=13)	11.1 (n=9)	20.0 (n=5)	28.6 (n=2)
Control dwellings	33.3 (n=6)	71.4 (n=7)	0 (n=8)	0 (n=6)	0 (n=9)	0 (n=7)	12.5 (n=8)	0 (0=9)	0 (n=2)	20 (n=5)
Treated dwellings	33.3 (n=6)	50.0 (n=4)	53.8 (n=13)	40.0 (n=10)	44.4 (n=18)	0 (n=5)	30 (n=10)	0 (n=5)	50 (n=2)	62.5 (n=8)

*** Statistically significant difference at $p \leq 0.001$
** Statistically significant difference at $p \leq 0.01$
* Statistically significant difference at $p \leq 0.05$

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