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MARTIN MARIETTA

Impacts of the Weatherization Assistance Program in Fuel-Oil Heated Houses

William P. Levins
Mark P. Ternes

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

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William P. Levins
Mark P. Ternes
Energy Division

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Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC
for the
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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ABSTRACT

In 1990, the U.S. Department of Energy (DOE) initiated a national evaluation of its low-income Weatherization Assistance Program. This report, which is one of five parts of that evaluation, evaluates the energy savings and cost-effectiveness of the Program as it had been applied to single-family houses heated primarily by fuel-oil. The study was based upon a representative sample (41 local weatherization agencies, 222 weatherized and 115 control houses) from the nine northeastern states during 1991 and 1992 program years.

Dwelling-specific and agency-level data on measures installed, costs, and service delivery procedures were collected from the sampled agencies. Space-heating fuel-oil consumption, indoor temperature, and outdoor temperature were monitored at each house. Dwelling characteristics, air-leakage measurements, space-heating system steady-state efficiency measurements, safety inspections, and occupant questionnaires were also collected or performed at each monitored house.

We estimate that the Program weatherized a total of 23,400 single-family fuel-oil heated houses in the nine northeastern states during program years 1991 and 1992. Annual fuel-oil savings were calculated using regression techniques to normalize the savings to standard weather conditions. For the northeast region, annual net fuel-oil savings averaged 160 gallons per house, or 17.7% of pre-weatherization consumption. Although indoor temperatures changed in individual houses following weatherization, there was no average change and no significant difference as compared to the control houses; thus, there was no overall indoor temperature take-back effect influencing fuel-oil savings.

The weatherization work was performed cost effectively in these houses from the Program perspective, which included both installation costs and overhead and management costs but did not include non-energy benefits (such as employment and environmental). Total average costs were $1819 per house ($1192 for installation labor and materials, and $627 for overhead and management), and the benefit-to-cost ratio was 1.48.

A general trend toward higher-than-average fuel-oil savings was observed in houses with high pre-weatherization fuel-oil consumption. Program savings could likely be increased by targeting higher energy consumers for weatherization, although equity issues would have to be considered. Weatherization measures associated with higher-than-average savings were use of a blower door for air-sealing, attic and wall insulation, and replacement space-heating systems. Space-heating system tune-ups were not particularly effective at improving the steady-state efficiency of systems, although other benefits such as improved seasonal efficiency, and system safety and reliability may have resulted. The Program should investigate methods of improving the selection and/or application of space-heating system tune-ups and actively promote improved tune-up procedures that have been developed as a primary technology transfer activity. Houses were more air-tight following weatherization, but still leakier than what is achievable. Additional technology transfer effort is recommended to increase the use of blower doors considering that only half the weatherized houses used a blower door during air sealing. A guidebook developed by a committee of experts and covering a full range of blower-door topics might be a useful technology transfer and training document. Weatherization appeared to make occupants feel better about their house and house environment.

EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

The U.S. Department of Energy (DOE) requested Oak Ridge National Laboratory to help design and conduct an up-to-date assessment of their Weatherization Assistance Program. Five separate studies make up the overall evaluation (Beschen and Brown 1991), which includes a single-family study (Brown et al. 1993, Berry et al. 1991), a high-density multifamily study (MacDonald 1993), and a fuel-oil study. The Fuel-Oil Study is the subject of this report.

The primary goal of the Fuel-Oil Study was to provide a region-wide estimate of the space-heating fuel oil saved by the Program in the Northeast during the 1991 and 1992 program years. Other goals were to identity and quantify non-energy impacts of the Program, to assess the cost effectiveness of the Program within the fuel-oil submarket, and to assess factors which caused fuel-oil savings to vary.

METHODOLOGY

The Fuel-Oil Study analyzed only single-family houses in the nine states in the Northeast census region and was performed over two heating seasons (1991 and 1992 program years). A total of 337 houses were instrumented to obtain field measurements of space-heating fuel-oil consumption and indoor and outdoor temperatures. A split-winter experimental design containing pre- and post-weatherization periods and including a control group was used (Fig. ES.1). Energy conservation measures were installed in each weatherized house by the local weatherization agency in January of each program year utilizing their usual audit and implementation procedures. Each house was monitored over one heating season.

Of the total 337 houses (222 weatherized houses and 115 control houses) monitored, there were 121 weatherized houses and 70 control houses monitored and distributed among 25 local weatherization agencies over the 1990-1991 heating season. The remaining 101 weatherized houses and 45 control houses were monitored from a different set of 16 agencies over the 1991-1992 heating season. All houses met a set of requirements concerning household Program

Group 1	1990-1991 Heating season
Weatherized group (121 houses)	pre W post
Control group (70 houses)	pre post W

Group 2		1991-1992 Heating season
Weatherized group (101 houses)		pre W post
Control group (45 houses)		pre post W

Note: W = Weatherization performed

Fig. ES.1. Split-winter experimental design.

eligibility, single-family construction, and fuel-oil heating systems. At least two agencies were chosen from each state during the 1990-1991 heating season and one from each state during the 1991-1992 heating season to ensure a representative sample. Selection of agencies and test houses was random.

Information about the physical characteristics of each house and its space-heating, space-cooling, and water-heating systems was collected at the end of the post-weatherization period. A comprehensive occupant questionnaire was conducted at the end of the post-weatherization period. The questionnaire provided occupant and house characteristics and occupant perceptions of Program impacts on health, safety, comfort, and heating affordability.

Air-leakage tests were performed in all houses using blower doors before and after weatherization to determine changes caused by the combined weatherization measures. The steady-state efficiency of each space-heating system was measured for both pre- and post-weatherization periods. A safety inspection of the space- and domestic water-heating systems was performed at the end of the post-weatherization period in all houses.

HOUSE AND OCCUPANT CHARACTERISTICS

The average number of occupants per house was three. The age distribution of the occupants was 13% preschool, 27% school age, 42% adults, and 18% over 65. Each family had resided at their present address for 19 years on average. Homeowners accounted for 87% of our sample, with half of these having no mortgage payments. The average monthly rent paid by the renters was $333. The average annual household income was $10,800.

Control and weatherized houses were similar in most respects. An average house participating in the field test was 63 years old (it was built in 1928) and had two floors built above a concrete basement. The non-basement floor area of the house was 1332 ft^2 and the total floor area of the house, including the usually unheated basement, was 1989 ft^2. An average of 1274 ft^2 of the total non-basement floor area, or 96%, was intentionally heated and 13% of the homeowners reported they heated their basements. The houses were wood-framed, with a wood siding exterior wall area of 1608 ft^2 and a window area (wooden-framed single-pane with metal storm windows) of 169 ft^2.

Control houses had less insulation, on average, than weatherized houses. Exterior wall cavity insulation was present in 52% of the control houses and in 60% of the weatherized houses after weatherization. Attic insulation was present in 82% of the control houses and 91% of the weatherized houses. Floor and foundation insulation were usually not present.

Forced-air furnaces were used in 44% of the houses, gravity furnaces were used in 2% of the houses, steam boilers were used in 12% of the houses, and boilers with hydronic distribution systems were used in 41% of the houses. The average ages of the heating systems by type were: forced-air furnaces, 14 years; gravity furnaces, 58 years; steam boilers, 26 years; and hydronic boilers, 18 years. Fifty-five percent of the burners were of the flame-retention type. Most of the participants, (67%) in the pre-weatherization period and 76% in the post-weatherization period, said they did not use any type of auxiliary heat.

Stand-alone systems accounted for 61% of the total domestic water-heating systems, while tankless or integrated systems comprised 39%. Electric stand-alone systems comprised 37% of the total, natural gas stand-alone systems 11%, propane stand-alone systems 8%, and stand-alone fuel-oil systems 5%. The average estimated hot water temperature was about 130°F.

INSTALLED MEASURES AND PROCEDURES

Based on data collected in the study, we estimated that 23,400 single-family houses heated by fuel-oil were weatherized by the local weatherization agencies over the 1991 and 1992 program years in the northeast. Weatherization activity in a house was performed completely by employees of local weatherization agencies in 27% of the houses, while activity was performed completely by contractor crews in 55% of the houses. Both in-house and contractor crews performed the work in the remaining houses. Space-heating system measures (predominately tune-ups) were primarily performed by heating contractors (78%).

An envelope measure selection procedure (usually a priority list) was applied to virtually all of the houses weatherized in the northeast region in 1991 and 1992. Blower doors were used to diagnose air leakage problems in about 75% of the houses. Diagnostic procedures to examine space-heating systems (primarily steady-state efficiency test and safety inspection) were used in about 80% of the houses. Carbon monoxide tests were performed in 28% of the houses and radon tests were never performed.

Insulation measures were installed in 82% of the houses, with 96% of the houses receiving air leakage measures (see Fig. ES.2). Measures addressing the domestic water-heating system were installed in 62%, and energy-efficiency improvements to windows and doors were made in only 41% of the houses. Space-heating system measures were installed in 53% of the houses. Funding from several sources were used for weatherization. Although most funds were spent following Weatherization Assistance Program rules, funds with fewer restrictions could also have been used.

A visual quality control inspection was performed on almost all houses, while a blower door was used as a post-inspection device in less than half the houses. A space-heating system quality control inspection was performed in all of the houses receiving a space-heating system measure.

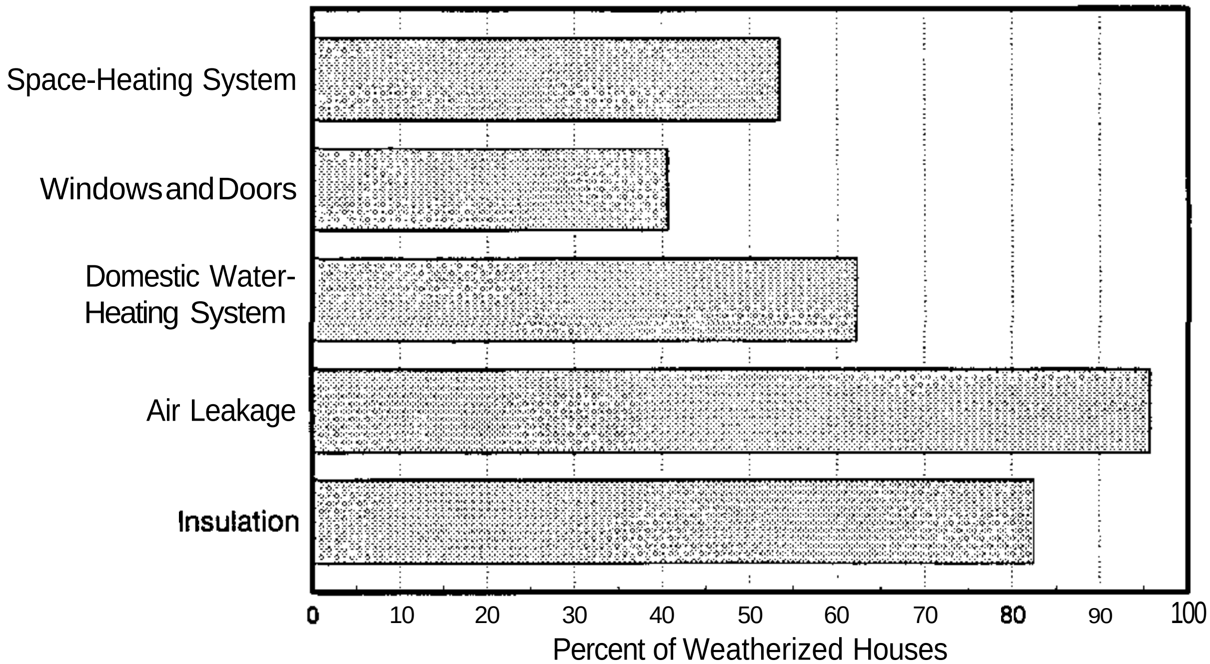

Fig. ES.2. Installation frequency of general types of weatherization measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

Client education was provided to over 95% of the weatherized households. In-person education was provided to 91% of the households, and literature was mailed or left with the client about half of the time.

ESTIMATES OF SAVINGS

Analyses were performed on 298 of the monitored houses (105 control houses and 193 weatherized houses). A useful set of pre- and post-weatherization monitoring data could not be collected from 39 houses because of various problems.

The measured pre- and post-weatherization consumptions could not be directly compared on the same basis because data were collected over different parts of the split-heating season. Therefore, it was necessary to normalize the measured consumptions. A predictive linear regression modeling equation relating consumption to an indoor-outdoor temperature difference was fitted to the daily measured data for each site for pre- and post-weatherization periods. An average indoor temperature for each site was determined for the pre-weatherization period and for the post-weatherization period. "Typical Meteorological Year" weather data tapes (based on historical data from the various locations they represent) were used with pre- and post-weatherization regression coefficients and average indoor temperatures from each site to estimate normalized annual fuel-oil consumptions. A normalized annual savings for each house was obtained by subtracting the normalized annual post-weatherization consumption from the normalized annual pre-weatherization value.

A weighted ratio-estimator averaging procedure was used to determine average regional weighted values of consumption and savings in the northeast region. Table ES.1 contains a summary of regional (weighted) results for both control and weatherized homes for the combined test years, 1990-1992. The average regional pre-weatherization fuel-oil consumption for the control houses was 918 gallons/year and 905 gallons/year for the weatherized houses[1]. The average regional fuel-oil consumption of the control houses increased to 956 gallons/year, for a gross change of -38 gallons/year (the control houses used 38 gallons/year more in the post-weatherization period than the pre-weatherization period) or negative 4.1% of pre-weatherization consumption. The average regional fuel-oil consumption of the weatherized houses decreased to 783 gallons/year following weatherization, for a gross savings of 122 gallons/year or 13.5% of pre-weatherization consumption. Gross savings measured for the weatherized houses were nearly identical for each program year. The regional gross savings for control and weatherized houses were statistically different from zero and from each other at a 0.05% level of significance.

The best estimate for the regional savings obtained from the Fuel-Oil Study is the net savings of weatherized houses (the gross change of the control houses subtracted from the gross savings of the weatherized houses). The net regional savings was 160 gallons/year, or 17.7% of pre-weatherization consumption. The dollar value of the net savings was $162, assuming a fuel cost of $1.01/gallon. The 90% confidence interval for the savings was ±31 gallons/year (±3.4% of pre-weatherization consumption).

[1] Fuel-oil consumptions can be converted from gallons to Btu by multiplying gallons by 140,000 Btu/gallon, the higher heating value of fuel oil.

Table ES.1. Regional (weighted) fuel-oil consumptions and savings

Item	Control houses		Weatherized houses	
	Weighted mean value (gallons)	90% confidence interval	Weighted mean value (gallons)	90% confidence interval
Annual pre-weatherization consumption	918	±64	905	±51
Annual post-weatherization consumption	956	±71	783	±52
Annual gross change	-38	±24	122	±19
Annual net savings			160	±31

Note: Fuel-oil consumptions can be converted from gallons to Btu by multiplying gallons by 140,000 Btu/gallon, the higher heating value of fuel oil.

As shown in Fig. ES.3, 65% of the weatherized houses had measured savings between 0 and 300 gallons/year. Only 4% of the sample had savings greater than 500 gallons/year and about 17% had negative savings (with most of these being limited to -100 to 0 gallons/year).

The average regional pre-weatherization indoor temperatures of the control and weatherized houses were nearly the same: 70.3° F and 70.5° F, respectively. The average regional indoor temperature change for the control houses was nearly zero, and only -0.1° F for the weatherized houses. This indicates that, on average, an indoor temperature "takeback" effect did not exist in our sample.[2]

AIR LEAKAGE MEASUREMENTS

The average sample pre-weatherization air leakage was 3468 cfm50 for the control houses and 3295 cfm50 for the weatherized houses (see Table ES.2). The two groups were statistically the same at a 0.05 level of significance. Houses in the northeast with air leakages between 1000

[2]For this study, a "takeback effect" would be an increase in the indoor temperature after weatherization has been completed in order to obtain more comfort by reinvesting some of the weatherization savings back into fuel oil.

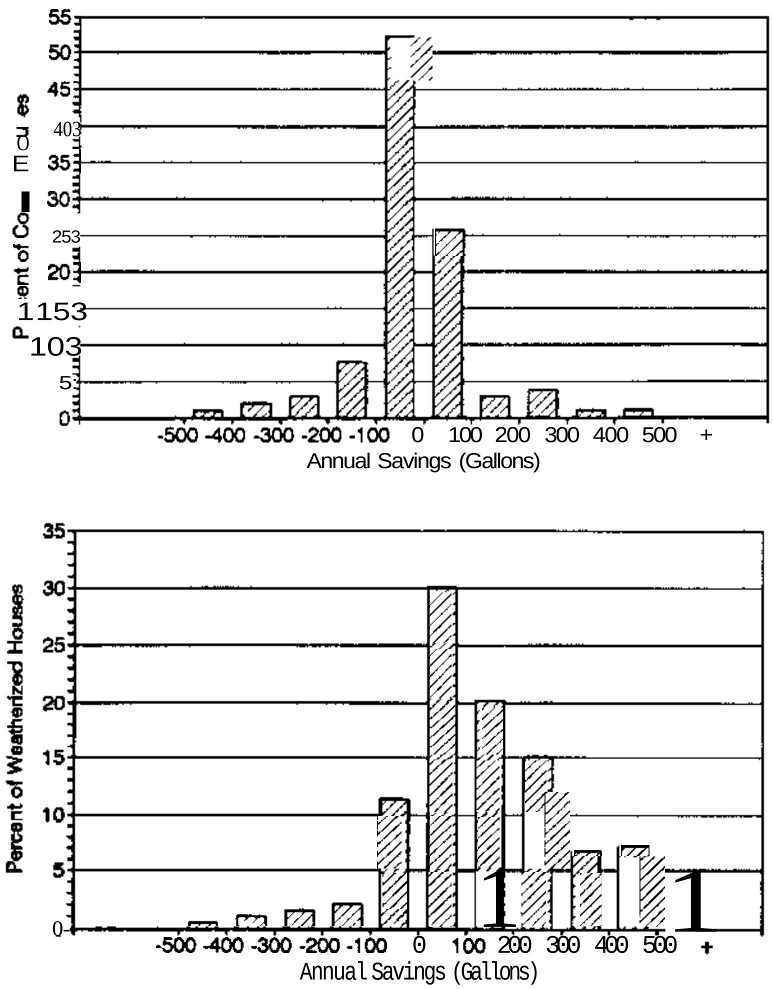

Fig. ES3. Distribution *of* **fuel-oil** savings for the control and weatherized houses. For the control **houses,** the sample (unweighted) mean was -20 **gallons/year** and the standard deviation was **117.** For the weatherized **houses,** the sample mean was 143 **gallons/year** and the **standard** deviation was 195.

and 1400 cfm50 are generally considered to be tight (Tsongas 1993), requiring no infiltration reduction work.

Weatherization work performed under the study achieved statistically significant reductions in air leakage. The average sample air-leakage reduction was 164 **cfm50** for the control houses and 570 **cfm50** for the weatherized houses. The control house reduction was not statistically different from zero at a 0.05 level of significance; the weatherized house reduction was statistically different from zero and from the control house reduction at this same confidence level.

Table ES.2. Control and weatherized house air-leakages

	Control houses	Weatherized houses
Number of houses	54	113
Pre-weatherization air leakage (cfm50)	3468	3295
Post-weatherization air leakage (cfm50)	3304	2725
Air-leakage reduction (cfm50)	164	570

On average, air leakage reductions were 240 cfm50 greater in houses in which blower doors were used in sealing work compared to houses not receiving this treatment. Similarly, reductions were 175 cfm50 greater in houses receiving wall insulation, and 300 cfm50 greater in houses receiving high-density wall insulation. Houses with forced-air distribution systems did not have greater air leakage reductions than houses without forced-air distribution systems, despite the fact that air distribution systems are often leaky and contribute to total house leakage. None of these differences were statistically significant at a 0.10 level of significance (use of a blower door and installation of high-density wall insulation would just be significant at a 0.20 level of significance).

HEATING SYSTEM MEASURES

A clean and tune-up was a measure performed on many heating systems. This service is supposed to increase system efficiency (both steady-state and seasonal) and also assure that a system is functioning reliably and safely. A sample group was selected containing all houses which did not receive a new heating system or a new burner, and had valid steady-state efficiency (SSE) data for both pre- and post-weatherization periods. A total of 208 houses were in the sample: 72 control houses and 136 weatherized houses. None of the control houses received a clean and tune, while 71 of the 136 weatherized houses received a clean and tune-up.

The weatherized houses receiving a clean and tune-up were originally less efficient and more in need of a tune-up than weatherized houses not receiving this services (see Table ES.3). The control houses, which received no clean and tune-up services, showed the greatest SSE increase of all three groups.

Table ES3. Mean values of measured space-heating system performance parameters

Type of house	Number in sample	Adjusted steady-state efficiency[1]		
		Pre-weatherization	Post-weatherization	Difference
WEATHERIZED	136			
No clean and tune-up	65	77.2	77.7	0.5
Clean and tune-up	71	75.0	75.8	0.8
CONTROL	72			
No clean & tune-up	72	75.0	76.6	1.5

[1]Steady-state efficiencies were adjusted for smoke numbers.

Figure ES.4 offers more insight into the effectiveness of clean and tune-up services. It shows a general trend (the R^2 value was low at about 0.2) for measured changes in SSE to be greater for sites with low SSEs at the beginning of a heating season. The change in SSE was usually negligible or negative if the pre-weatherization SSE was greater than about 77%. A 3 percentage point improvement was obtained at sites with a pre-weatherization SSE of 70%. Unfortunately, the same trend was observed for control houses and weatherized houses not receiving a clean and tune-up. Ternes et al. (1991) found the same type of behavior in a study dealing with gas space-heating systems in New York state.

The results for the weatherized houses receiving a clean and tune-up, interpreted by themselves, indicate that clean and tune-ups should be performed only when pre-weatherization efficiencies are less than 70%; clean and tune-ups consistently increased steady-state efficiencies only when pre-weatherization efficiencies were less than 70%. The scattered results and low average increases in SSE obtained from clean and tune-ups performed at houses with higher pre-weatherization efficiencies suggest that clean and tune-ups are not long lasting (our SSE measurements were made at the end of the heating season), clean and tunes are not done properly, or systems in these houses are already operating at their maximum efficiency. The results from the control houses and weatherized houses not receiving a clean and tune-up indicate that clean and tune-ups were not the cause for efficiency increases, suggesting that clean and tune-ups should not be performed with expectations of improved SSEs.

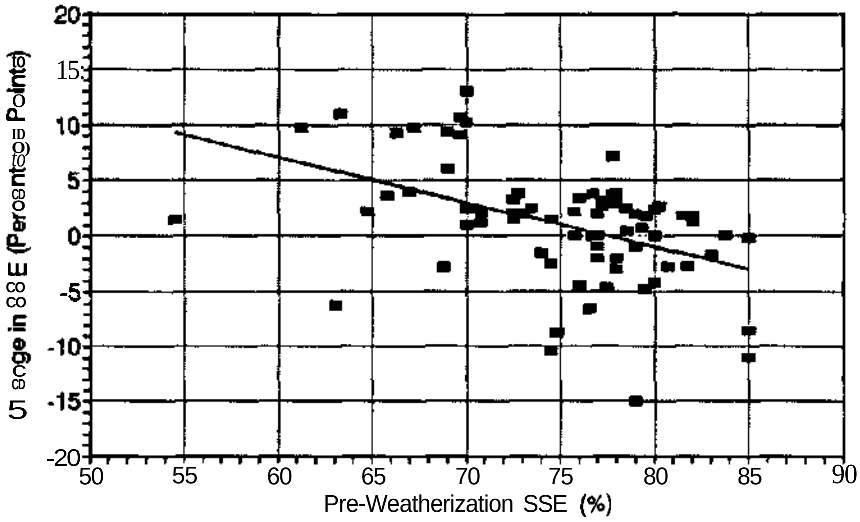

Fig. ES.4. Comparison of the change in adjusted steady-state efficiency to the pre-weatherization efficiency for the weatherized houses receiving a clean and tune.

A visual and instrumented inspection of each heating system was conducted at the conclusion of each heating season. Overall, the systems were relatively safe. Visual inspections showed little difference overall in safety between control and weatherized houses, although the severity of problems can differ between groups. Combustible material near the flue, distribution system structural problems, no return air system present, and presence of a barometric damper were the main areas where weatherized and control houses differed. All differences favored weatherized houses, indicating that the weatherized houses were safer.

The safety inspection included checking the settings of fan operating (high and low limit) and cutout (maximum operating temperature limit) switches. All forced-air heating systems in both groups had fan operating and cutout switches present. Average switch settings for control and weatherized forced-air heating systems were essentially the same. Fan-on (upper-limit) switches for control and weatherized houses both averaged 137°F, while fan-off (lower-limit) switches averaged 99°F for control houses and 100°F for weatherized houses. Cutout switch settings averaged 197°F for control houses and 196°F for weatherized houses. Two control houses (7%) and two weatherized houses (2%) were noted as having potentially dangerous fan-on settings of 190°F to 200°F. The average operating temperatures for hydronic boilers was 164°F for both control and weatherized houses. Cutoff temperatures averaged about 190°F. Two (4%) hydronic boilers in control houses had operating temperatures of 200°F, while three (4%) boilers in weatherized houses were operating above 195°F. These five systems were operating at too-high a temperature for maximum efficiency and safety.

The average time for all heating systems to establish a draft was about 9 seconds. However, two control houses and one weatherized house took over 60 seconds to establish a draft, with one of each type requiring 180 seconds.

Measurements were made of carbon monoxide 5 ft from furnaces, in living rooms, in kitchens, and from hot-air registers. No houses had an appreciable carbon monoxide problem (carbon monoxide level ≥ 10 ppm) at the end of the heating season. Differences between control and weatherized houses were minor.

OCCUPANT FEEDBACK

The average indoor temperature levels reported by the occupants when a house was occupied was 69°F. Measured temperatures were about a degree or so higher than perceived temperatures. Fifty-three percent of weatherized-house respondents said they regularly changed the temperature in their house during the day in the pre-weatherization period, and 51% said they changed it during the post-weatherization period. Control house responses were similar: 56% said the temperature was changed during the day in the pre-weatherization period, and 55% said the temperature was changed in the post-weatherization period. Setbacks of temperatures reported by the occupants when a house was unoccupied or when the occupants were sleeping averaged about 5°F.

About 16% of control and weatherized households had inoperative space-heating systems sometime during the pre-weatherization period such that heat could not be provided. About 13% of the households did not have any fuel oil at some time during the pre-weatherization period. Mechanical problems decreased during the post-weatherization period (12% of control and weatherized households had problems), while running out of fuel oil decreased to 11% for weatherized houses and 8% for control houses. A utility stopped service because of failure to pay bills in about 5% of all houses during each period.

Occupants were asked to rate various indoor conditions and heating affordability on a scale of 1 to 7, where 1 was poor and 7 was very good. Control house responses did not change significantly from pre- to post-weatherization periods, whereas weatherized house perceptions all improved after weatherization (see Fig. ES.5). Control house responses were higher than weatherized responses in the pre-weatherization period, which could illustrate some bias to the weatherized group responses — they were thankful for the weatherization work and wanted to make us feel good. Nevertheless, weatherized house responses were higher than control house responses in the post-weatherization period, indicating improved satisfaction from weatherization. The areas of health and safety were the only areas both groups thought were acceptable before weatherization. Most people thought their homes were expensive to heat in the pre-weatherization period; occupants of weatherized houses felt that costs were much more reasonable after weatherization. Comfort, and especially draftiness, were also improved after weatherization according to weatherized home responses.

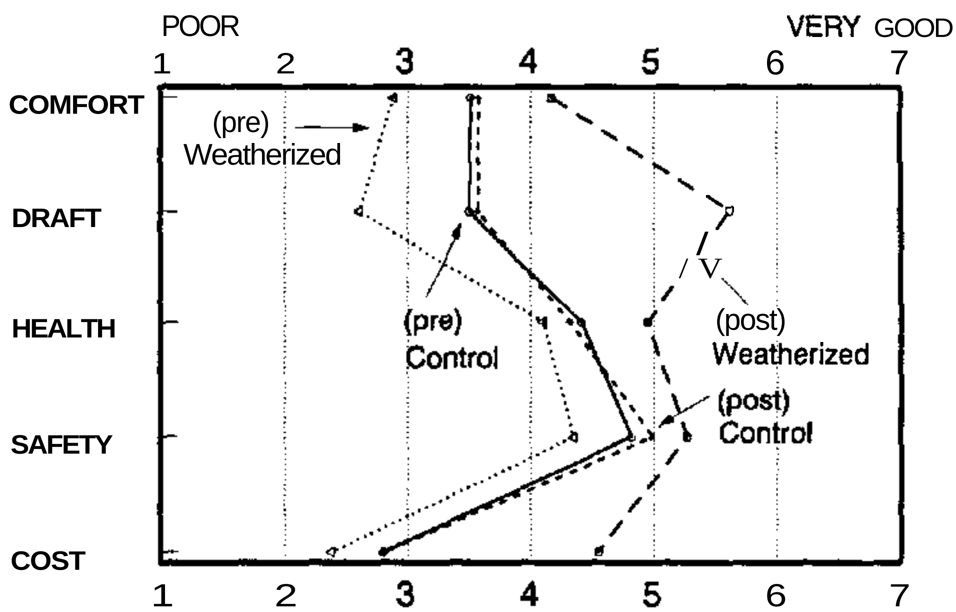

Fig. ES.5. Average rating provided by the occupants on indoor conditions and heating affordability before and after weatherization. A scale of 1 to 7 was used, where 1 was poor and 7 was very good.

PROGRAM COSTS

Total program costs were divided into installation costs and overhead and management costs. Installation costs included the actual costs for (1) materials installed in the houses and (2) labor required to install the materials and perform other energy-efficiency-improvement work on the house. Overhead and management costs include all other costs associated with providing the weatherization services. These expenses were divided into installation-related overhead and program management categories. Installation-related overhead expenses for contractors were estimated to be 15% of total billed cost. Installation labor costs for contractors were then calculated by subtracting material and overhead costs from the total billed cost. State expenditures for implementation of the Program were not included in the overhead and management costs presented in this section.

The regionwide average value for installation costs was $1192 for program years 1991 and 1992 combined. Material costs for these years were $745 for an average house weatherized, and labor costs were $447. Installation costs and their breakdown into material and labor costs were consistent for each program year. Installation costs for an individual house differed substantially from the average value of $1192, but was between $600 and $1500 in 58% of the houses. The minimum expenditure was $15 and the maximum was $4383.

Contractor expenditures accounted for 63% of the average installation costs. As previously stated, 27% of the houses had work performed completely by in-house crews only, 55% completely by contractors only, with the remaining done by a mixture of both. In houses in which both crew types were involved, about 75% of the expenditures were by the in-house crew. Higher costs associated with contractors were likely due to differences in the measures performed by contractors, and do not imply that they were inherently more expensive than in-house crews.

Figure ES.6 shows a cost breakdown of materials for an average weatherized house. Insulation materials accounted for a third of the total material expenditure. Material costs for air leakage, window and door, and space-heating system measures were approximately equal (12% - 18%). Expenditures on domestic water-heating system materials were rather small, being only 2% of the total material costs.

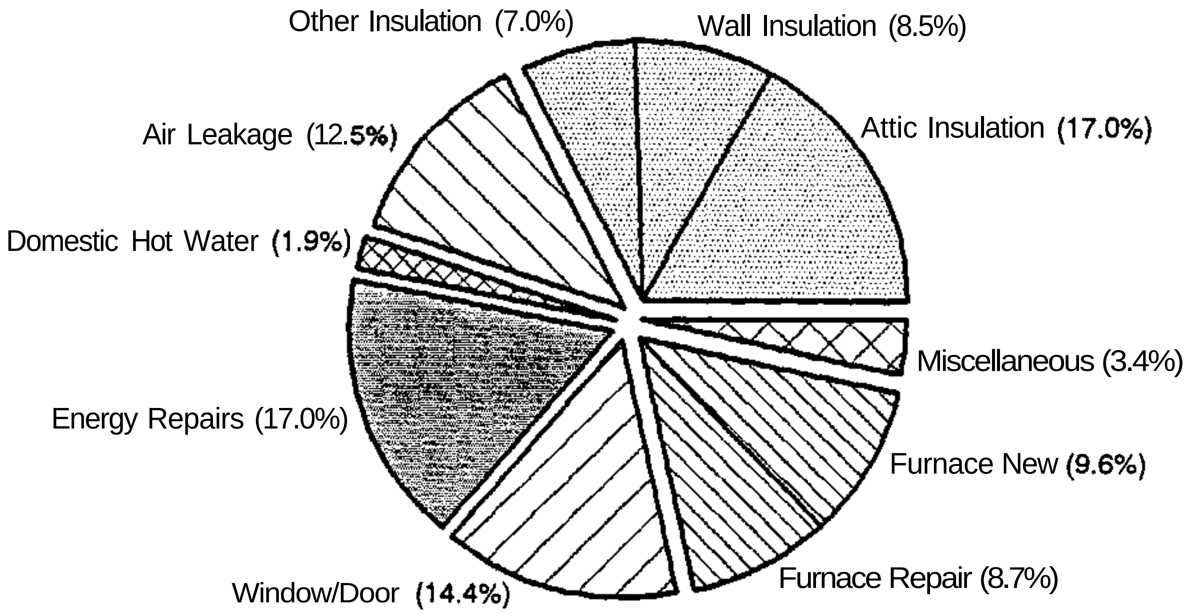

Fig. ES.6. Material cost breakdown for an average weatherized house (total cost was $745/house).

We estimated an average overhead and management cost of $627 per house to weatherize a single-family fuel-oil heated house in the northeast region. This cost included $438 for program management, $59 for in-house crew installation-related overhead, and $130 for contractor installation-related overhead.

Local weatherization agencies rely on a number of different funding sources to perform weatherizations, including the DOE Weatherization Assistance Program, Petroleum Violation Escrow (PVE) funds, the Low-Income Heating Energy Assistance Program operated by the Department of Health and Human Services, and various foundation, state, and utility programs. For single-family fuel-oil heated houses weatherized in the northeast region, 73% of the installation costs were provided by the Weatherization Assistance Program and PVE.

Average per house installation expenditures increased as the percent of total house costs covered by the Weatherization Assistance Program funds decreased. Average costs were $1114 in houses receiving just Weatherization Assistance Program funds, $1227 in houses where

Weatherization Assistance Program funds covered 50% or more of the total house expenditure, and $1417 in houses where Weatherization Assistance Program funds covered less than 50% of total house expenditures. This result was consistent with expectations because funding sources other than Weatherization Assistance Program funds were often used to install measures that were not allowed under Program guidelines (such as space-heating system replacements).

COST EFFECTIVENESS

The cost effectiveness of Weatherization measures was estimated using benefit-to-cost ratio. This indicator compares the discounted lifetime benefits obtained from the Program to the costs of achieving them. A program is cost-effective whenever the benefit-to-cost ratio is greater than or equal to unity.

Measured input values used to calculate benefit-to cost-ratios were a regional net average fuel-oil savings of 160 gallons/year, an average regional installation cost of $1192, and an average overhead and management cost of $627. Fuel-oil savings were converted to regional dollar value estimates using a fuel-oil cost of $1.01/gallon (the average regional fuel-oil cost in the northeast during the study). A "real" discount rate of 4.7% and a fuel escalation rate were used in the calculation of benefit-to-cost ratio as recommended by the Department of Commerce for the year 1991 (Lippiat and Ruegg 1990).

Benefit-to-cost ratios were calculated from three perspectives. An installation perspective is defined to consider only energy savings benefits and on-site installation costs. This perspective is the most narrowly defined. It provides insight into how well the measures performed based on their primary function (i.e., to save energy) without considering the indirect costs required to operate a program. A program perspective is defined to consider energy savings benefits and the total costs required for Weatherization (installation costs combined with overhead and management costs). The program perspective is the most conservative estimate of program cost effectiveness. A societal perspective was developed to consider the broadest definitions of benefits and costs: benefits include energy and nonenergy benefits, and costs include installation, overhead, and management expenses.

Table ES.4. Cost-effectiveness estimates

Measure life (years)	Benefit-to-cost ratio		
	Installation perspective	Program perspective	Societal perspective
10	1.25	0.82	1.35
15	1.79	1.17	1.71
20	2.26	1.48	2.01
25	2.65	1.74	2.27

Nonenergy (or societal) benefits can result from the weatherization activity performed under the Program. A quantitative value for these nonenergy benefits is not as simple to estimate as are the energy savings and costs associated with weatherization. Nonenergy benefits can be grouped into five major categories:

- preservation of affordable housing,
- comfort, health, and safety impacts,
- impacts on household budgets,
- employment and economic impacts, and
- environmental externality impacts.

Brown et al. (1993) extensively examined nonenergy impacts of low-income weatherization and concluded that the average net present dollar value of nonenergy impacts for the Program in 1989 was $976 per weatherized house. This value was used for the societal perspective.

Table ES.4 summarizes the results of the benefit-to-cost ratio calculations performed. These results are plotted in Fig. ES.7. The program is cost effective from all three perspectives under the conditions analyzed except for the program perspective assuming a 10-year lifetime for the measures. The Program is cost effective from the societal and installation perspectives assuming measure lifetimes as low as six and eight years, respectively. The Program is cost effective from a program perspective when measure lifetimes exceed 12.5 years.

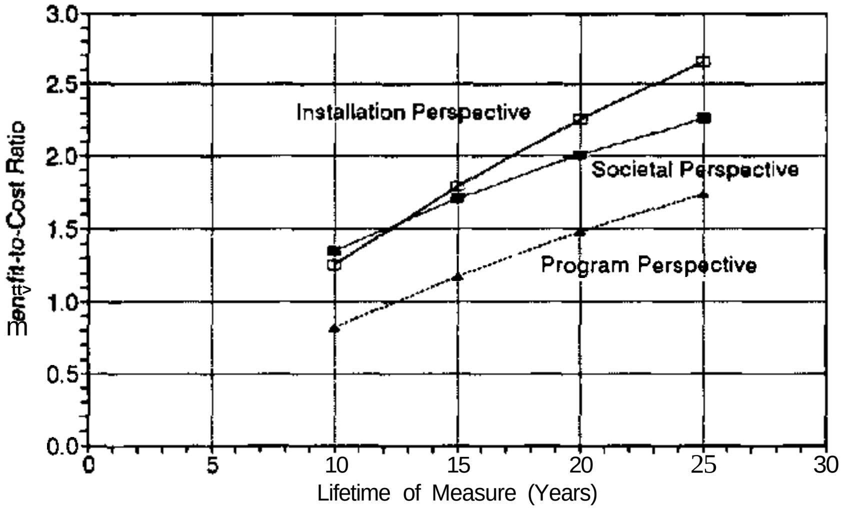

Fig. ES.7. Comparison of benefit-to-cost ratios to measure lifetimes.

Estimated lifetimes for the various weatherization measures installed in the study houses range from 1 to 5 years for caulking to 30 plus years for insulation, with 20 years being a fair average for all measures combined (Brown et al. 1993). A 20-year estimated life results in a benefit-to-cost ratio of 2.26 from an installation perspective, 2.01 from a societal perspective, and 1.48 from a program perspective. All three estimates show that the Weatherization Assistance Program is indeed cost effective for fuel-oil heated houses in the northeast.

FACTORS ASSOCIATED WITH SAVINGS

An analysis conducted to determine which measures provided the most savings in this study was difficult. Sample houses were randomly chosen to determine energy savings rather than to determine what caused the savings. A sample aimed at differentiating savings among measures would have contained houses receiving individual measures and selected combinations of measures. For example, almost all houses in our sample received standard caulking and weatherstripping, making it impossible to study this measure. Also, the sample size was too small and not sufficiently randomly distributed to study the large number of combinations of measures installed, house characteristics, procedures, etc. Another item to note is that inspections were conducted on the test houses after weatherization had been accomplished and not before. Thus, detailed information is available on conditions existing in a house after weatherization was done, but not before weatherization.

This study showed a definite trend for savings to be greater in houses with high pre-weatherization consumption and high pre-weatherization consumption per unit floor area. On average, households in this study with a pre-weatherization fuel-oil usage of 1 gallon/square foot/year achieved a savings of 20%.

The cost to weatherize a house was found to be associated with the savings obtained by that house. The houses on which more than $1200 was spent for installation (labor and materials) saved more than twice as much fuel-oil as houses that had less than $1200 spent on them. The houses receiving the higher expenditures also used more fuel-oil in the pre-weatherization period. This suggests that the money spent to weatherize houses was, on average, spent properly because the most needy houses (the largest consumers) received more than the more efficient houses.

The effect of four occupant and dwelling characteristics on the savings obtained from weatherization were investigated: ownership, occupancy by an elderly or handicapped person, and number of stories in the house. All four factors were not associated with higher-than-average savings.

Average measured savings in houses receiving a particular measure during weatherization were compared to the remaining houses to determine the savings associated with the particular measure (see Table ES.5). It is not possible to precisely estimate how much energy is saved by a single measure based on this analysis approach because the savings are for the house with the specific measure in question plus all other measures that may have been installed in the house. The particular measure being examined may not be the cause of a significant difference in energy savings because extensive correlation existed among the variables.

Table ES.5. House-level energy savings associated with selected measures

Houses receiving measures including:	Annual pre-weatherization consumption (gallons)	Annual savings (gallons)	Number of dwellings	Significance level
All Houses	930	162	149	
Air Leakage				
General caulking	936	168	136	—
Air sealing without a blower door	919	162	77	—
Air sealing with a blower door	1041	193	40	*
Distribution system	952	206	26	—
Other	924	195	31	—
Insulation				
Attic insulation, first time	1032	237	54	*
Attic insulation, added	829	165	55	—
Wall insulation, standard	970	223	42	*
Wall insulation, high-density	965	313	16	*
Rim or band joist insulation	1012	171	32	—
Floor insulation	970	194	58	—
Other	986	193	33	—
Windows and Doors				
Storm window(s)	951	154	46	---
Storm door(s)	784	30	7	*
Window films of shades	–	--	0	—
Other	795	71	6	—
Space-Heating System				
Clean and tune-up	998	191	63	—
New system	1031	305	5	*
Set-back thermostat	972	190	9	—
Component retrofit	996	163	9	—

* means that differences in savings are different from zero at the 0.05 level of significance.
— means that differences in savings are not significantly different from zero.

Table ES.5. House-level energy savings associated with selected measures (continued)

Houses receiving measures including:	Annual pre-weatherization consumption (gallons/year)	Annual savings (gallons)	Number of dwellings	Significance level
Water Heating Measures				
Tank insulation	843	171	43	—
New system	953	456	1	—
Pipe insulation	914	166	80	—
Temperature reduction	1019	219	22	—
Low-flow showerhead	923	214	15	—
Other	982	160	18	—
Structural Measures				
Attic ventilation	938	203	71	*
Roof	743	125	5	—
Doors	959	190	34	—
Doors replacement	968	222	24	—
Windows glazing	933	177	89	—
Window replacement	1014	126	26	—
Walls	997	185	9	—
Floor	755	157	2	—
Other	838	168	53	—

* means that differences in savings are different from zero at the 0.05 level or greater.
— means that differences in savings are not significantly different from zero.

Using a blower door for sealing was the only air-leakage control measure that showed statistically significant (0.05 level of significance) higher-than-average savings. Houses receiving this treatment also appeared to have higher-than-average pre-weatherization consumptions. No statistically significant differences existed between houses receiving general caulking, distribution system work, or other infiltration reduction techniques and houses not receiving these measures.

Houses in which new attic insulation, normal wall insulation, and high-density wall insulation were added had statistically significant, higher-than-average savings. Houses receiving new attic insulation had pre-weatherization consumptions greater than average, while houses receiving wall insulation were about average. Pre-weatherization consumptions of houses receiving and not receiving wall insulation may not have been as different as one would expect because some houses needing wall insulation still did not receive this measure.

Houses receiving the addition of storm doors had statistically significant, lower-than-average savings (30 gallons/year). This does not imply that storm doors increase fuel-oil consumption. The pre-weatherization consumption of houses receiving a storm door were much lower than average, indicating that the houses were already relatively efficient. Storm doors may have been installed in these houses because other, more effective measures were already in place. There were only seven houses receiving storm doors, so the results may possibly be viewed as being inconclusive because of the small sample size. Savings for houses receiving all other window and door measures such as adding storm windows were not statistically different from houses not receiving these measures.

The only space-heating and water-heating system measure associated with statistically significant higher-than-average savings was replacement of the entire heating system. Houses receiving this measure saved 305 gallons/year, or about twice the average of all houses. A small sample size of five units may add some uncertainty to this result. This measure was expensive, typically costing about $2000 to $2500 to complete. Houses receiving a new system had higher pre-weatherization consumptions than average; in fact, houses receiving any space-heating system measure generally had higher-than-average pre-weatherization consumptions.

Attic ventilation was the only structural measure (i.e., those measures which are either energy related, such as replacing broken window glass, or are necessary in order to enable other energy-related repairs to be accomplished) associated with statistically significant, higher-than-average savings. Obviously, attic ventilation by itself cannot bring about such savings, so it must be correlated with some other variable like attic insulation. Discussions with weatherization agency employees confirmed that an attic was often not vented if it did not have any insulation in it. A check of 54 houses receiving new attic insulation showed that 80% of them also received attic ventilation. Chi-square tests verified this correlation.

None of the measure selection approaches or diagnostic procedures were associated with statistically significant above-average savings. The use of heating system performance data to select space-heating system measures and the use of a blower door to measure leakage rates were significant at a 0.10 level of significance, however.

Houses receiving a visual inspection of space-heating systems had a statistically significant, above-average savings of 200 gallons/year. However, the savings improvement observed could be due to the fact that space-heating system work was performed (and thus inspected). Almost all houses (95%) receiving a space-heating system measure also received a visual inspection.

None of the client education measures were associated with statistically significant, above-average savings, perhaps because almost all houses (94%) received in-person education.

In order to examine why differences occurred between those houses which saved the most energy and those which saved the least, two groups were formed which contained the top and bottom 12%. As shown in Table ES.6, the high savers averaged 498 gallons/year of fuel oil saved (37%) while the low savers saved -44 gallons/year (-6%). The low savers used considerably less fuel in the pre-weatherization period than the high savers (873 vs 1392 gallons/year, respectively) even though both groups were identical in heated area. After weatherization, however, the high savers used about the same amount of fuel as the low savers (894 vs 917 gallons/year, respectively). The high savers were weatherized cost effectively with an average of $1604 being spent on each for labor and materials. The low savers were not weatherized cost effectively, even though an average of $892 was spent on each. The high savers benefitted more from air leakage measures than the low savers, but both ended up at about the same level of tightness. The low savers had more efficient heating systems and higher indoor temperatures than the high savers. These facts suggest the high savers were houses that really needed weatherization, while the low savers were houses that were relatively more energy efficient. The annual consumption of the low savers averaged 0.67 gal/ft^2/year, which also was the post-weatherization consumption of the high savers.

Table ES.6. Mean values of measured variables

Variable	Bottom 12% (losers)	Top 12% (winners)
Annual savings (gallons)	-44	498
Percent savings	-5.7	37.5
Weatherization cost ($ for labor + materials)	892	1604
Pre-weatherization gal/ft²/year	0.67	1.06
Post-weatherization gal/ft²/year	0.71	0.66
Pre-weatherization inside temperature (°F)	72.3	70.7
Post-weatherization inside temperature (°F)	72.4	70.1
Heated area (ft^2)	1457	1467
Pre-weatherization consumption (gallons)	873	1393
Post-weatherization consumption (gallons)	917	895
Pre-weatherization air leakage (cfm50)	3580	3856
Post-weatherization air leakage (cfm50)	3290	3191
Air leakage difference (cfm50)	290	665
Pre-weatherization steady state efficiency	76.5	72.9
Program benefit-to-cost ratio at 15 years	--	2.96

Similar measures were installed in both groups, but the frequency at which measures were installed were not the same. Measures installed in only the high savers were new space-heating systems, high-density wall insulation, low-flow showerheads, and domestic hot-water temperature reduction. Measures installed more frequently (difference of 20 percentage points or more) in the high savers than the low savers were new or additional attic insulation, regular wall insulation, floor insulation, air sealing using a blower door, replacement of broken glass in windows, and heating system clean and tunes. Measures installed more frequently in the low savers than the high savers were replacement windows and new storm doors.

The service delivery procedures differed little between these two groups. About 80% of both groups used a priority list to select envelope measures and 60% used a visual inspection to select space-heating measures. A blower door was used to find and measure leakage areas in about 80% of the high savers compared to 60% of the low savers. About 90% of both groups measured the furnace steady-state efficiency before weatherization. A visual inspection of envelope measures was performed in all houses of both groups after weatherization. A blower door was used on 50% of the high savers compared to 11% of the low savers for quality control of envelope measures. About 60% of the high savers conducted visual and testing inspections on heating systems compared to 35% of the low savers.

An overview agency-level analysis showed three agencies standing out as their average savings were above 400 gallons/year, but one of these agencies had only one house in its sample while a second had only two. Five agencies had mean annual savings of less than 50 gallons/house. A consumption versus savings analysis on an agency level shows a weak relationship between pre-weatherization consumption and savings. However, some agencies having high pre-weatherization consumptions had low savings and visa-versa. About 63% of the agencies obtained an average annual savings between 100-250 gallons/house, while 23% averaged below 100 gallons/house and 15% averaged above 250 gallons/house. These analyses show that differences exist in savings among agencies.

Since the agencies are monitored by their respective states, the average savings per house attained by each of the nine states in which the Fuel-Oil Study was examined. Two states attained well-below-average savings, five states attained average savings, and two states attained well-above-average savings. There was no statistical difference in savings among the states at the 95% confidence level, but we believe that differences in state policies toward weatherization have an impact on the achievable savings of the Program.

CONCLUSIONS AND RECOMMENDATIONS

The Weatherization Assistance Program cost-effectively weatherized a total of 23,400 single-family fuel-oil-heated houses in the nine northeastern states during program years 1991 and 1992. An average annual net fuel-oil savings of 160 gallons (17.7% of pre-weatherization consumption) was achieved at a total average cost of $1819 ($1192 for installation labor and materials and $627 for overhead and management); the resulting program-perspective benefit-to-cost ratio was 1.48 and the societal perspective ratio was 2.01. Although indoor temperatures changed in individual houses following weatherization, there was no average difference when compared to the control houses; thus, there was no overall indoor-temperature take-back effect influencing fuel-oil savings.

A general trend toward higher-than-average fuel-oil savings was observed in houses with high pre-weatherization fuel-oil consumption. Program savings could likely be increased by targeting higher energy consumers for weatherization, although equity issues would have to be considered.

Weatherization measures associated with statistically significant, higher-than-average savings were use of a blower door for air-sealing, attic and wall insulation, and replacement space-heating systems. More extensive analysis of the data should be performed to further investigate various interacting factors leading to improved fuel-oil savings and cost-effectiveness. An intangible factor of "state/local weatherization agency leadership and quality" that many feel is an important cause of improved performance could not be addressed by this study.

Space-heating system tune-ups were not particularly effective at improving the steady-state efficiency of systems and were not associated with statistically significant, higher-than-average savings, although improved seasonal efficiency and system safety and reliability may have resulted. Tune-ups were performed on some systems that were already operating efficiently, and they did not achieve maximum savings potential on many inefficient systems. The need to use licensed technicians to audit systems and perform tune-ups led to the extraneous tune-up problems and the increased costs, although increased use of fully qualified technicians might improve performance. The Weatherization Assistance Program should investigate methods of improving the selection and/or application of space-heating system tune-ups and actively study and promote adoption of improved tune-up procedures as a primary technology transfer activity. A committee composed of experts in the field could be assembled to develop recommended approaches and consult with states to verify benefits. State and local weatherization agency data should be collected to further study and refine tune-up techniques.

Air-leakage measurements showed that weatherized houses were more air-tight following weatherization, but still leakier than what is achievable. Although not statistically verifiable, the use of blower doors and installation of wall insulation were two measures that likely led to greater-than-average air-leakage reductions. Additional technology transfer effort is recommended to increase the use of blower doors considering that only half the weatherized houses used a blower door. A guidebook developed by a committee of experts and covering the following topic areas might be a useful technology transfer and training document: air-leakage theory, use of a blower door, measuring air leakage, finding and sealing leakage sites, and incorporating a blower door into a weatherization program. State and local weatherization agency data should be collected to further study the air-leakage reductions being achieved and the tightness of houses before and after weatherization.

Weatherization appeared to make occupants feel better about their house and house environment. Most occupants felt that their houses were healthy and safe, and this was supported by field inspections. Occupants felt that weatherization made their houses much more affordable to heat and much less drafty.

IMPACTS OF THE WEATHERIZATION ASSISTANCE PROGRAM
IN FUEL-OIL HEATED HOUSES

1. INTRODUCTION

1.1 BACKGROUND

Recognizing the need for an up-to-date and comprehensive assessment of the Weatherization Assistance Program, the U.S. Department of Energy (DOE) requested Oak Ridge National Laboratory to help design and conduct an up-to-date evaluation of the Program. The evaluation was comprised of three "impact" studies and two "policy" studies (Beschen and Brown 1991). The three "impact" studies focused on the energy savings and cost effectiveness of the Program in key DOE markets:

- single-family and small multifamily dwellings using gas or electricity for heating (Brown et al. 1993, Berry et al. 1991),
- high-density multifamily buildings using gas, electricity, or fuel-oil for heating (MacDonald 1993), and
- fuel-oil heated single-family homes.

The latter study is the subject of this report.

1.2 OBJECTIVES

There were four main goals of the Fuel-Oil Study. The primary goal was to provide a region-wide estimate of the space-heating fuel oil saved by the Program in the Northeast during the 1991 and 1992 program years (a typical program year generally runs from April to March). This estimate focused on fuel oil used for space heating. Space cooling was not prominent in this region and was not addressed.

The second goal was to identify and quantify (to the extent possible) non-energy impacts of the Program. The impacts of interest included program-induced improvements in the affordability of housing due to reduced household energy costs; reductions in the number of unsafe space- and domestic water-heating systems due to remedial actions taken or recommended during weatherization; and improvements in the comfort of houses due to reduced draftiness, increased indoor temperature, increased amount of heated living space, and occupants' perception of comfort improvements.

The third goal was to assess the cost effectiveness of the Program within the fuel-oil submarket using simple payback period and benefit-to-cost ratio as indicators.

The final goal was to identify factors which caused fuel-oil savings to vary. This assessment provided, to the extent possible, insights about groups of measures that were effective in reducing fuel-oil consumption, service delivery procedures that may enhance cost effectiveness, and market segments that future program efforts should consider targeting. Factors of interest included climate, dwelling unit characteristics prior to weatherization, packages of energy efficiency measures, audit procedures, and other service delivery practices.

These major goals cover the most significant issues and also focus on producing useful and practical information for program planning, implementation, and management that could be obtained for reasonable costs. For example, information from the evaluation will be useful for identifying how to best allocate Program resources, the market segments (such as high energy users) that future program efforts should target under specific circumstances, the service delivery procedures that are most effective for particular building types, the packages of measures that are shown to provide the most benefit, and the level of energy savings that can be expected per public dollar spent.

The Fuel-Oil Study, as well as the other studies, will provide essential inputs to the process of planning future roles for the Program network in brokering, demonstrating, evaluating, and accelerating the market penetration of energy-efficient, cost-effective building technologies.

2. EVALUATION DESIGN

The Fuel-Oil Study analyzed only single-family houses in the nine states in the Northeast census region. The study was performed over two heating seasons (1991 and 1992 program years) and involved submetered field measurements of space-heating fuel-oil consumption and indoor temperature in 337 houses. Detailed planning was performed to develop the evaluation design (Ternes, Levins, and Brown 1992). Details of the evaluation design as implemented are presented in this section.

2.1 EXPERIMENTAL DESIGN

A split-winter experimental design containing pre- and post-weatherization periods and including a control group was used (see Fig. 2.1). Submetered fuel-oil consumption was monitored in all the test houses. Each house was monitored over one heating season, with 191 test houses being monitored in 1990-1991 and 146 in 1991-1992.

Group 1	1990-1991 Heating season
Weatherized group (121 houses)	pre W post
Control group (70 houses)	pre post W

Group 2		1991-1992 Heating season
Weatherized group (101 houses)		pre W post
Control group (45 houses)		pre post W

Note: W = Weatherization performed

Fig. 2.1. Split-winter experimental design.

Pre- and post-weatherization testing allowed individual house space-heating fuel-oil savings to be determined because the houses served as their own reference. Individual house savings were averaged to determine group savings. Inclusion of a control group allowed estimation of energy consumption changes that would have occurred in the absence of the program. For instance, it controlled for factors such as differing ground temperatures between the pre- and post-weatherization periods and trends in the price of fuel oil. Savings for weatherized houses were adjusted by the savings for the control group to account for these factors.

In the split-winter design, each house was monitored over one heating season. Energy conservation measures were installed in the weatherized houses by the local weatherization agency in January of each program year utilizing their usual audit and implementation procedures. The split-winter design was chosen instead of a full winter of pre- and post-weatherization monitoring for the following reasons:

- Houses used as controls were weatherized within a time frame agreeable to the states and local weatherization agencies.
- Instead of monitoring all study houses over two heating seasons as needed under a full winter of pre- and post-weatherization monitoring, the split-winter design allowed half the houses to be monitored one heating season and the remaining half the second heating season. The reduced number of houses monitored each heating season made it easier to identify the required number of houses for the study from current eligibility lists and reduced the time needed to install instrumentation. Additionally, reuse of instrumentation for the 1991-1992 heating season reduced instrumentation costs and allowed indoor temperature to be monitored in all the houses.
- Attrition was reduced, which was particularly important because renters were included in the sample.

Disadvantages of the split-winter design identified at the start of the study included uncertainty associated with fuel-oil savings measured from shorter-term, split-winter testing and the need to weatherize all scheduled homes in a relatively short period in January. Previous studies performed with pre- and post-weatherization data collected over just half the heating season (McCold et al. 1988, Ternes et al. 1991) had been successfully performed. Results from this present study confirmed that split-winter testing is a viable monitoring approach provided the heating season is sufficiently long in duration. Discussions with state Weatherization Program directors and local weatherization agency personnel at the start of the study indicated that agencies could weatherize houses in January sufficient for the study and that weatherization operations performed in the heating season were quite similar to those performed during the summer. Few significant problems in completing the weatherizations as scheduled were encountered during the study.

22 SAMPLING PROCEDURE

A total of 337 houses were monitored over the two heating seasons of the study and were drawn from the population of houses meeting the eligibility requirements listed in Sect. 2.3. The houses were divided into 222 weatherized houses and 115 control houses. Over the 1990-1991 heating season, 121 weatherized houses and 70 control houses were monitored among 25 local weatherization agencies. Over the 1991-1992 heating season, the remaining 101 weatherized houses and 45 control houses were monitored from a different set of 16 agencies. The location of agencies monitored in each heating season are identified in Fig. 2.2. Available resources limited the total number of houses that could be monitored. Calculations performed during the design of the study indicated that the estimated savings of installed weatherization measures would be within 26% of the actual savings if this design were chosen (at a 90% confidence level and assuming a 20% attrition rate).

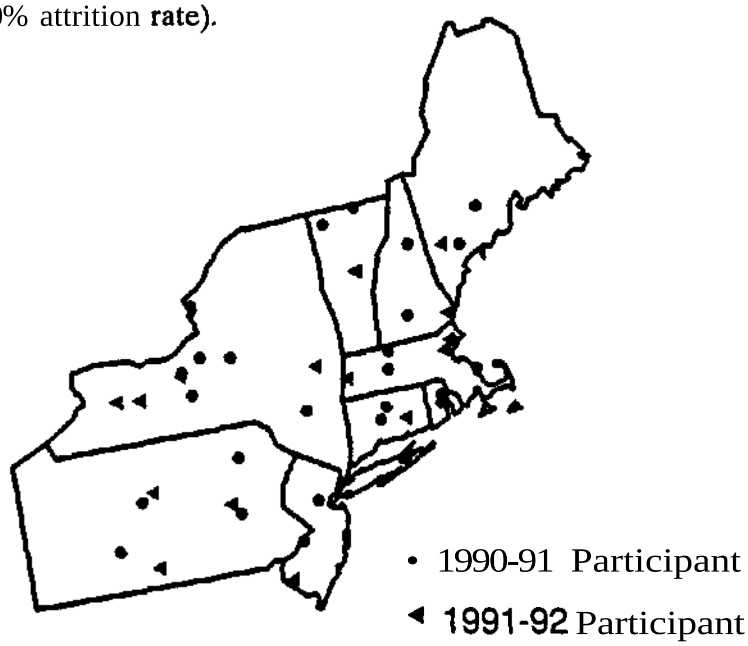

Fig. 2.2. Locations of weatherization agencies taking part in the Fuel-Oil Study.

For the 1990-1991 heating season, a clustered sampling procedure was used: 25 local weatherization agencies were selected using states as a stratification variable; eight individual houses per agency were then selected. The selection of houses proceeded in two steps:

1. A total of 25 agencies were selected from the nine northeast states and distributed as follows: Maine (2), New Hampshire (2), Vermont (2), Massachusetts (4), Rhode Island (2), Connecticut (2), New York (5), Pennsylvania (4), and New Jersey (2). At least two agencies were chosen from each state to ensure a representative sample. Agencies from each state that weatherized a significant number of single-family houses heated by fuel oil (typically greater than 15 such houses per year) were identified. Sampling was limited to these agencies to ensure that eight houses eligible for the study could be identified from the agency if selected. The sample of agencies for each state was drawn randomly with probabilities proportional to the number of single-family houses heated by fuel oil and weatherized by the agency.

2. For each agency selected, houses on the waiting list and/or selected for weatherization that met the eligibility requirements listed in Sect. 2.3 were identified. A random sample of eight of these houses was then chosen. Their eligibility for the study was verified through a house visit by the agency. The household's consent (and building owner's if the household was a renter) was also obtained. If these requirements could not be met, a replacement house was selected from the original list. If eight eligible houses could not be identified, then additional outreach was performed to obtain the necessary number of houses.

The eight houses selected from each local weatherization agency were randomly divided into weatherization and control groups during the pre-weatherization period. These assignments were made as late as possible to minimize the effect of attrition creating unequal groups.

A similar procedure was used during the 1991-1992 heating season which involved 16 local weatherization agencies with 11 participating houses in each. In this year, at least one agency was chosen from each state. States in which more than one agency was monitored were: Massachusetts (3), New York (4), and Pennsylvania (3).

To reimburse those households participating in the study for any inconveniences they may have endured and for services provided during the study, the following monetary payments were made to the occupants during the heating season their house was monitored: a $75 service payment to each participating household in January, and an additional $75 payment to each control house in May. In some cases, these payments also acted as incentives to obtain the participation of the households.

23 HOUSE ELIGIBILITY

Houses included in the study were limited to those with the following characteristics:

1. Occupants were eligible for the Weatherization Assistance Program administered in their state for the respective program years.

2. Houses were single-family buildings. Mobile homes, mobile homes with room additions, or other similar housing assembled on-site from factory-built modules were excluded. A single-family building is defined in the Residential Energy Consumption Survey (RECS) (Energy Information Administration 1989):

> "[A] single-family housing unit [is] a structure that provides living space for one household or family. The structure may be detached, attached on one side (semidetached), or attached on two sides. Attached houses are considered single-family houses as long as the house itself is not divided into more than one housing unit and has an independent outside entrance. A single-family house is contained within walls that go from the basement (or the ground floor, if there is no basement) to the roof. (A mobile home with one or more rooms added is classified as a single-family home.)"

Although a mobile home with one or more rooms added is classified as a single-family house in RECS, such a house was not considered for this study. Energy savings and weatherization techniques for mobile homes are being examined by other DOE sponsored studies and, thus, were not included in this study. In interpreting the RECS definition, row houses and side-by-side duplexes (twins) were single-family houses, whereas over-and-under duplexes were small multifamily buildings.[1]

Energy savings of single-family and small multifamily buildings heated by fuel oil were not assessed using primary data in the single-family study (Brown et al. 1993). Small multifamily buildings were not included in the Fuel-Oil Study to simplify its design and implementation, a simplification especially needed to allow monitoring to start during the 1990-1991 heating season. The 1987 RECS data (Energy Information Administration 1989) indicate that there are almost three times as many single-family households heated by oil with occupants whose income level is less than 125% of the poverty level as there are small multifamily households.

High-density multifamily buildings (five or more units per building) heated by fuel oil were assessed under the high-density Multifamily Study (Beschen and Brown 1991).

3. Primary space-heating systems used fuel oil. Single-family houses primarily heated by other common fuels such as gas and electricity were assessed in the Single-Family Study (Brown et al. 1993).

4. Houses were located in the nine states in the northeast census region (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, and New Jersey), The 1987 RECS data (Energy Information Administration 1989) indicate that almost half of the single-family houses heated by fuel oil with occupants whose income is less than 125% of the poverty level are located in these nine states. About 70% of all households that use fuel oil as their main heating fuel are located in

[1]Small multifamily buildings are also defined by RECS: "[A] house or building with two to four housing units [is] a structure that is divided into living quarters for two, three, or four families or households. This category also includes houses originally intended for occupancy by one family (or for some other use) that have since been converted to separate dwellings for two to four families. Typical arrangements in these types of living quarters are separate apartments downstairs and upstairs, or one apartment on each of three or four floors."

these states; about 40% of the households in these states heat with fuel oil (households in these latter statistics include all income levels and building types).

5. Secondary space-heating systems (such as wood stoves, fireplaces, or portable space heaters) were not used to substantially heat a house (use of supplemental space-heating systems one day per week or in the bathroom was acceptable). Energy consumption of secondary space-heating systems could not easily be monitored.

6. Occupants intended to remain at home for the entire heating season monitoring period (no lengthy vacations away from home). Houses whose occupants moved during the study were to be dropped from the analysis.

7. Occupants had a working telephone line in the house. Data collected by the data logger installed in each house were transmitted to a central computer over the telephone.

2.4 DATA PARAMETERS AND INSTRUMENTATION

The data collected for this study can be divided into three types: time-sequential data, survey information, and point-in-time measurements. The time-sequential data were recorded on an hourly basis: space-heating system fuel-oil consumption, indoor temperature, and outdoor temperature. The survey information included descriptive data on the building shell and mechanical systems of the house, data on occupant characteristics and their responses to weatherization, cost data, and other data characterizing the states and local weatherization agencies. The point-in-time measurements evaluated the building shell and mechanical systems.

Z4.1 Time-Sequential Measurements

A four-channel data logger (two temperature, one digital, and one analog voltage) was used to measure and record the time-sequential data at each house. The unit measured 8 in. x 10 in. x 5 in. and was programmable. Internal batteries, capable of powering the unit for about three months, were used as a back-up power supply to externally provided power. Each data logger contained an internal modem for communications. Data were retrieved over telephone lines using the internal modem and software developed by the manufacturer. The unit measured indoor and outdoor temperatures and an analog voltage (which corresponded to space-heating system run-time) once a second, and stored averaged hourly data in solid state memory. The digital channel was not used.

The amount of fuel-oil delivered to the oil-fired space-heating system was calculated from a measurement of the run-time of the oil burner. The hourly run-time was multiplied by the rated flow of the nozzle on the burner to arrive at the gallon input into the burner each hour. This was not the energy delivered into the house, but that delivered to the burner. An on-site calibration of the oil burner flow rate was not performed. The rated flow rate of the nozzle was documented both at the time instrumentation was installed and when it was removed.

The hourly run-time of the oil burner was measured using the analog voltage channel of the data logger and a low-voltage (contact closure) relay placed across the pump motor of the oil burner. The relay closed when power was supplied to the pump (delivering oil to the burner) and was open when power to the pump was interrupted. The data logger supplied the relay with a voltage source of approximately 8 volts; this was read as 5.12 volts by the data logger (its maximum or "pegged" range) when the space-heating system was on and 0.00 volts when off. By recording the average voltage over the hour, the hourly run-time of the oil burner was calculated by dividing the average voltage by 5.12 volts (i.e., 5.12 volts = 100% on time, 3.1 volts - 60.54% on time, etc.).

This approach measured burner run-time rather than the time the thermostat called for heat. Thus, it was applicable to all fuel-oil space-heating systems encountered in this study, especially hydronic systems, in which the thermostat controlled a pump circulating heated water through the house rather than delivery of fuel to the burner. The actual amount of fuel delivered to the oil burner was accurately estimated so long as the oil pump maintained a delivery pressure to the nozzle which maintained a steady flow equal to the rated nozzle flow.

The hourly indoor temperature of each house was monitored at the thermostat using an integrated-circuit temperature sensor and the data logger. The temperature at the thermostat was chosen because the thermostat operated the space-heating system in response to this temperature and because this temperature was expected to be reasonably representative of the house temperature. The sensor was installed to minimize its exposure to radiant energy from the sun, exterior walls, windows, lamps, and other significant radiators. The sensor was not exposed to heat or cold sources such as vents or appliances in the surrounding area.

The hourly outdoor temperature at each house was also monitored using an integrated-circuit temperature sensor and the data logger. The temperature sensor was located where it was minimally affected by heat sources or sinks in the surrounding area and where the ambient air was well mixed with the surrounding air. A sensor location on the north side of the house and below roof level was preferred. The sensor was placed in an inverted U-shaped pipe to protect it from the weather and to act as a radiation shield.

2.4.2 Survey Information

Information about the physical characteristics of each house and its space-heating, space-cooling, and water-heating systems was collected at the end of the post-weatherization period using the first survey provided in Appendix A. Information on the floor area, volume, number of rooms, and number of heated rooms was also collected at the beginning of the pre-weatherization period in all houses using the second survey provided in Appendix A.

A comprehensive questionnaire was conducted at the end of the post-weatherization period. Subjects included were ownership status (renter or owner), length of residence, house age, heating fuels, demographics, the amount of conditioned space, thermostat management, fuel assistance, and occupant perceptions of Program impacts on health, safety, comfort, thermostat operation, and affordability. A majority of the questions in the questionnaires (separate questionnaires were developed for the weatherized and control houses and are provided in Appendix B) were reprinted verbatim from the 1990 RECS. Similar questionnaires were used in the Single-Family Study. All questions that were not drawn from RECS were pretested. Approval from the Office of Management and Budget were obtained for the questionnaires.

The following information was collected from the local weatherization agencies using the first survey presented in Appendix C after the houses were weatherized: service delivery procedures (audit type, use of contractor or in-house crews, use of blower doors, inspection procedures, etc.), the dates the houses were weatherized, installed measures and costs, the average overhead and management costs per housing unit for the agency, and household income. Household income was also collected from the control houses (second survey provided in Appendix C). The number of single-family houses heated by fuel oil and weatherized in the monitored program year were obtained from the states and participating agencies.

2.4.3 Point-in-Time Measurements

Air-leakage tests were performed in all houses using blower doors. Each weatherized house was tested before and after weatherization to determine changes in house air-leakage caused by the combined weatherization measures. Control houses were tested during the pre- and post-weatherization periods. Data collected included blower-door air flow rates at different pressure differences between the inside and outside of the house, indoor and outdoor temperatures during the test, and local shielding class.

The air-leakage tests were performed following the procedure provided in Appendix D. The procedure minimized errors from procedural differences between technicians. It also minimized gauge-induced errors due to calibration and hysteresis. The procedure was sufficiently rigorous to ensure comparability of individual house measurements made under this study and the Single-Family Study even after considering that:

- tests were performed by different personnel,
- tests were performed by different organizations,
- tests were performed using different brands of blower doors,
- houses were located in a wide variety of locations, elevations, and terrains, and
- houses likely had air leakages that varied greatly.

This procedure was adapted from a procedure developed for the Bonneville Power Administration to evaluate air-leakage characteristics of over 500 Northwest houses (Ecotope 1989). Bonneville's procedure was extensively field tested and proven capable of producing high quality results — i.e., collecting data with minimal random errors that could be extrapolated to the required conditions for standard analysis with the Lawrence Berkeley Laboratory Infiltration Model (Sherman and Modera 1984).

Only tests in which the house volume was depressurized were performed. Both depressurized and pressurized tests (averaged to obtain a composite result) are specified in Standard E779-87 for measuring air leakage (ASTM 1987) to reduce the effect of random errors in individual data sets and thereby increase the accuracy of estimating the air leakage. Reliance on depressurized tests only was selected based on a study performed by Sherman et al. (1984). Sherman determined that systematic errors between pressurized and depressurized tests did not occur, but significant random errors in individual tests could be compensated for by combining the results from both tests. Results from the Bonneville project (upon which the test procedure in Appendix D was based) indicated that the pressurization test did not improve the accuracy of the air-leakage measurement or reduce its standard error. Based on these latter results and because of the increased cost to perform a pressurized test (especially to seal all vent areas), pressurized tests were not performed.

Each house was measured in its normal leakage condition for this study. Only those openings in the envelope that could naturally be shut (such as windows, external doors, and fireplace dampers) were closed for the test rather than sealing all possible openings in the envelope (such as vents, animal gates, and window air conditioners). Reasons for this choice were:

- to represent the "as found" condition of the house desired for the evaluation,
- to test the house in the condition requiring the least modification by testing personnel to limit the time required for setup of the house, and
- to reduce the number of special leakage areas sealed for the pre-weatherization test that would have to be replicated for the post-weatherization test to ensure comparable results.

The steady-state efficiency of each space-heating system was measured for both pre- and post-weatherization periods. These measurements were made following the procedure in Appendix E. A smoke test was also conducted when the efficiency was measured.

A safety inspection of the space- and domestic water-heating systems was performed at the end of the post-weatherization period in all houses. The inspection included examination for cracked heat-exchanger, excessive carbon monoxide in the flue gases (incomplete combustion), carbon monoxide in the air surrounding the system, carbon monoxide in the distribution air (force$-air system), insufficient draft, damaged or improperly installed flue/chimney, oil leak, improperly set safety switches, improperly set pressure switches (boiler systems), and missing or dirty filters. If an unsafe condition was found, it was brought to the attention of the local weatherization agency and resolved either through the Program or this study. The inspection was performed following the procedure in Appendix F.

3. OCCUPANT AND HOUSE CHARACTERISTICS

Occupant and house descriptive information was collected for both control and weatherized houses during the removal of the monitoring instrumentation at the end of each heating season. Each program applicant (or another responsible adult member of the household) was personally queried to obtain occupant information through the use of the Fuel-Oil Study Occupant Questionnaire provided in Appendix B. The Fuel-Oil Study House Characteristics Survey (Appendix A) and the Oil-Fired Space- and Water-Heating System Inspection Procedure (Appendix F) were used to record specific house physical measurements and visual observations. Air leakage and steady-state heating-system efficiencies were measured before and after weatherization, and a safety inspection of the space- and domestic water-heating systems was performed at the end of the post-weatherization period. These results latter are presented in Sects. 6 and 7.

Because this information was taken after the weatherized houses were weatherized, information concerning the condition of the weatherized houses before weatherization was not available. Control house data represent, for the most part, the original condition of the control houses.

House descriptive information was collected after the houses were weatherized because our prime concern was to install energy-consumption monitoring equipment in all houses before the start of the heating season in order to obtain sufficient data for split-season analysis. About three or four hours were required per house to properly install the instrumentation and verify its operation. Additionally, some houses were not selected until the heating season had started because of Program logistics (many people do not apply until the weather becomes cold, and many are directed to the Program by other agencies such as The Low-Income Heating Energy Assistance Program). These reasons and financial considerations made the collection of house physical and occupant characteristic data impractical until the end of the heating season.

We installed instrumentation in 337 houses (115 control and 222 weatherized), but only collected physical data on 320 houses (106 control and 214 weatherized) and occupant survey data on 306 families (99 control and 207 weatherized). Attrition was caused by factors such as the death of an occupant, families moving, house sales, loss of a house because of nonpayment of a mortgage, and uncooperative or unavailable occupants.

Discussions in this section are based on unweighted sample statistics since we are describing the sample and its distribution. Statistics for parameters unaffected by the weatherization process represent the control and weatherized houses combined. Separate statistics for control and weatherized houses are provided for parameters affected by the weatherization process (such as insulation levels).

Tables and distribution plots for most of the occupant and house characteristics are provided in Appendix G to supplement the discussion provided below. Some questions were not answered by an occupant and some measurements were not able to be made in some houses for a multitude of reasons. Therefore, the number of responses to different questions and measurements vary, but we do not feel that those random omissions bias our findings. The number of responses is given for each category presented in the Appendix.

3.1 OCCUPANT CHARACTERISTICS

The number of occupants in each house varied between 1 and 10. About 90% of the houses had five or fewer occupants, and about 50% had either one or two occupants (see Fig. 3.1). The average number of occupants per house was three. The most common number of occupants per house was one, with two the next most common. The age distribution of the occupants was 13% preschool, 27% school age, 42% adults, and 18% over 65.

The length of time each family had resided at their present address varied between 1 and 60 years, the mean being 19 years. Homeowners accounted for 87% of our sample, with half of these having no mortgage payments. Renters paid an average monthly rent of $333. The average annual household income of our sample was $10,800.[2]

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[2]Household income data provided to us by the local weatherization agencies was sometimes for a 30-60 day period. Because of fluctuations in monthly income, extrapolation of these values may not be a precise representation of annual income.

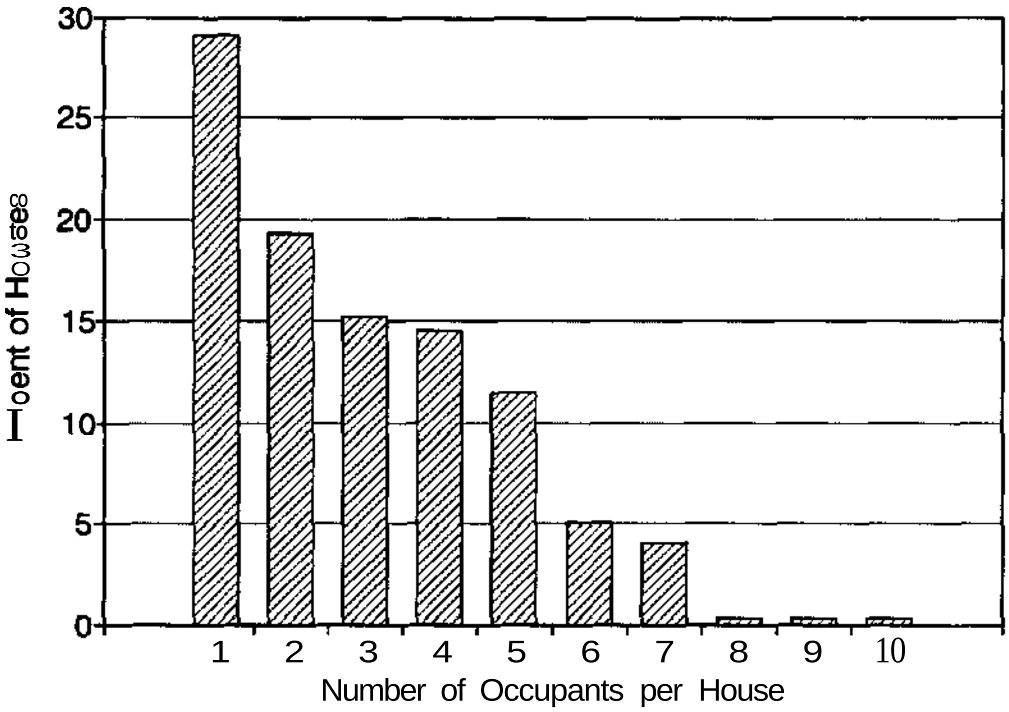

Fig. 3.1. Distribution of the number of occupants per house (mean = 3, and standard deviation = 1.9).

3.2 HOUSE CHARACTERISTICS

An average house participating in the field test was approximately 63 years old (it was built in 1928) and had two floors built above a concrete basement. The non-basement floor area of the house (which in most cases was the main living area and intentionally heated) was 1332 ft^2 and the total floor area of the house (which included the usually unheated basement) was 1989 ft^2. The average house was heated with a 19-year old oil-fired forced-air furnace or hydronic boiler, with no auxiliary heat used. The house had some insulation in the attic and in the exterior walls, but none in the floors or foundation.

As shown in Fig. 3.2, 27% of the houses were built before 1900, with about 5-10% of the houses being built each decade from 1900 to 1980. About 40% of the houses in the field test were built during the 1930's through the 1960's. Those houses built prior to 1900 were arbitrarily assumed to have been built in 1890, since an exact construction date was unobtainable on most. The average age of 63 years was obtained using this assumption.

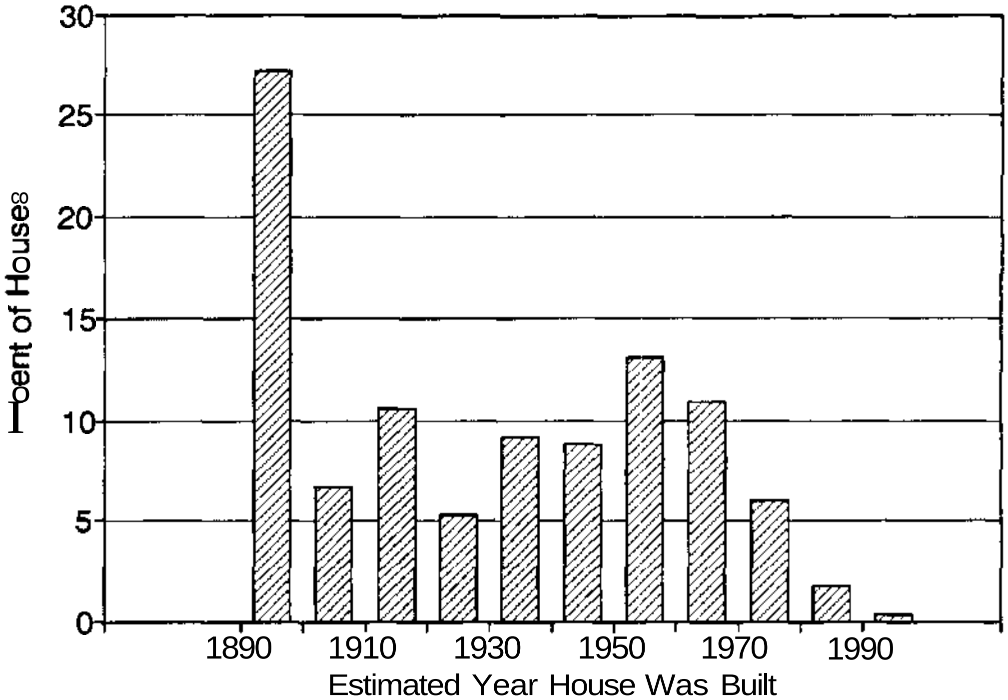

Fig. 3.2. Distribution of house age (mean = 1928, and standard deviation = 30).

Most of the houses (303 of 320 or 95%) had basements and 234 of 320 (73%) houses were multi-story. The basements were made from either poured concrete or concrete block walls. For those houses with a basement, the basement floor areas averaged 694 ft^2. The ratio of the basement floor area to total floor area averaged 34%.

The non-basement floor area of the field-test houses averaged 1332 ft^2. The distribution of floor area is shown in Fig. 3.3. An average of 1274 ft^2 of the total non-basement floor area, or 96%, was intentionally heated. Additionally, 43 (13%) of the homeowners reported that they typically heated their basements.

The predominately two-story houses were wood-framed, with wood, aluminum, and brick being the most popular siding in that order. Total exterior wall area averaged 1608 ft^2, and window area averaged 169 ft^2, varying between 50 and 563 ft^2. The predominant type of window used in the participating houses was wooden single-pane with a metal storm window.

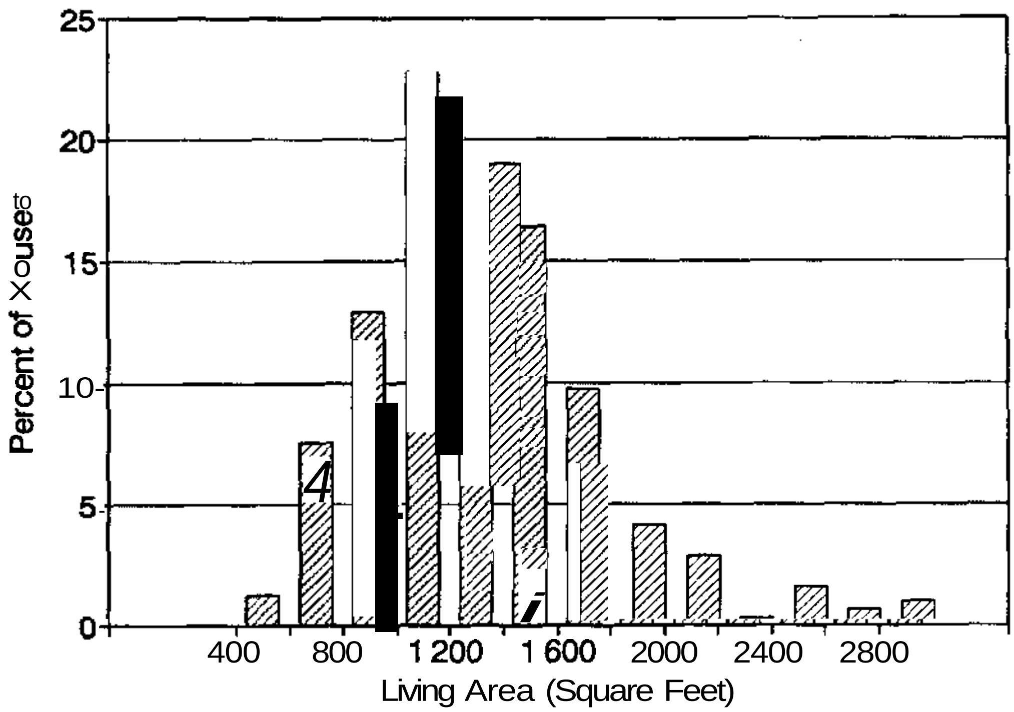

Fig. 33. Distribution of house living area (mean = 1332 ft^2, and standard deviation = 465).

Since the weatherized houses had already been weatherized, one would expect to find both more houses with insulation and higher insulation levels in the weatherized houses than in the control houses. Foundation ceiling insulation (also called floor insulation) was present in 8% of the control houses and 21% of the weatherized houses. Exterior wall-cavity insulation was present in 52% of the control houses and in 60% of the weatherized houses. Attic insulation was present in 82% of the control houses and 91% of the weatherized houses. Only about 6% of the control and weatherized houses had any foundation wall insulation.

The most popular type of wall and attic insulation present in weatherized houses was blown cellulose, followed by fiberglass batts. Control houses had more fiberglass batts in the wall than blown cellulose. These two insulating materials were used with equal frequency in the attics of both groups. All other insulating materials lagged far behind blown cellulose and fiberglass batts in usage.

Control houses had less insulation, on average, than weatherized houses except with respect to the foundation wall. Average insulation depths, in inches, for all control and weatherized houses, respectively, were: exterior wall, 1.62 and 1.90; unfinished attic, 4.59 and 6.57; finished attic, 2.84 and 4.68; foundation wall, 0.25 and 0.19; and foundation ceiling, 0.44 and 0.97.

As specified by the house selection criteria presented in Sect. 2.3, all primary space-heating systems used fuel oil. Forced-air furnaces were used in 138 (44%) of the houses, gravity furnaces were used in 7 (2%) of the houses, steam boilers were used in 39 (12%) of the houses, and boilers with hydronic distribution systems were used in 128 (41%) of the houses. The average ages of the heating systems by type were: forced-air furnaces, 14 years; gravity furnaces, 58 years; steam boilers, 26 years; and hydronic boilers, 18 years.

The average firing rate of all space-heating systems was 132,500 Btu/h (corresponding to a nozzle size of 0.95 gallons/h). The burners were of the flame-retention type in 152 (54%) of the houses, and vent dampers were present on 89 (29%) of the systems.

Most of the participants, 139 of 209 (67%) in the pre-weatherization period and 159 of 208 (76%) in the post-weatherization period, said they did not use any type of auxiliary heat (see Table 3.1). Electricity and wood were the most common auxiliary heat sources used. Of the 70 families using auxiliary heat during the pre-weatherization period, 62% said they used it all the time, 24% said they used it 75% of the time, and 14% said they used it 50% or less. Of the 49 families using auxiliary heat in the post-weatherization period, 69% used it all the time, 24% used it 75% of the time, and 7% used it 50% of the time or less. Of the 29 weatherized houses using auxiliary heat in both the pre- and post-weatherization periods, 80% did not change their time of usage, 20% increased their time of usage, and none decreased it. Tables G.6 and G.7 in Appendix G contain more information on auxiliary fuel usage.

The domestic water-heating systems in the houses varied in both fuel type and type of system. Stand-alone systems accounted for 61% of the total, while tankless or integrated systems (those systems with a water-heating coil located in the boiler and no storage tank) comprised the remaining 39%. There were 115 (37%) stand-alone electric systems, 35 (11%) stand-alone

Table 3.1. Summary of homes using auxiliary heat

Period(s) auxiliary heat was used	Control houses		Weatherized houses	
	Number	Percent of controls	Number	Percent of weatherized
Pre period only	4	6%	22	16%
Both pre and post periods	15	23%	29	20%
Post period only	1	1%	4	3%

natural gas systems, 25 (8%) stand-alone propane systems, 15 (5%) stand-alone fuel-oil systems, and 120 (39%) tankless fuel-oil systems. The average estimated hot water temperature was about 130° F, with the oil-heated tankless heaters running at about 160° F[3]. The domestic water-heating system was usually located in an unintentionally conditioned (maintained unintentionally at 55° F or higher) basement area.

A summary of the appliances found in the houses is provided in Table 3.2. Almost all houses had a cooking range, a conventional refrigerator/freezer, and at least one television set. A large percentage of houses also contained a clothes washer, clothes dryer, and microwave oven. About 26% of the cooking ranges used either natural gas or propane; just about all other appliance types, including clothes dryers, were electrically operated. More than half of the washers and dryers were located in intentionally heated areas of a house.

33 COMPARISON OF WEATHERIZED AND CONTROL GROUPS

Field test houses were divided into weatherized and control groups using a random assignment procedure in order to remove any bias between the two groups. In some limited cases, certain houses were designated as weatherized houses because the occupants did not want to go a whole heating season without undergoing any house weatherization. While it is physically impossible to achieve absolute "equality" among the houses in each group, the random assignment

[3]Although this temperature is higher than desired for efficiency and safety reasons, the available control over the water temperature in tankless systems is often limited.

Table 3.2. Summary statistics concerning appliances (320 total observations)

Type of appliance	Total		Electric		Natural gas		Propane		Location	
	Number	%	Number	%	Number	%	Number	%	IH (%)	UH (%)
Cooking range	298	93	222	74	44	15	32	11	100	0
Stove top range	20	6	16	75	1	5	3	5	85	15
Detached oven	30	9	25	83	1	3	4	13	100	0
Refrigerator	307	96	307	100	0	0	0	0	99	1
Microwave oven	212	66	212	100	0	0	0	0	99	1
Dishwasher	70	22	70	100	0	0	0	0	100	0
Freezer	82	26	82	100	0	0	0	0	65	35
Clothes washer	267	83	267	100	0	0	0	0	62	38
Clothes dryer	219	68	208	95	8	4	3	1	56	44
Television	300	94	300	100	0	0	0	0	96	4
Well pump	100	31	100	100	0	0	0	0	38	62

Notes: Total — houses containing a specific appliance regardless of fuel type
Electric — part of "Total" that primarily runs on electricity
Natural gas — part of "Total" that primarily runs on natural gas
Propane — part of "Total" that primarily runs on propane
Number — number of houses containing a specific appliance
% — percent of houses containing a specific appliance
Location — physical location of a specific appliance
IH — intentionally heated area
UH — unintentionally heated area

procedure appeared to work well. Examination of Table 3.3 and the distribution plots and tables in Appendix G showed that house and occupant characteristics between groups were similar in most areas deemed to be important.

Table 33. Comparison of mean values of selected house characteristics

Category	All houses	Control	Weatherized
GENERAL INFORMATION			
Number of occupants	2.97	3.25	2.84
Years resided in house	19	19	19
Number of renters (%)	13	13	14
Monthly rent ($, of renters paying rent)	333	355	326
Annual income ($)	10,869	11,101	10,763
Year house built	1928	1930	1927
HOUSE AREAS (Ft^2)			
Basement	693	747	667
Living space	1332	1372	1313
Heated living space	1274	1337	1243
External wall	1608	1670	1578
Window	169	180	164
Finished attic	736	794	713
Unfinished attic	782	839	792
INSULATION PRESENT (% of Houses)[1]			
Foundation ceiling	17%	8%	21%
Foundation wall	6%	6%	6%
Exterior wall	57%	52%	60%
Attic	88%	82%	91%
INSULATION DEPTH (Inches)[1]			
Foundation ceiling	0.79	0.44	0.97
Foundation wall	0.21	0.25	0.19
Exterior wall	1.8	1.6	1.9
Unfinished attic	5.9	4.6	6.6
Finished attic	4.1	2.8	4.7
SPACE-HEATING SYSTEM[1]			
Firing rate (Btu/h)	132,500	140,000	129,000
Flame retention burner present	53%	50%	55%

[1] Conditions existing at the end of the heating season, after weatherization had been done.

4. DESCRIPTION OF WEATHERIZATION ACTIVITIES

Information was collected on the service delivery procedures and weatherization measures applied to 218 of the 222 weatherized houses monitored during the study using the Fuel-Oil Study Weatherization Information Survey provided in Appendix C[4]. Estimates of the frequency with which service delivery procedures were applied and weatherization measures were installed for the northeast region as a whole are presented in this section. Weighted analyses were performed to be consistent with the regional fuel-oil savings calculated in Sect. 5.

From the data collected under the study, we estimated that 23,400 single-family houses heated by fuel-oil were weatherized by local weatherization agencies in the 1991 and 1992 program years in the northeast: 11,751 in program year 1991 and 11,670 in program year 1992. The results presented in this section are primarily for both program years combined. Unless otherwise noted, percentages for individual years were within five percentage points of the value for the combined years. Differences between years were likely due to sampling different local weatherization agencies rather than changes in DOE or state policies, guidance, and program design.

4.1 SERVICE DELIVERY PROCEDURES

An envelope measure selection procedure was applied to virtually all fuel-oil heated houses weatherized in the northeast region during program years 1991 and 1992 (Fig. 4.1). A space-heating system measure selection procedure was applied to 77% of the houses, implying

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[4]Information used in this section was obtained directly from the local weatherization agencies and was based upon their records. Some inconsistencies associated with the information remained following close examination of the data and discussions with the agencies. Major weatherization measures (attic insulation, storm windows, etc.) were correctly identified. Some ambiguity remained in differentiating between air leakage measures, window and door measures, and other energy-efficiency work because of the similarity between these categories. Examples include identifying weatherstripping as a window and door "other" measure rather than general caulking and weatherstripping, listing window pane installations as a window and door "other" measure rather than structural weatherization measure, and identifying sash lock installation as an "other" measure of either air leakage, window and door, or structural measure. Thus, the frequency of the minor weatherization measures and "other" categories should be considered with caution.

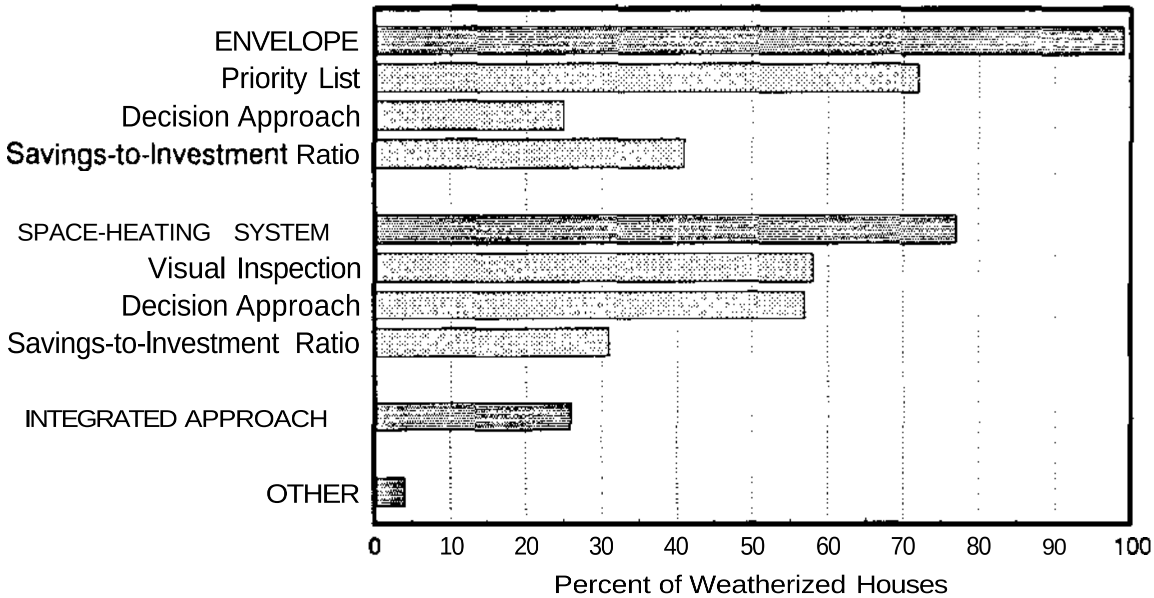

Fig. 4.1. **Application** frequency of measure selection procedures in **fuel-oil** heated houses during program years 1991 and 1992 for the northeast **region.**

that space-heating system measures were not options in the remaining 23% of the houses. These procedures were generally applied separately, although an integratEd approach (accounting for the influence among measures) was used in 25% of the houses.

A priority list (a checklist or prescribed list of measures) was usually employed to select envelope measures, whereas a decision approach or scoring (calculation) performed for each house was not used very often. A space-heating system measure selection procedure based on physical characteristics or a standard approach (this included a visual inspection and safety inspection) was used in 58% of the houses. Similarly, a decision approach or scoring (calculation) based on operating performance (steady-state efficiency, smoke number, or carbon monoxide reading) was used in 57% of the houses. Envelope measures were selected in 41% of the houses and space-heating system measures were selected in 31% of the houses based on an analysis of energy savings per dollar invested for that particular house.

Table 4,1. Comparison of measure selection procedures used by program year

	Program year		
	1991	1992	Combined
Envelope selection procedure applied	99%	99%	99%
priority list	76%	67%	72%
decision approach	18%	32%	25%
analysis of energy savings per dollar invested	31%	50%	41%
Space-heating system selection procedure applied	97%	56%	77%
physical characteristics based on visual inspection	74%	43%	58%
decision approach based on operating performance	72%	41%	57%
analysis of energy savings per dollar invested	23%	39%	31%

Table 4.1 shows that there were significant differences in the selection procedures used during the two program years. There was a shift in program year 1992 from envelope measure selection procedures based on a priority list to a decision approach or analysis of energy savings per dollar invested for the house. A space-heating system measure selection procedure was applied in only 56% of the houses in program year 1992 compared to 97% in 1991. In program year 1992, there was greater emphasis on an analysis of energy savings per dollar invested in selecting the space-heating system measures.

The frequency of use of selected diagnostic procedures is shown in Fig. 4.2. Blower doors were used to diagnose air leakage problems in about 75% of the houses. The blower doors were used in almost all of these houses to measure air leakage rates and locate leakage areas. In over half of these houses, a cost-effective guideline was also used to help determine when to stop sealing. Diagnostic procedures to examine space-heating systems were used in about 80% of the houses.[5] In almost all cases, a steady-state efficiency test and safety inspection were conducted.

[5]This is somewhat inconsistent with the data indicating that a space-heating system measure selection procedure was applied in 77% of the houses and that a selection procedure based on operating performance was applied in just 57% of the houses. This inconsistency may have resulted from the fact that space-heating system measures were installed in some houses before

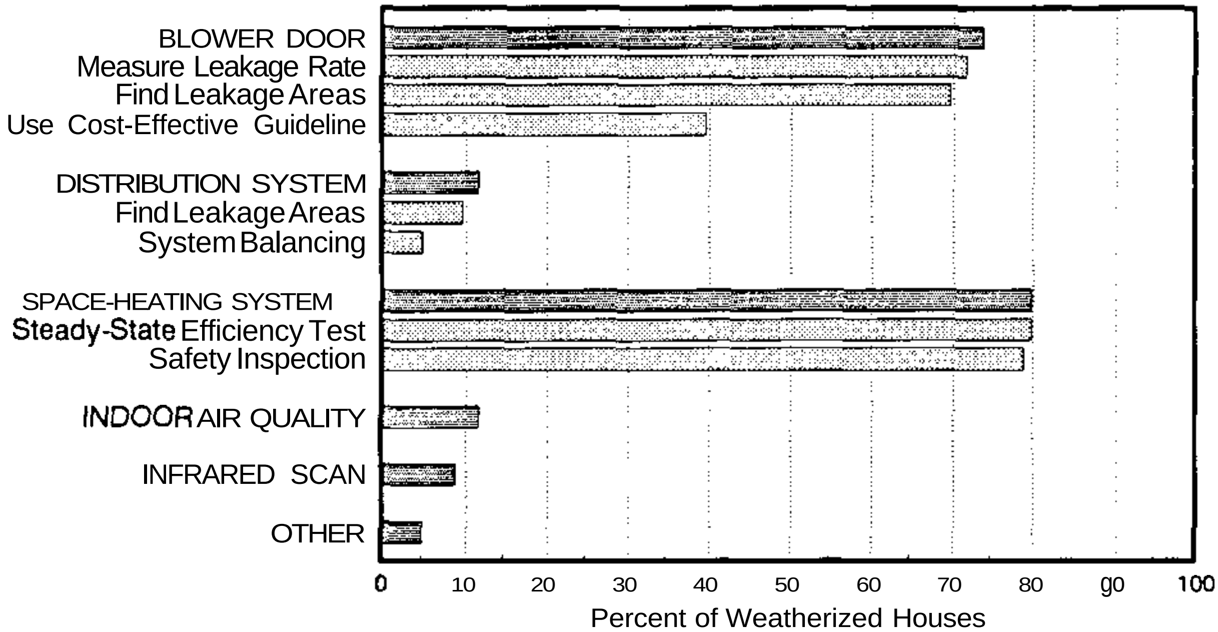

Fig. 4.2. Application frequency of selected diagnostic procedures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

Air distribution system diagnostics were used in 11% of the houses, but this represented a usage rate of over 20% in houses that had air distribution systems. Indoor air quality tests and infrared scans were performed infrequently in the houses. Carbon monoxide tests were performed in 28% of the houses and radon tests were never performed. Because indoor air quality tests were performed in just 12% of the houses, a large portion of the carbon monoxide tests were likely performed in conjunction with the space-heating system diagnostics and did not specifically address the main living areas of the house.

A space-heating system steady-state efficiency test and safety inspection was performed in almost every house (97% and 96%, respectively) in program year 1991, whereas these diagnostics were performed in just 63% and 61%, respectively, of the houses in program year 1992. This is consistent with the difference between years observed in the use of a space-heating system

pre-weatherization data were collected because the systems were determined to be inoperative or operating unsafely.

measure selection procedure. The use of blower doors to find leakage areas was slightly greater in program year 1992 compared to 1991.

A quality control inspection of the installed envelope measures was performed in almost all houses (Fig. 4.3). A visual inspection was performed in all inspected houses, and a blower door was used as a post inspection device in less than 40% of the houses, which was much less frequent than its use as a pre-inspection device. A quality control inspection of the space-heating system was performed in every house receiving a space-heating system measure (53% of the houses, as will be discussed in Sect 4,2). Inspections based on visual examinations and diagnostic testing (primarily steady-state efficiency testing) were used with equal frequency (both were used in about 80% of the houses receiving a space-heating system measure). Visual inspections were performed more frequently in program year 1991 (in 91% of the houses receiving space-heating system measures) than 1992 (64%).

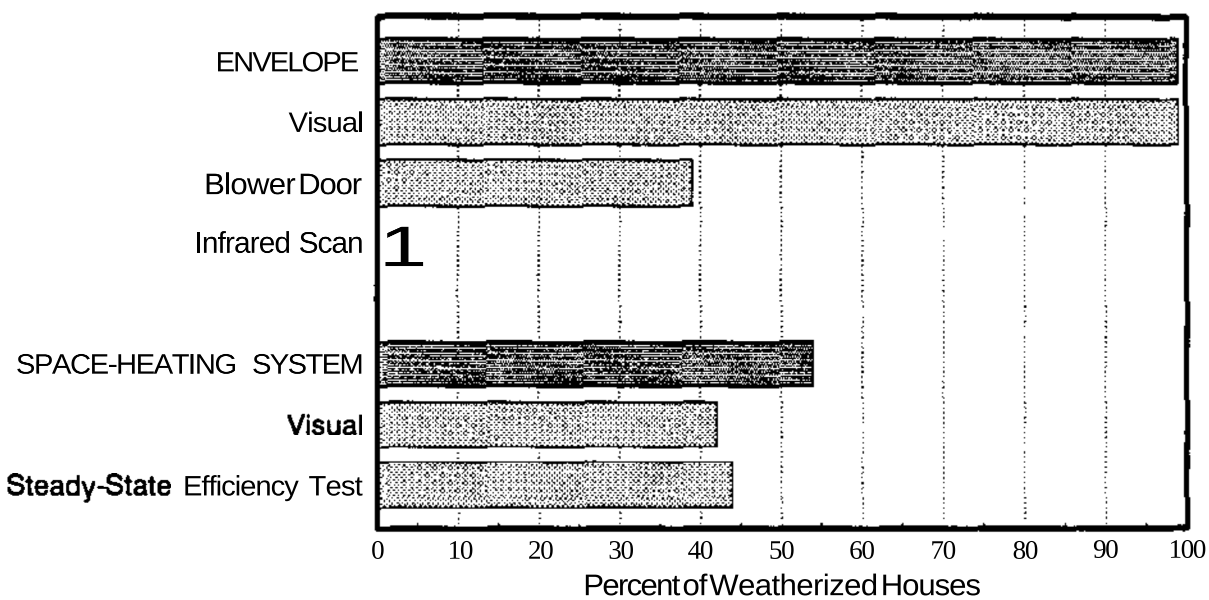

Fig. 43. Application frequency of quality control inspections in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

4.2 WEATHERIZATION MEASURES INSTALLED

The five most common types of weatherization measures are shown in Fig. 4.4. We estimated that insulation measures were installed in 82% of the 23,421 fuel-oil heated houses weatherized in the northeast region during program years 1991 and 1992, with 96% of the houses receiving air leakage measures. This is consistent with the Program's historical emphasis on infiltration mitigation and envelope improvements. Measures addressing the domestic water-heating system were installed in 62% of the houses, and energy-efficiency improvements to windows and doors were made in only 41% of the houses. Space-heating system measures, which have received increasing emphasis in recent years, were installed in 53% of the houses. Space-cooling system measures (such as air-conditioner tune-ups and replacements) were never performed.

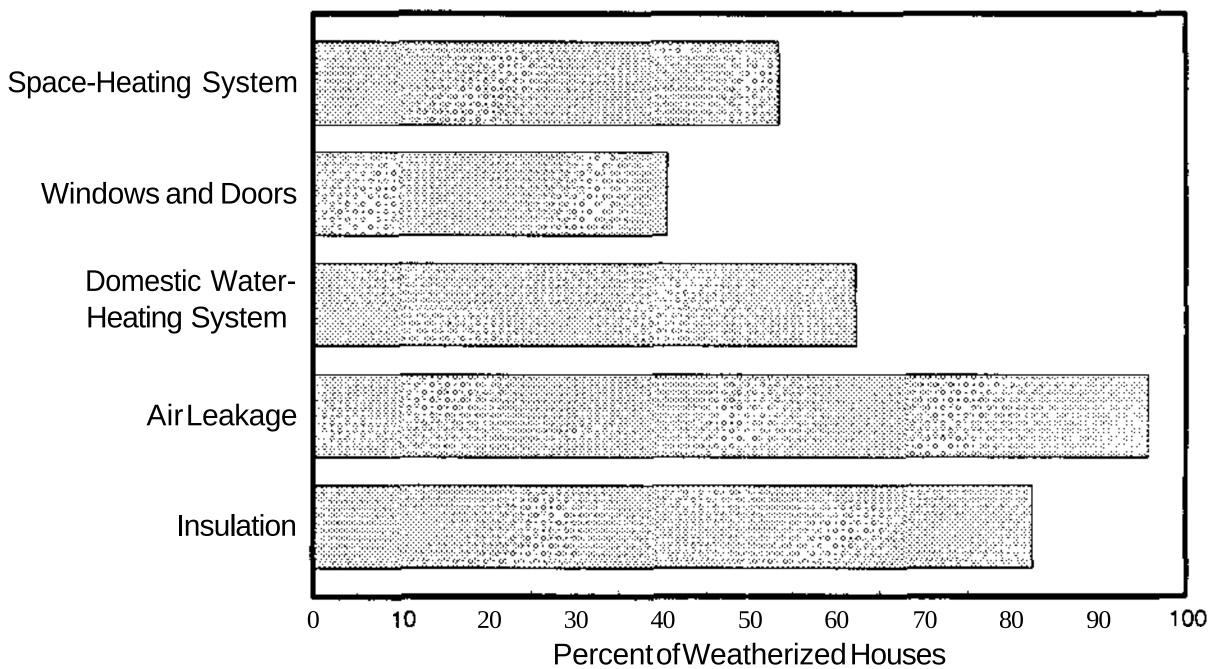

Fig. 4.4- Installation frequency of general types of weatherization measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

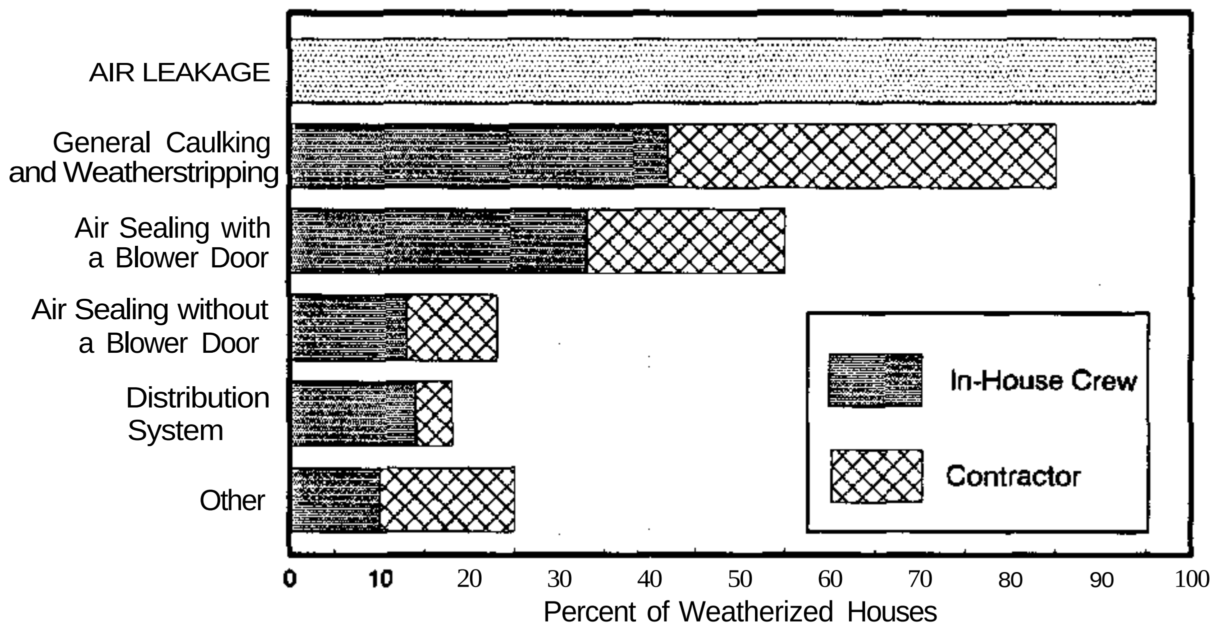

Fig. 4.5. Installation frequency of specific air leakage measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

Each of these categories is examined in more depth in the following paragraphs. It should be remembered that the presentation identifies all measures installed in the houses regardless of funding source. Although most funds may have required following Program rules, funds with fewer restrictions could also have been used.

General caulking and weatherstripping of doors and windows was the most frequent air leakage measure performed on the houses (Fig. 4.5). Air sealing work (defined as work emphasizing air-leakage bypasses) was also an important air leakage measure, being performed most often using a blower door. Air sealing work using a blower door was performed in 46% of the houses in program year 1990, compared to 63% in program year 1992. For both years combined, 54% of the houses had air sealing work performed using a blower door. This is somewhat inconsistent with the reported use of blower doors as a diagnostic tool in about 75% of the houses (Sect. 4.1). This discrepancy may be explained if houses receiving a blower-door diagnostic did not require air sealing work. Air distribution system leaks were repaired in only 18% of the houses, but this represents a repair rate of a little less than 50% in houses with air distribution systems. This, too, is somewhat inconsistent with the reported use of air distribution

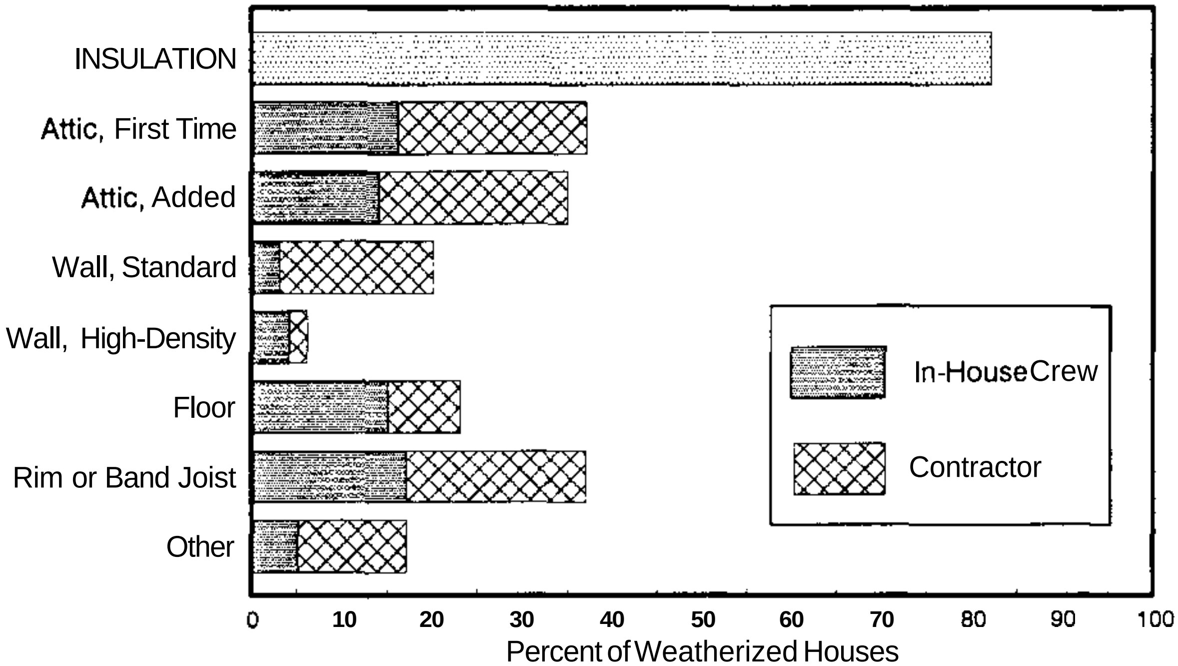

Fig. 4.6. Installation frequency of specific insulation measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

system diagnostics in 11% of the houses, although identification of distribution system leakage areas as part of the general air sealing work could explain this difference.

Installation of attic insulation (either for the first time where no insulation previously existed or added to existing insulation) was commonly performed in fuel-oil heated houses weatherized during program years 1991 and 1992 (Fig. 4.6)[6]. As with the two types of attic insulation, rim or band joist insulation was installed in about a third of the weatherized houses. Floor insulation and wall insulation were installed in 25% and 20% of the houses, respectively. The standard, two-hole technique for installing wall insulation was usually employed, although some installations were performed using a single-hole, tube-fill approach. This latter approach allowed wall insulation to be installed at higher densities, which can decrease air infiltration, and it emphasized concurrent sealing of major air-leakage bypasses while insulating the walls.

[6]A house could receive both new and added insulation if a portion of the attic was uninsulated and another portion had an insufficient level of insulation.

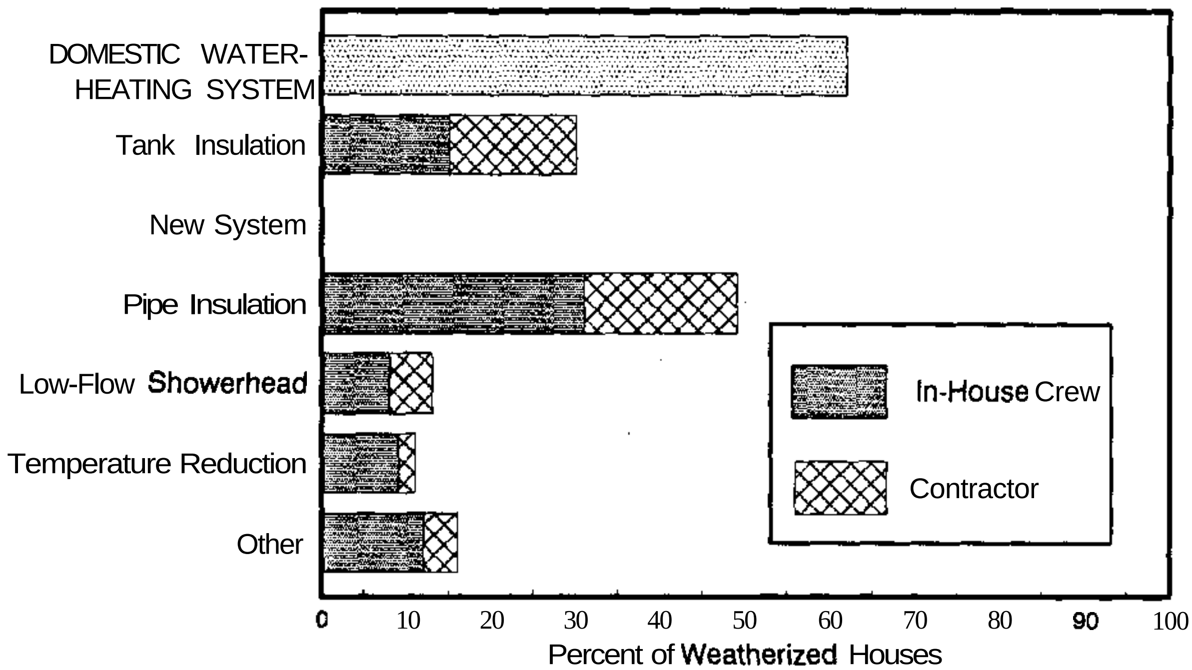

Fig. 4.7. Installation frequency of specific domestic water-heating system measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

Primary domestic water-heating system measures were pipe and tank insulation (Fig. 4.7). No new systems were installed, which is consistent with the fact that new systems are not an approved Program measure. Tank insulation was installed relatively infrequently (in just 29% of the houses) primarily because 39% of the houses had tankless systems (for which this measure is not applicable). Tank insulation was installed in about 50% of the houses with stand-alone systems for which insulation is applicable. Somewhat surprisingly, tank set-point temperatures were reduced in only 11% of the houses. This, again, may be partly due to the presence of tankless systems which allow little control over domestic hot water temperature. The installation of low-flow showerheads was much less the second year: 21% of the houses received low-flow showerheads in program year 1991 while only 4% received them in program year 1992.

Energy-efficiency improvements were made to space-heating systems in 53% of the houses weatherized during the two program years, or about 70% of the houses in which space-heating system measures were considered an option. Measures were installed somewhat more frequently in program year 1991 (59% of the houses) than in 1992 (48%). This is consistent with the fact

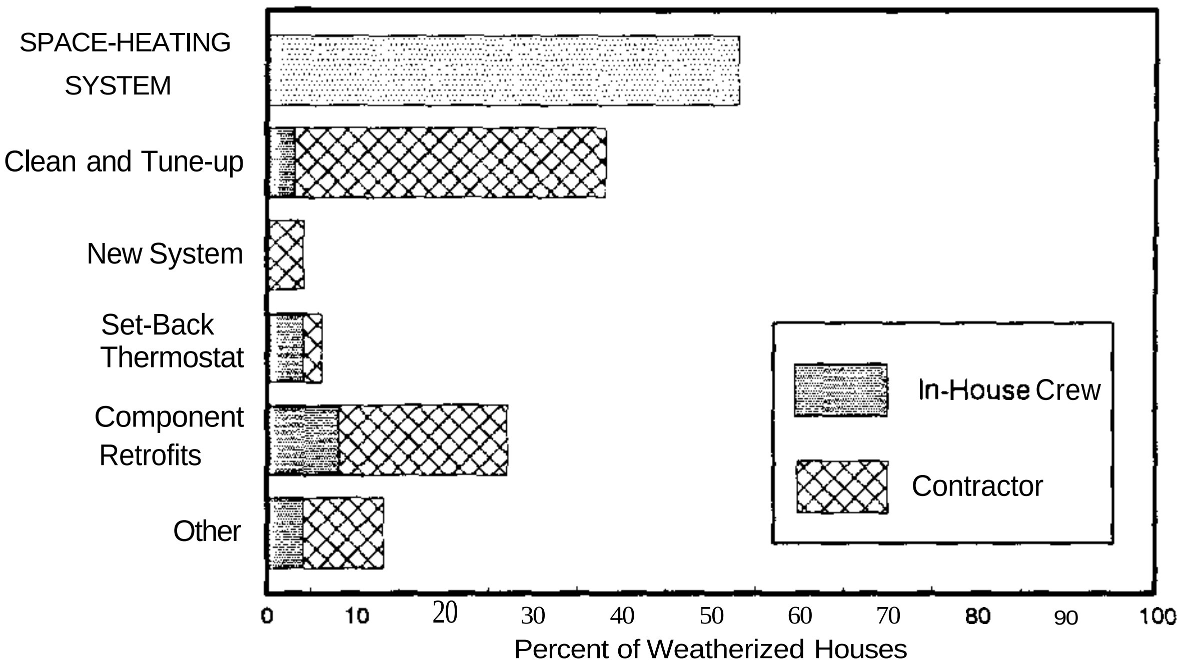

Fig. 4.8. Installation frequency of specific space-heating system measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

that space-heating system measures were considered as options more frequently in program year 1991. A system clean and tune-up was the most commonly performed space-heating system measure (Fig. 4.8). This measure was performed in 38% of the houses, or more than two-thirds of the houses receiving a space-heating system measure. Installation or repair of heating system components was also a frequently performed measure. Examples of components include vent dampers, flame-retention burners, duct insulation, and system balancing. Repairs were performed to fix inoperative equipment and/or for safety reasons. One common concern with performing space-heating system measures is that new, expensive systems will be frequently installed. This concern may be unfounded, because new, complete heating systems were installed in only 4% of all the houses, or less than 10% of those houses receiving a space-heating system measure. One noteworthy finding is that all of the new burners installed as components or as part of a new system were of the flame-retention type. These are very efficient burners.

Space-heating system items accounted for most of the measures performed outside of the weatherization period.

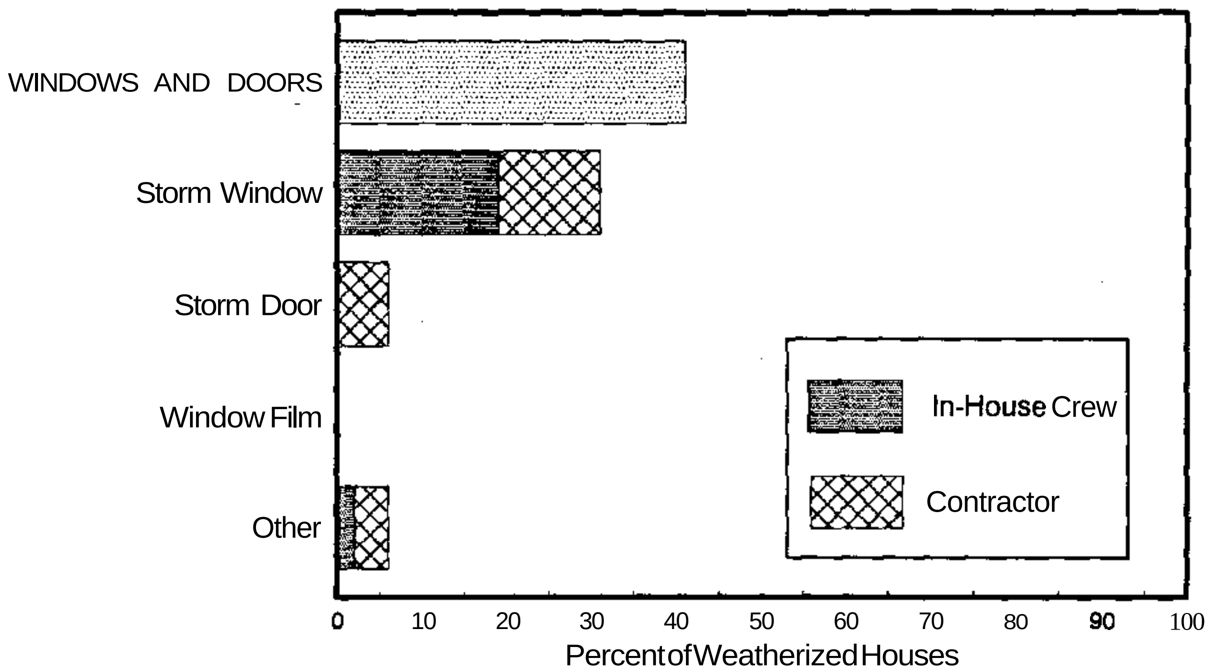

Fig. 4.9. Installation frequency of specific window and door measures in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

Energy-efficiency improvements to windows and doors were performed more frequently in program year 1992 (in 53% of the houses) than program year 1991 (28% of the houses). Storm windows were predominately installed (Fig. 4.9), and were the primary reason for the difference in window and door installation frequency between the two program years (storm windows were installed in 25% of the houses in program year 1991 and in 37% in program year 1992). Storm doors were installed in only 6% of the houses. Window films, which are measures designed primarily to reduce cooling loads, were never installed.

Other energy-efficiency items not falling within the five major weatherization categories discussed above were frequently performed in the houses (Fig. 4.10). Structural weatherization measures were common, being performed in over 80% of the houses. This work involved replacing broken window panes or entire window units, reglazing windows, fixing or replacing doors, and increasing attic ventilation. The degree of window glazing activity (in over 50% of the houses) is consistent with the level of caulking and weatherstripping performed as air leakage; these activities are often performed as general heat waste reduction. The frequent installation of

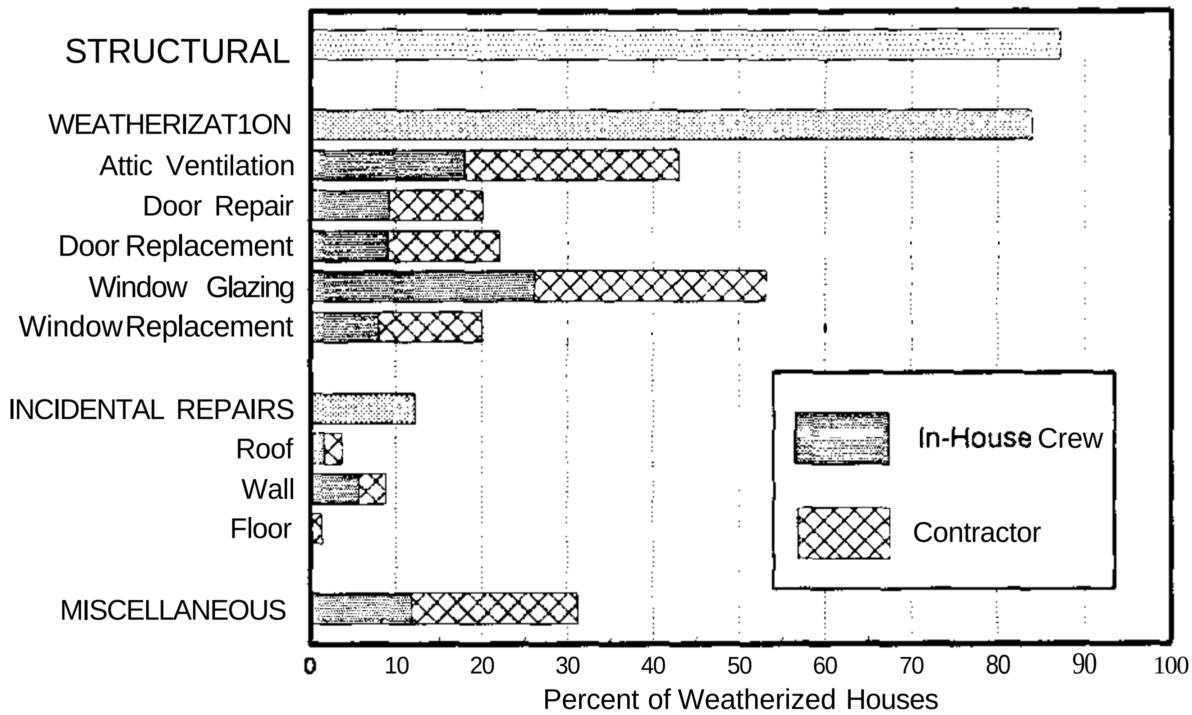

Fig. 4.10. Installation frequency of structural weatherization measures and repairs in fuel-oil heated houses during program years 1991 and 1992 for the northeast region.

attic ventilation (in 43% of the houses) is explained by its association with attic insulation; installation of adequate attic ventilation is often required before attic insulation can be installed. Incidental repairs made to the roof, wall, and floor to protect the integrity of installed efficiency measures were performed in only about 10% of the houses. Miscellaneous work that could not be categorized was performed in about 30% of the houses.

Client education was provided to over 95% of the weatherized households (Fig. 4.11). In-person education was provided to 91% of the households, and literature was mailed or left with the client about half of the time. Smoke detectors were installed in 3% of the houses as a health and safety measure.

Weatherization activity in a house was performed completely by employees of local weatherization agencies (in-house crews) in 27% of the houses, while activity was performed completely by contractor crews in 55% of the houses. Both in-house and contractor crews performed the work in the remaining houses. In-house crews and contractors generally installed

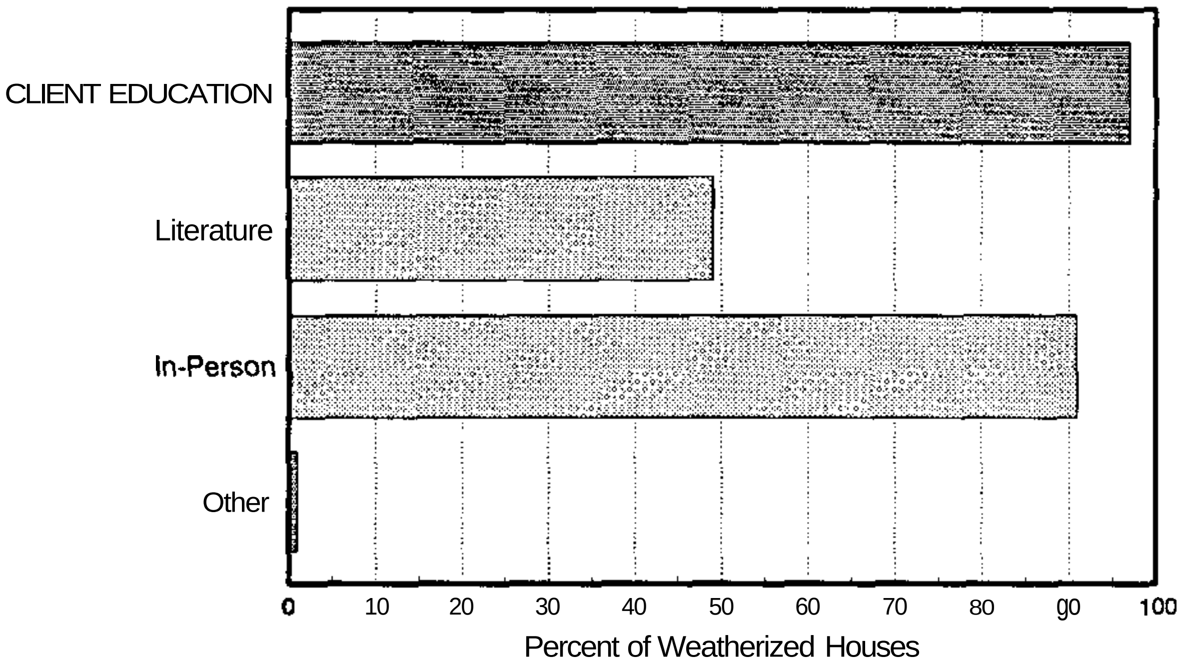

Fig. 4.11. Frequency of **client** education provided in **fuel-oil** heated houses during program years 1991 and 1992 for the northeast **region.**

window and door measures and air-leakage measures with equal frequency. Space-heating system measures (predominately tune-ups) were primarily performed by contractor crews (78%), whereas domestic water-heating system measures (predominately pipe insulation) were performed more often by in-house crews (63%). Insulation measures were performed somewhat more frequently by contractors (58%), especially standard wall insulation. In Figs. 4.5 - 4.10, the division between in-house and contractor crews is indicated for each specific measure.

5. FUEL-OIL CONSUMPTIONS AND SAVINGS

Data loggers were installed in 337 houses (191 in program year 1991 and 146 in program year 1992) in order to monitor space-heating system fuel-oil consumption as well as indoor and outdoor air temperatures for the split-season study. The data loggers remained in each house for only one heating season. Each heating season was split into a pre-weatherization period and a post-weatherization period. The weatherized houses were weatherized during January of each respective year, while the control group remained unchanged, except for any emergency measures necessary to keep them operational. The periods were slightly different for each control and weatherized house for a number of reasons:

- The pre-weatherization period started when instrumentation was installed in each house. This varied for each house, typically between October and November.
- The pre-weatherization period ended when weatherization of the house was started, usually in about the middle of January.
- The post-weatherization period started when weatherization was completed, a process that usually took less than a week.
- Post-weatherization periods ended at the end of April, when house heating needs became sporadic in most areas.

Control houses were arbitrarily assigned a January 15 date for the end of the pre-weatherization period and the start of the post-weatherization period.

A majority of the houses monitored in the study had separate space-heating and domestic water-heating systems. For these houses, the fuel-oil consumption and savings presented in this section are normalized annual space-heating system values. The remaining houses (48% of the control houses and 34% of the weatherized houses) had tankless domestic hot-water systems. The space-heating system provides heat for domestic hot water in tankless systems during the winter and summer using a coil imbedded in the space-heating system boiler. The fuel-oil consumption and savings presented for these latter houses are normalized annual space-heating values and heating-season only domestic hot-water values combined.

The terms "gross savings" or "gross change" are used to represent the difference between weather-normalized pre- and post-weatherization fuel-oil consumptions for both control and weatherized houses. An average gross savings was found by summing across houses and dividing by the number of houses summed. A positive savings means the pre-weatherization consumption was higher than the post-weatherization value, and visa versa for a negative savings. Using "savings" may sound strange when referring to a control house value, but it allows explaining differences between control and weatherized variables in the same terms. A "net savings" per weatherized house is also reported. The net savings was determined by subtracting the average gross savings of the control houses from the average gross savings of the weatherized houses. This adjustment accounts for non-Program induced factors affecting space-heating fuel-oil consumption not included in the normalization process. Average gross and net percent savings were calculated by dividing the average savings by the average pre-weatherization consumption and multiplying by 100.

In order to utilize measured data for predicting savings, measured pre- and post-weatherization consumptions were normalized so that they could be compared on the same basis. Normalization of the data was necessary because pre- and post-weatherization data collection periods occurred over different parts of the split heating season, so outdoor temperatures were different and data did not represent a full heating season. Also, indoor temperatures may not have remained constant at each site for both periods. The normalization process is described in more detail in Sect. 5.1.

Analyses were performed on 298 of the monitored houses (105 control houses and 193 weatherized houses). A useful set of pre- and post-weatherization monitoring data could not be collected from 10 control and 29 weatherized houses (12% of our sample) because of:

- disconnected or incompatible telephone services,
- sensor or lead wire failures,
- sensor mis-wirings by fuel-oil technicians during repairs,
- data logger problems,
- occupants moved out,
- occupants died during test period,
- occupants changed their mind about participating in the field test,
- mortgage foreclosures, and
- houses were sold.

The 12% attrition rate was lower than our initial estimate of 20%.[7]

5.1 METHOD OF ANALYSIS

Measured hourly heating system run-time data were multiplied by the burner nozzle size for each site to obtain the hourly amount of fuel oil consumed. These were summed to obtain daily values for each house. Any changes in replacement nozzle sizes (following space-heating system tune-ups, for example) were accounted for in the calculations. Measured hourly indoor and outdoor temperatures were also converted into daily averages. A predictive linear regression modeling equation of the form

$$\text{Fuel-oil consumption} = M \times (\text{Indoor temperature} - \text{Outdoor temperature}) + B$$

was fitted to the daily measured data for each site, where M (the slope) and B (a regression constant) are empirical constants determined by a regression analysis of the data. The model states that fuel-oil consumption (energy input into the burner) is equal to a driving force (temperature difference) multiplied by a resistance (primarily the thermal integrity of the house envelope) plus a constant (which includes contributions from items such as heat generated from house internal loads). For tankless systems, the constant includes domestic hot-water fuel-oil consumption and the slope includes temperature dependent fuel-oil consumption for hot water.

The data from each house were divided into pre- and post-weatherization sets. A separate regression was run on each measured data set, so that two sets of regression coefficients were obtained for each house — one set describing the house fuel-oil consumption before weatherization, and one set describing fuel-oil consumption after weatherization.

Indoor temperatures for each house and historical outdoor temperatures for each location were needed to calculate normalized annual consumptions and savings. An average indoor temperature for each site was determined for the pre-weatherization period and for the post-

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[7] A 15% attrition rate appears to be an attainable goal in a large-scale field test, but persistence on the part of the supporting field personnel is essential.

weatherization period by averaging measured data for each period. "Typical Meteorological Year" (TMY) weather data tapes, available from the National Oceanographic and Atmospheric Administration, were obtained for the Northeast region.[8] These weather data, which represent average annual weather conditions, are based on historical data from the various locations they represent and are in an hourly format. Table H.1 contains information on which TMY city was used for each local weatherization agency.[9] The TMY hourly outdoor temperature data were converted into average daily temperatures for use in the normalizations.

The pre-weatherization regression coefficients from each site, the average pre-weatherization indoor temperatures from that site, and the selected-city daily TMY outdoor temperature data were used to estimate pre-weatherization daily fuel-oil consumptions for each house beginning October 1 and ending April 30 (essentially representing a typical heating season). Negative values of fuel-oil consumption (which occurred when outdoor temperatures were sufficiently warm to cause the regression models to predict negative fuel-oil usages) were set equal to zero. Normalized annual pre-weatherization fuel-oil consumptions for each house were then calculated by summing the daily estimates for the heating season.

The same procedure, but using post-weatherization regression coefficients and post-weatherization indoor temperatures, was followed to calculate normalized annual post-weatherization fuel-oil consumptions for each house.

A normalized annual gross savings for each house was obtained by subtracting the normalized annual post-weatherization consumption from the normalized annual pre-weatherization value. A percent savings was obtained by dividing the normalized gross annual savings by the normalized pre-weatherization consumption and multiplying the result by 100.

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[8]Evaluations based on the Princeton Scorekeeping Method (PRISM) typically use 10-year historical weather to perform normalizations rather than TMY data.

[9]Every effort was made to choose a TMY city that represented the climate for the local weatherization agency. In some instances, though, the limited choice of TMY cities resulted in less than optimum selections.

5.2 WEIGHTING

A weighted ratio-estimator averaging procedure was used to determine average regional weighted values of consumption and savings for the nine states in the northeast region (average weighted or regional values). A direct or unweighted analysis of test house data was also performed to determine the average consumptions and savings for the sample itself (average unweighted or sample values). Although sample statistics are very interesting and informative, weighted statistics are necessary to accurately estimate regional values.

A weighted analysis was performed to develop regional values because a clustered sampling procedure (see Sect. 2.2) was used to select sample houses for the study rather than selecting a sample directly proportional to the population of eligible houses in the region. Under the clustered sampling procedure, at least three local weatherization agencies were monitored from each state in the region over the two program years to ensure that each state (despite the number of single-family, fuel-oil heated houses weatherized) was represented in the study.

A ratio-estimator averaging procedure was used to estimate the average savings for a given state over one program year. A ratio-estimator of the average may have potential bias, although in many cases it can be better than an unbiased estimator. A ratio estimator was used because it did not require knowing the exact number of single-family, fuel-oil heated homes weatherized by each state over each program year. These numbers, which were not known, would have been required to determine an unbiased estimate of the average. The use of estimated numbers would have introduced bias and/or error into the calculation of an "unbiased estimator."

The equations used to calculate the average regional values under the weighted ratio-estimator averaging procedure are provided in Appendix I. Under this procedure, each monitored house represents a number of houses in the overall population of interest. This number is often referred to as a weighting factor. Development of weighting factors is also described in Appendix I. Weighting factors are presented in Table I.1.

The weighted averaging procedure was used separately for the weatherized and control houses to arrive at regional estimates for each group. For the sample of houses monitored from an individual local weatherization agency, the following were known: the average value of a variable for the houses, the number of houses monitored, the standard deviation of the value, and the total number of single-family, fuel-oil heated houses weatherized by the agency during the program year. Additionally, the number of agencies in each state that weatherized single-family, fuel-oil heated houses and the number of agencies monitored in each state were known. A regional average value and accompanying variance were determined for each program year by first calculating and then combining state values. Results for each program year were then combined to obtain the final regional estimates.

53 FUEL-OIL CONSUMPTION AND SAVINGS RESULTS

Table 5.1 summarizes the sample (unweighted) results and regional (weighted) results for both control and weatherized homes for each test year, 1990-1991 and 1991-1992, and the combined test years, 1990-1992. Average regional results are primarily discussed in the remainder of the report. Table 5.2 presents 90% confidence intervals for regional consumptions and savings. Table H.2 contains a detailed summary of data and results for each house taking part in the study. Tables H.3 and H.4 present detailed statistical descriptions of the following variables for the control and weatherized houses, respectively: pre- and post-weatherization indoor temperatures, pre- and post-weatherization fuel-oil consumptions, and fuel-oil savings (expressed in gallons and percent).

Coefficients of determination (R^2) derived from the pre- and post-weatherization regressions for each house are contained in Table H.2, with pre- and post-weatherization distributions for both control and weatherized houses being shown in Fig. 5.1. The coefficient of determination is one of the most often used measures to judge the adequacy of a linear regression model. Coefficients for control houses were slightly better than for weatherized houses: 90% of the control house values were above 0.70, while 84% of the weatherized house values were above 0.70. There was little difference between pre- and post-weatherization periods. All houses regardless of their coefficients of determination were used in the analysis presented in this section. Section 5.4 discusses changes in results when houses with low coefficients of determination are dropped from the analysis.

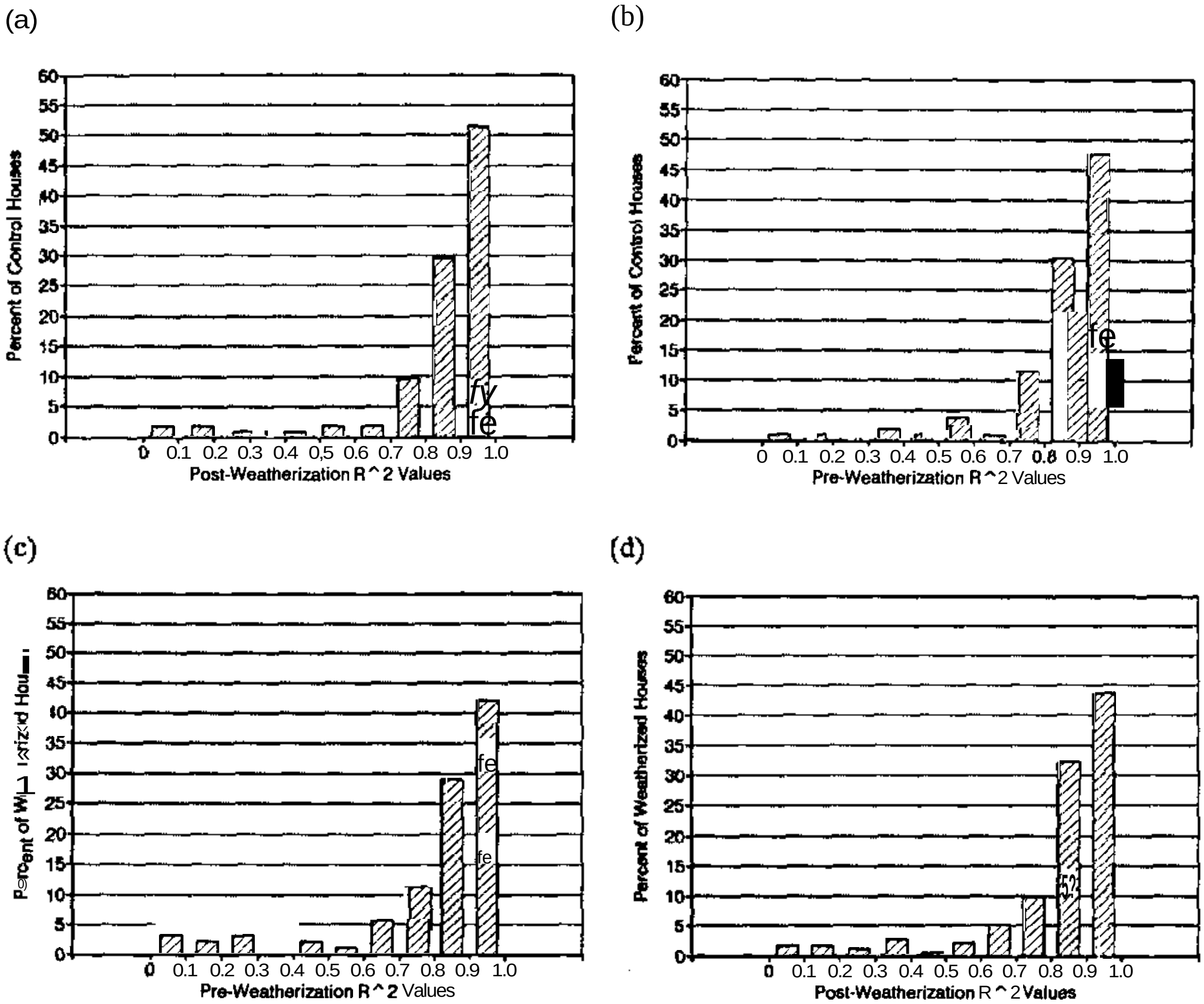

Fig. 5.1. Distributions of pre- and **post-weatherization** coefficients of determination **(R^2)** for control (a and b) and **weatherized** (c and d) **houses, respectively.** Mean values for the pre- **and** post-weatherization periods were 0.84 for the control houses, and 0.80 and 0.82 for the weatherized **houses.** Standard deviations for the **pre-** and post-weatherization periods were 0.18 and 0.19 for the control **houses,** and **0.23** and 0.19 for the weatherized houses.

Tables 5.1 and 5.2 show that the average regional pre-weatherization fuel-oil consumption for the control houses was greater than the weatherized houses, 918 gallons/year compared to 905 gallons/year.[10] The comparison between groups is reversed if consumption is normalized by floor area: the consumptions were 0.638 gallons/year/ft² for the control houses and 0.676

[10]Fuel-oil consumptions can be converted from gallons to Btu by multiplying gallons by 140,000 Btu/gallon, the higher heating value of fuel oil.

Table 5.1. Summary of **fuel-oil** consumptions and savings

Summary of Sample: Control Houses

Year	Number of houses	Heated area (ft^2)	Annual fuel-oil consumption (gallons)			
			Pre	Post	Gross savings	Percent savings
1990-91	60	1431	996	1025	-29	-2.9
1991-92	45	1468	860	869	-9	-1.0
1990-92	105	1447	938	958	-20	-2.2

Summary of Sample: Weatherized Houses

Year	Number of houses	Heated area (ft^2)	Annual fuel-oil consumption (gallons)			
			Pre	Post	Gross savings	Percent savings
1990-91	102	1237	913	757	156	17.1
1991-92	91	1398	847	719	128	15.1
1990-92	193	1313	882	739	143	16.2

Regional Summary: Control Houses

Year	Number of houses	Heated area (ft^2)	Annual fuel-oil consumption (gallons)			
			Pre	Post	Gross savings	Percent savings
1990-91	60	1459	969	1026	-57	-5.9
1991-92	45	1418	859	874	-15	-1.8
1990-92	105	1438	918	956	-38	-4.1

Regional Summary: Weatherized Houses

Year	Number of houses	Heated area (ft^2)	Annual fuel-oil consumption (gallons)			
			Pre	Post	Gross savings	Percent savings
1990-91	102	1249	913	790	123	13.5
1991-92	91	1429	897	776	121	13.4
1990-92	193	1339	905	783	122	13.5

Note: Fuel-oil consumptions and savings can be converted from gallons to Btu by multiplying gallons by 140,000 Btu/gallon, the higher heating value of fuel oil.

Table 5.2. **Confidence intervals** of regional **fuel-oil** consumptions and savings

Item	Control houses		Weatherized houses	
	Weighted mean value (gallons)	90% confidence interval	Weighted mean value (gallons)	90% confidence interval
Annual pre-weatherization consumption	918	±64	905	±51
Annual post-weatherization consumption	956	±71	783	±52
Annual gross savings	-38	±24	122	±19
Annual net savings			160	±31

Note: Fuel-oil consumptions and savings can be converted from gallons to Btu by multiplying gallons by 140,000 Btu/gallon, the higher heating value of fuel oil.

gallons/year/ft² for the weatherized houses.[11] These sets of values were not statistically different from each other at a 0.05 level of significance. The large variation in individual house consumptions for both groups was similar as shown in Fig. 5.2: 49% of the control houses and 45% of the weatherized houses had pre-weatherization consumptions between 600 and 1000 gallons/year, with most houses being between 400 and 1200 gallons/year. The fact that 40% of the houses include fuel-oil consumption to heat domestic hot water likely contributes to the high end of the observed distribution.

As shown in Tables 5.1 and 5.2, the average regional fuel-oil consumption of the control houses increased to 956 gallons/year, for a gross change of -38 gallons/year (the control houses averaged 38 gallons/year more in the post-weatherization period than the pre-weatherization period) or negative 4.1% of pre-weatherization consumption. The average regional fuel-oil consumption of the weatherized houses decreased to 783 gallons/year following weatherization,

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[11]Control houses being 6.5% more efficient on a square foot basis could indicate some bias in the selection process. Obtaining occupant agreement to act as a control for the heating season was more difficult than obtaining occupant agreement to be in the weatherized group. The occupants' decisions may have been based, to some degree, on the thermal integrity of their houses, which would have tended to put more "energy-inefficient" houses in the weatherized group. However, this is pure speculation, and we have no evidence to support such a hypothesis.

(a)

(b)

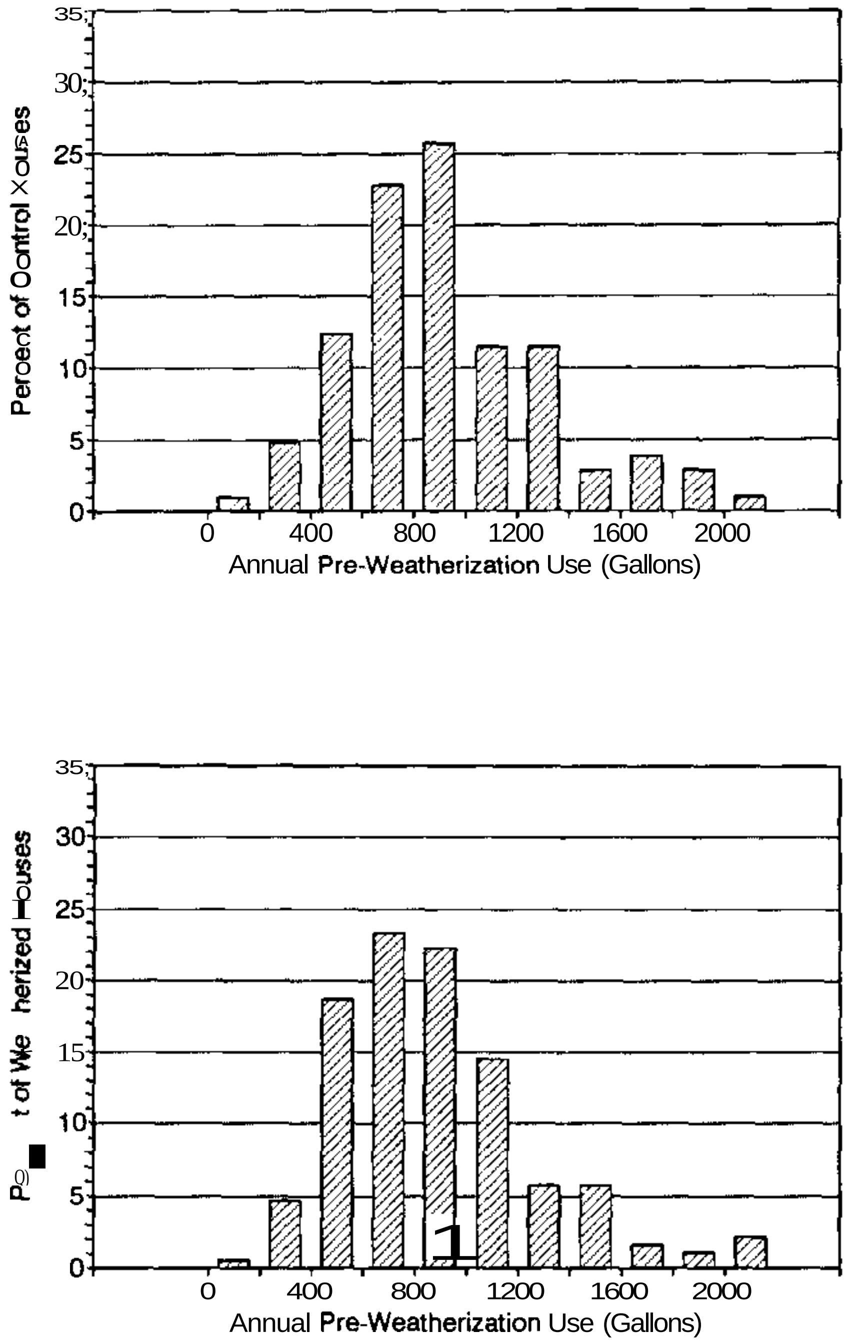

Fig. **5.2.** Distribution of **pre-weatherization fuel-oil** consumptions for the control (a) and **weatherized** (b) houses. For the control houses, the sample mean was 938 **gallons/year and** the standard deviation was 407. For the weatherized houses, the sample mean was 882 **gallons/year** and the standard deviation was 379.

for a gross savings of 122 gallons/year or 13.5% of pre-weatherization consumption.[12] The regional gross savings for the control and weatherized houses were statistically different from zero and from each other at a 0.05 level of significance. Gross savings measured for the weatherized houses were nearly identical for each program year. Also, the savings measured in houses that used auxiliary heat were not statistically different than those measured in houses that did not use auxiliary heat.

To remain consistent with results reported from evaluations from other programs, the best estimate for the regional savings obtained from the Fuel-Oil Study is the net savings of the weatherized houses (the gross change of the control houses subtracted from the gross savings of the weatherized houses). The net regional savings was 160 gallons/year, or 17.7% of pre-weatherization consumption. The dollar value of the net savings was $162, assuming a fuel cost of $1.01/gallon. The 90% confidence interval for the savings was ±31 gallons/year (±3.4% of pre-weatherization consumption). The ratio of the confidence interval to the savings was 19%. This was lower than the ratio of 26% estimated in the experimental design for a 90% confidence interval because of higher savings and lower standard errors than our original estimates. Thus, the measured savings were more accurate than expected.[13]

The distribution of post-weatherization consumptions for the weatherized houses is shown in Fig. 5.3 (the distribution of post-weatherization consumptions for the control houses was nearly identical to their pre-weatherization distribution). Almost 60% of the weatherized houses had consumptions between 400 and 800 gallons/year.

Two distribution plots of pre- and post-weatherization fuel-oil consumptions for the control and weatherized houses are shown in Fig. 5.4. The data in these figures are plotted

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[12]Average sample consumptions and savings were in close agreement with the regional (weighted) results. The average sample savings was -2.2% for the control houses and 16.2% for the weatherized houses, for an average net savings of 18.4%.

[13]The 95% confidence interval for the net savings of the weatherized houses was ±37 gallons/year (±4.1% of pre-weatherization regional consumption). The ratio of the 95% confidence interval to the savings was 23%, which was still more accurate than estimated in the experimental design.

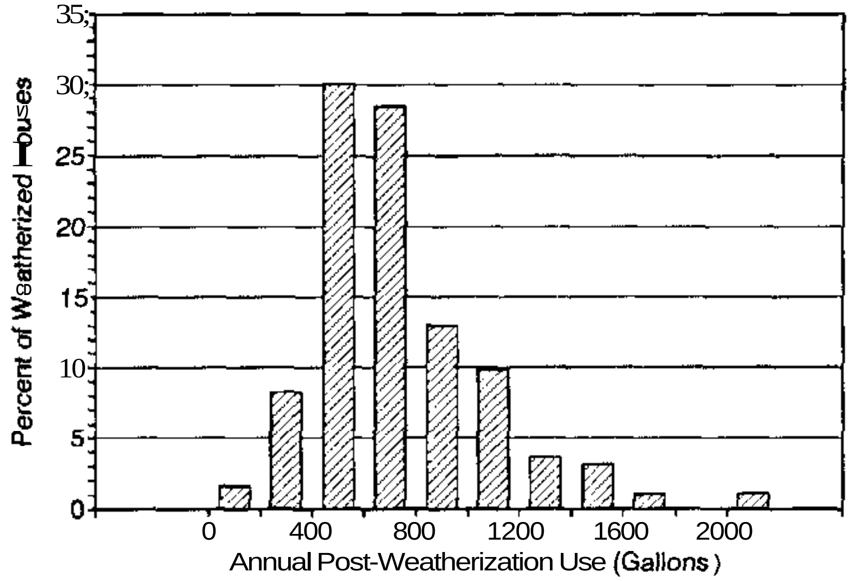
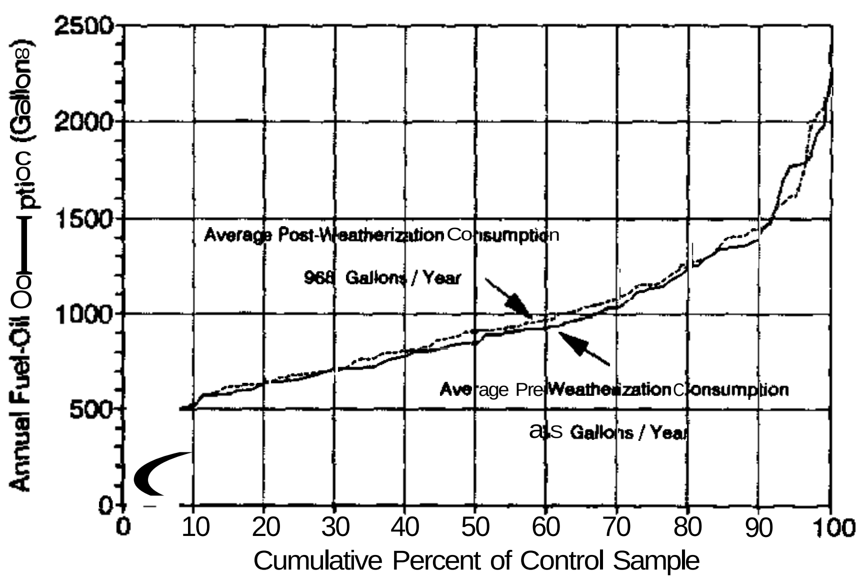


Fig. 53. Distribution of post-weatherization fuel-oil consumptions for the weatherized houses. The sample mean was 739 gallons/year and the standard deviation was 340.

differently than usual distribution plots, in that the abscissa (x-axis) represents a cumulative percent of the sample. Medians are easily seen on these plots as the points where curves cross the 50% grids of the abscissas. Note that all medians lie below the sample averages for pre- and post-weatherization fuel consumption. Since these figures are distribution plots, there is no relationship between the pre- and post-weatherization fuel-oil consumptions lying along the same value of the abscissa. The two curves plotted on each figure were generated from independent and sorted data sets. These plots do, however, illustrate a slightly higher average fuel-oil consumption for control houses during the post-weatherization period, and a lower average fuel-oil consumption for weatherized houses after weatherization.

As shown in Fig. 5.5(a), about 80% of the control houses had measured gross savings between -100 and 100 gallons/year, with about twice as many houses between -100 and 0 gallons/year compared to 0 to 100 gallons/year. Because the control houses were not weatherized, a distribution of savings around zero was expected.

(a)



(b)

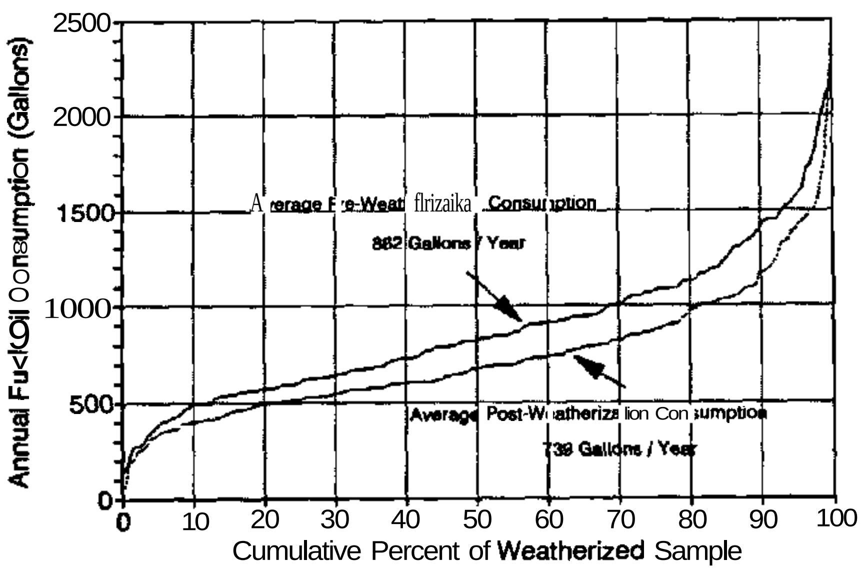


Fig. 5.4. Distribution of **pre-** and **post-weatherization fuel-oil** consumptions for the control (a) and **weatherized** (b) houses, where the abscissa **(x-axis)** represents a cumulative percent of the **sample.**

As shown in Fig. 5.5(b), 65% of the weatherized houses had measured savings between 0 and 300 gallons/year. Only 4% of the sample had savings greater than 500 gallons/year and about 17% had negative savings (with most of these being limited to -100 to 0 gallons/year).

Cumulative distribution plots for percent fuel-oil savings are shown in Fig. 5.6. Figure 5.6(a) shows that the control group is more closely grouped (the percent savings span is less) in the middle 20% to 80% of the sample than is the weatherized group in Figure 5.6(b).

5.4 SAMPLE REFINEMENT

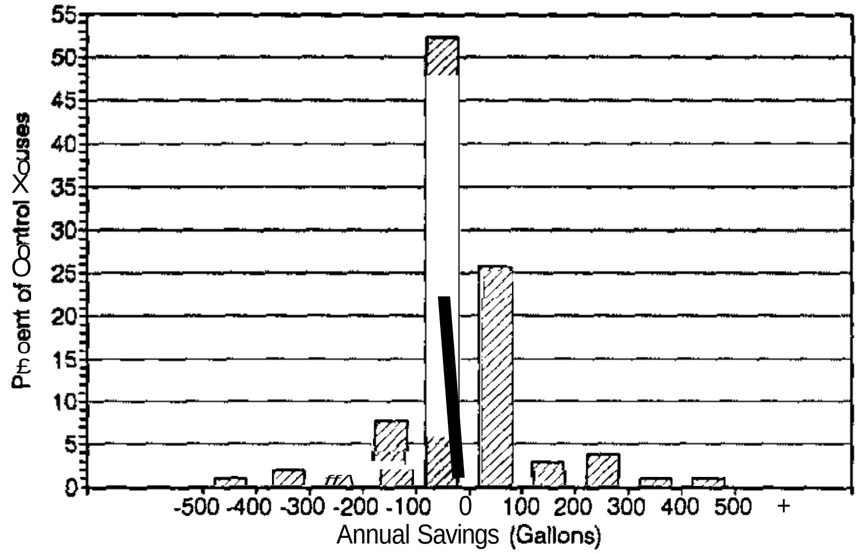
The results presented in Sect. 5.3 are based on an analysis of all 298 houses with complete monitored data sets, disregarding the adequacy of the regression results. Figure 5.7 shows plots of average sample (unweighted) pre-weatherization fuel-oil consumptions, fuel-oil savings, and percent savings for the control and weatherized houses when using data from:

- all sites regardless of the R^2 value,
- houses with an R^2 above 0.5 for both pre- and post-weatherization periods, and
- houses with an R^2 above 0.7 for both periods.

Table H.5 contains a summary of control house sample statistics for each of the three data sets, and Table H.6 contains similar sample statistics for the weatherized houses. Figure 5.7 shows that values for all three variables increased for the weatherized houses as the minimum R^2 value increased. The greatest change occurred with the savings, which increased from 143 to 162 gallons/year (a change of 13%). Values changed less for the control houses, increasing as the minimum R^2 changed from 0.0 to 0.5, but decreasing as the minimum R^2 changed from 0.5 to 0.7. The sample size decreased by about 25% when moving from a minimum R^2 of 0 to a minimum R^2 of 0.7.

Tables H.7 and H.8 contain information with distribution plots on the following variables for control and weatherized houses, respectively, with a minimum R^2 of 0.7: pre- and post-weatherization period indoor temperatures, pre- and post-weatherization fuel-oil consumption, and fuel-oil savings (gallons and percent). Comparison of these tables directly with Tables H.4 and H.5, which contain the same data for all houses, indicated little differences in the distribution

(a)



(b)

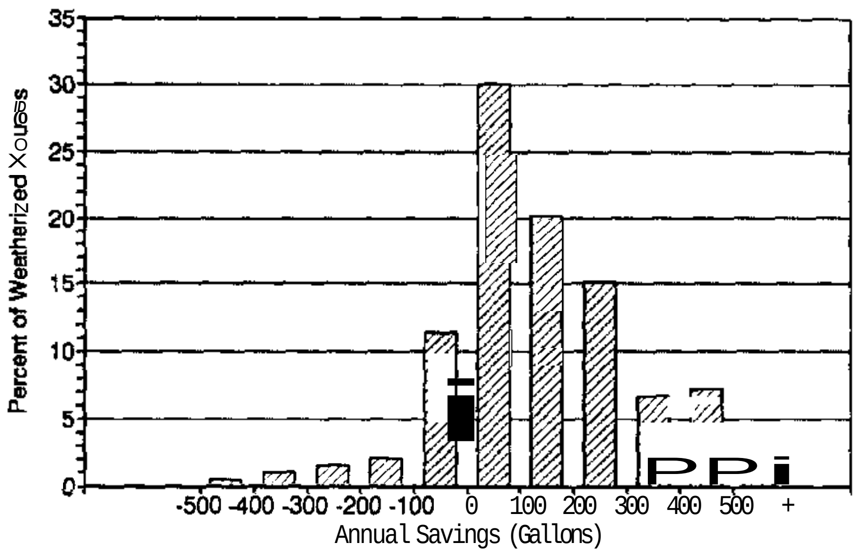
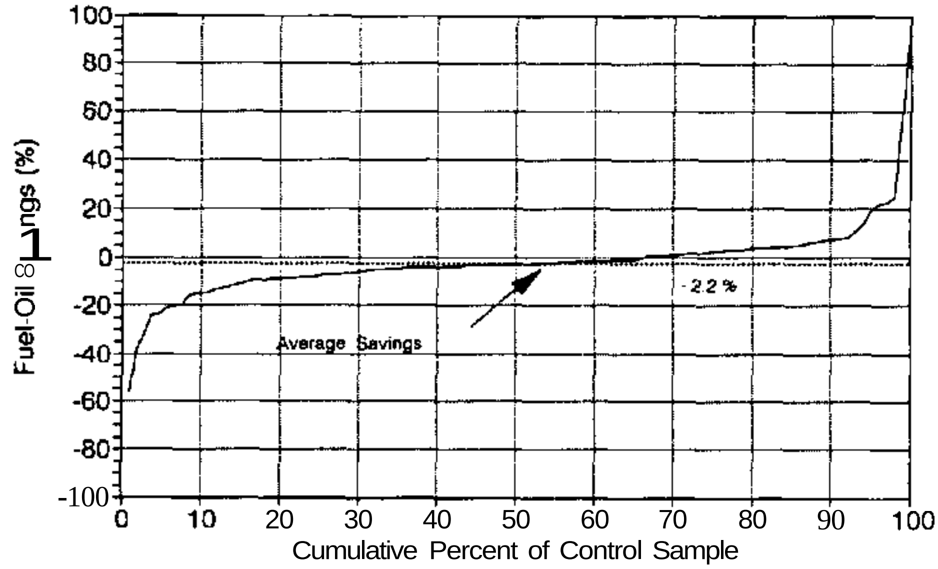


***Fig. 5.5.* Distribution of fuel-oil savings for the control (a) and weatherized (b) houses. For the control houses, the sample mean was -20 gallons/year and the standard deviation was 117. For the weatherized bouses, the sample mean was 143 gallons/year and the standard deviation was 195.**

(a)



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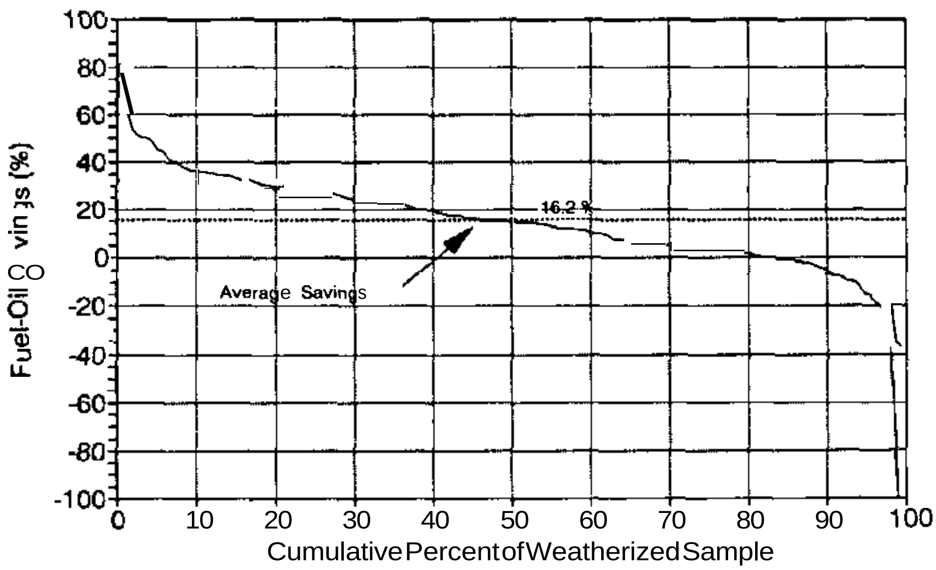


Fig. 5.6. Distribution of percent **fuel-oil** savings for the **control** (a) and **weatherized (b)** houses, where the abscissa (x-axis) represents a cumulative percent of the sample.

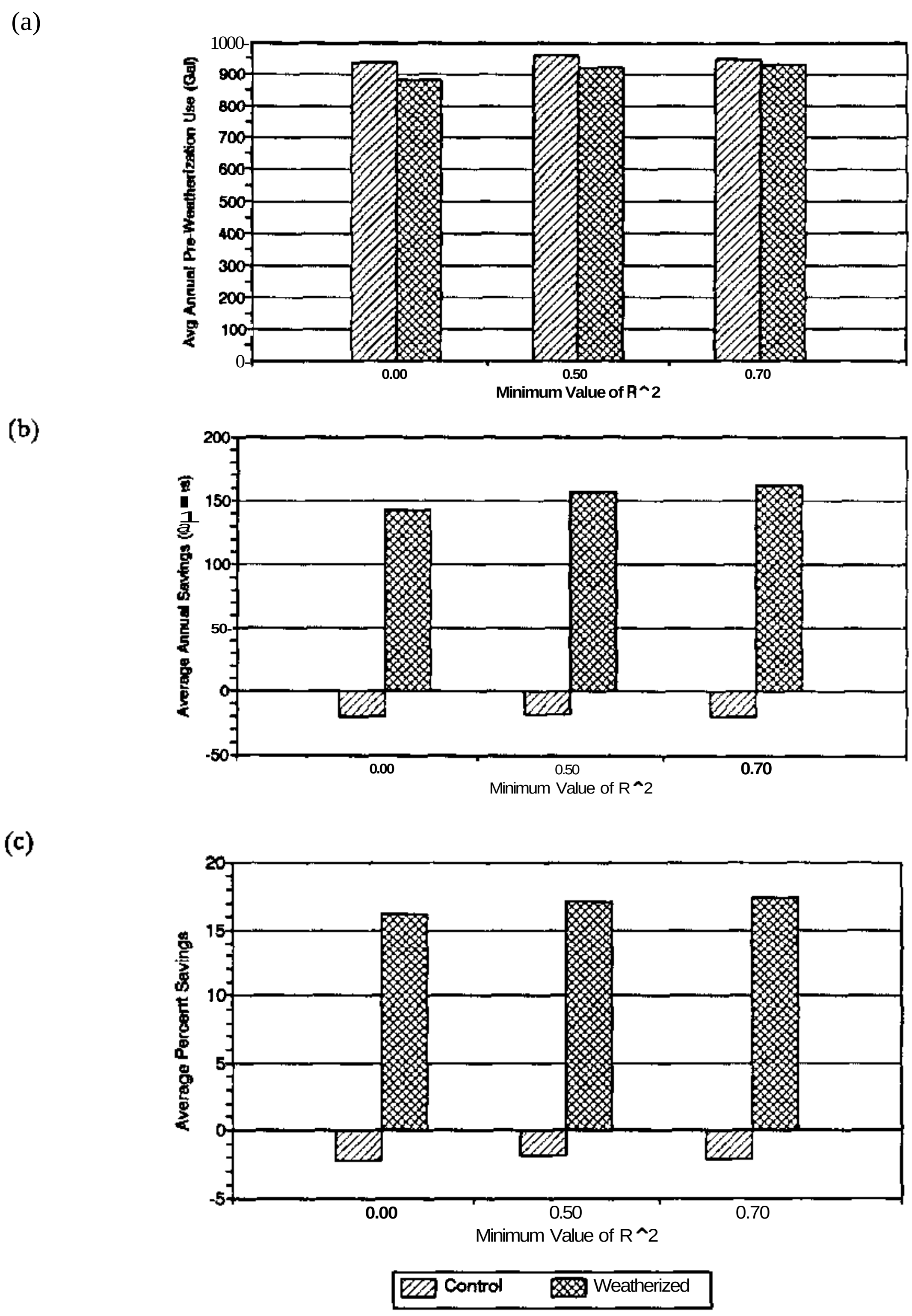


Fig. 5.7. Average sample pre-weatherization fuel-oil consumption (a), savings (b), and percent savings (c) for the control and weatherized houses using different data sets depending on the adequacy of the consumption regressions.

of pre-weatherization consumption for the refined data set. Savings distributions were also similar, although there were fewer outlying data points with the refined data set.

Primary analysis was performed without excluding any houses due to regression curvefit inadequacies. Although this decision estimated a slightly lower percentage savings than would have been obtained by limiting the analysis to houses with higher R^2 fits, it allowed a more accurate estimation of the confidence interval of the savings estimate because of the higher number of houses used in the determination. Standard deviations between test sites in a local weatherization agency were necessary for confidence-interval estimation; increasing the minimum R^2 value reduced the available sample size in some agencies to the point where one or no control and/or weatherized sites were left from which to determine standard deviations. Standard deviations between agencies in a given state were also needed to avoid use of assumptions about the sample; again, increasing the minimum R^2 value would have eliminated entire agencies to the point where there was only one per state.

An additional investigation showed that the use of auxiliary heat effected the R^2 values of the fuel-oil consumption regressions, primarily in the weatherized houses (see Table 5.3). T-tests showed that the average R^2 value for the weatherized houses using auxiliary heat in both periods was lower than the value for weatherized houses not using auxiliary heat at a significance level of 0.002 for both the pre- and post-weatherization periods. The average control house R^2 values, however, were only different from each other for the pre period at a significance level of about 0.07, but not significantly different from each other in the post period.

Weatherized houses using some form of auxiliary heat were two to three times more likely to have low R^2 fits than the control houses using some form of auxiliary heat: 36% of the weatherized houses but only 20% of the control houses that used auxiliary heat in the pre-weatherization period had R^2 values less than 0.7, while 33% of the weatherized houses but only 10% of the control houses that used auxiliary heat in the post-weatherization period had R^2 values less than 0.7. Recall from Sect. 5.3 that 90% of all the control houses and 84% of all the weatherized houses had R^2 values of 0.7 or higher.

Table 53. Effect of use of auxiliary heat on R^2 fit of fuel-oil consumption data

Type of house	Auxiliary heat usage	No.	Pre-weatherization			Post-weatherization			Savings (gallons)
			R^2	Number of R^2 <0.7	Usage (gallons)	R^2	Number of R^2 <0.7	Usage (gallons)	
Weatherized	Pre	15	0.73	4	1060	0.84	2	903	157
Weatherized	Post	2	0.89	0	887	0.88	0	710	177
Weatherized	Both	25	0.60	11	772	0.63	12	671	101
Weatherized	None	80	0.86	8	860	0.87	4	706	154
Control	Pre	4	0.81	1	824	0.94	0	848	-24
Control	Post	1	0.96	0	2419	0.97	0	2349	70
Control	Both	15	0.76	3	830	0.79	2	879	-48
Control	None	42	0.87	3	926	0.86	3	969	-43

The use of auxiliary heat did not have any major effects on the savings results. T-tests revealed that the pre fuel-oil consumptions, post fuel-oil consumptions, and fuel-oil savings for the weatherized houses using auxiliary heat during both periods were not statistically different from weatherized houses that did not use any auxiliary heat. A similar result occurred for the control houses.

5.5 INDOOR TEMPERATURES

Table 5.4 shows that the average regional pre-weatherization indoor temperatures of the control and weatherized houses were nearly the same: 70.3° F and 70.5° F, respectively. Control houses were about 1°F warmer the first year compared to the second year, while the weatherized house were about 0.7° F warmer the second year. The control houses were 0.6° F warmer than the weatherized houses the first year and 1.2° F cooler the second year.

Figure 5.8 shows cumulative distribution plots of control and weatherized indoor temperatures. The most striking part of Fig. 5.8 is that there is very little difference between the pre- and post-weatherization temperature distributions for each group. About 80% of the houses were maintained between 65° F and 75° F throughout the monitoring periods. Little change between pre- and post-weatherization periods is evident.

Table 5.4. Summary of indoor temperatures

Control Houses

Year	Number of houses	Indoor temperature (°F)					
		Sample			Regional (weighted)		
		Pre	Post	Change	Pre	Post	Change
1990-91	60	70.3	70.2	-0.1	70.8	71.0	0.2
1991-92	45	69.4	69.1	-03	69.7	69.4	-0.3
1990-92	105	69.9	69.8	-0.1	70.3	70.3	0.0

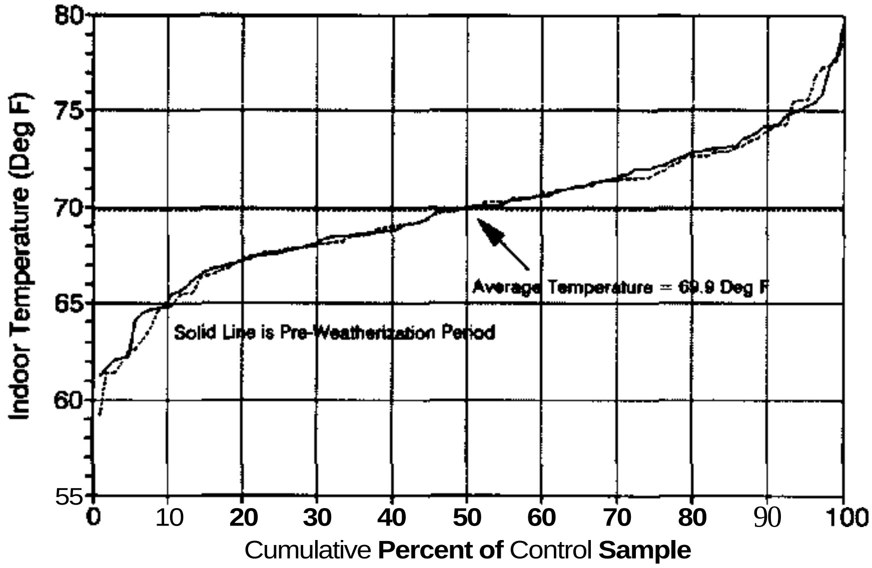
Weatherized Houses

Year	Number of houses	Indoor temperature (°F)					
		Sample			Regional (weighted)		
		Pre	Post	Change	Pre	Post	Change
1990-91	102	69.9	70.2	0.3	70.2	70.3	0.1
1991-92	91	70.5	70.0	-0.5	70.9	70.5	-0.4
1990-92	193	70.2	70.1	-0.1	70.5	70.4	-0.1

Table 5.4 shows that the average regional indoor temperature change for the control houses was nearly zero, and only -0.1°F for the weatherized houses (the negative value means that the indoor temperature was lower during the post-weatherization period than it was during the pre-weatherization period). Indoor temperatures tended to increase the first year during the post-weatherization period for both control and weatherized houses, but tended to decrease the second year.

Figure 5.9 shows cumulative distribution plots of indoor-temperature differences for the control and weatherized groups. Although the average indoor temperature difference for both groups was nearly zero, the distribution is interesting. Assuming differences between ± 1°F were too close to be significantly different, Fig. 5.9 shows about 20% of the weatherized houses had a lower indoor temperature after weatherization, while 15% of the weatherized houses increased their indoor temperature. Control house results were slightly different. About 15% of the

(a)



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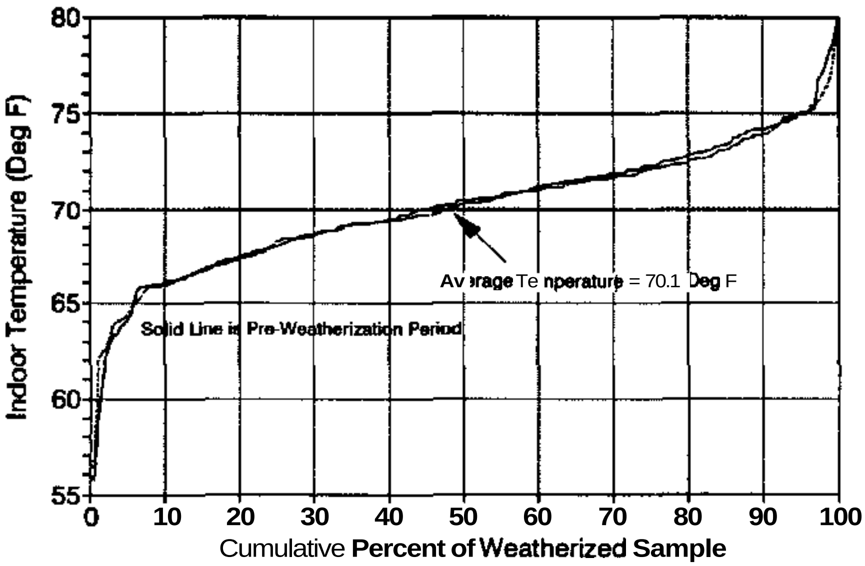
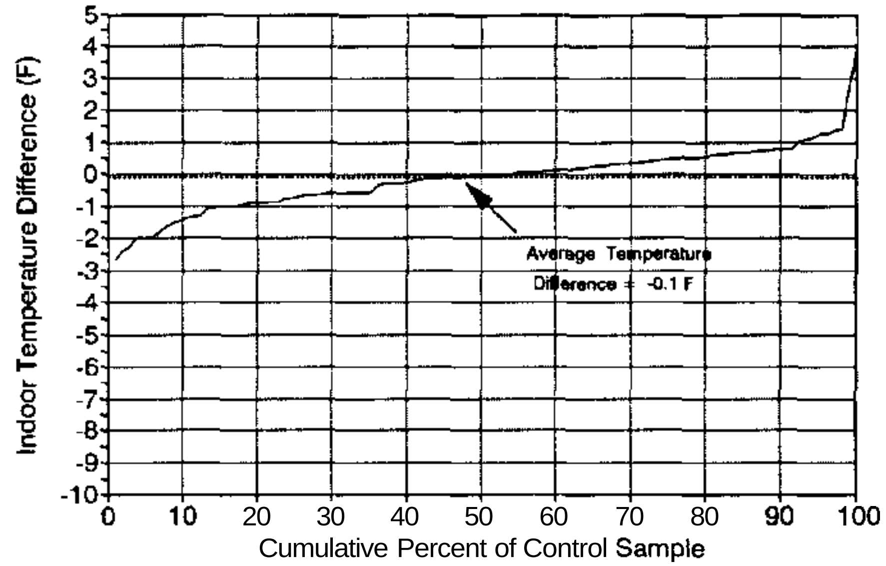


Fig. 5.8. Distribution of pre- and post-weatherization indoor temperatures for the control (a) and weathenzed (b) houses, where the abscissa (x-axis) represents a cumulative percent of the sample.

(a)



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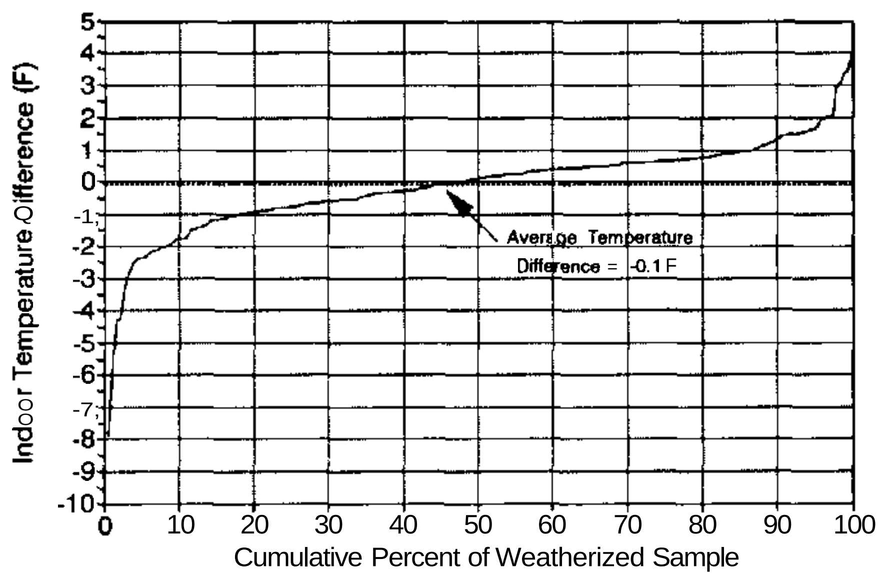

Fig. 5.9. Distribution of indoor temperature differences for the control (a) and **weatherized** (b) houses, where the abscissa (x-axis) represents a cumulative percent of the sample (negative temperature differences mean that the indoor temperature was lower during the post-**weatherization** period than it was during the **pre-weatherization** period).

control houses lowered their indoor temperature more than 1°F for the post-weatherization period, while only 8% increased their indoor temperature by more than 1°F. The control houses displayed a slightly tighter grouping than did the weatherized group.

These results indicate that client education (a measure provided to almost every house) did not lead to lower temperatures. These results also indicate that, on average, an indoor temperature "takeback" effect did not exist in our sample.[14]

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[14]For this study, a "takeback" effect would be an increase in the indoor temperature after weatherization has been completed in order to get more comfort by reinvesting some of the weatherization savings back into fuel oil.

6. AIR-LEAKAGE REDUCTIONS

House air-leakages were measured at the beginning of the pre-weatherization period and at the end of the post-weatherization period following the procedure outlined in Appendix D.[15] Differences between pre- and post-weatherization measurements in the weatherized houses represent changes due to all the work performed in the houses (including, for example, wall insulation and storm windows) rather than just specific infiltration-reduction work because measurements were made at the beginning and end of the heating season.

Pre- and/or post-weatherization measurements were made in 329 houses, but both pre- and post-weatherization measurements were made in only 250 of these houses. The data set was further refined for the analysis presented in this section by only including houses with high quality pre- and post-weatherization air-leakage data (coefficients of determination [R^2] were greater than 0.96) and with consistent basement door positions (closed or open) for the pre- and post-weatherization measurements (most measurements were performed with the basement door closed). The final sample size was 167 houses (54 control houses and 113 weatherized houses). The coefficient of determination criteria eliminated 35 houses and the basement door position criteria eliminated the remaining 48 houses.[16]

6.1 ANALYSIS APPROACH

The air tightness of the houses and the change following weatherization were analyzed using the air flow rate at a 50 Pa pressure difference (house depressurized) across the building shell (cfm50).[17] The cfm50 value was calculated from the data collected under the air-leakage tests. An air-leakage test consisted of a series of air flow measurements (Q) made at pressure

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[15]In a few limited cases, agency measurements were recorded because independent measurements for the study could not be performed.

[16]Raising the coefficient of determination cutoff to 0.98 would have reduced the sample size by another 19 houses.

[17]Other possible indicators include effective leakage area, average seasonal air exchange rate ($cfm_{natural}$), and these indicators normalized to the total exposed surface area of the house or house volume.

Table 6.1. Control and weatherized house air-leakages

	Control houses	Weatherized houses
Number of houses	54	113
Pre-weatherization air leakage (cfm50)	3468	3295
Post-weatherization air leakage (cfm50)	3304	2725
Air-leakage reduction (cfm50)	164	570

differences between the inside and outside of the house (AP). These data follow the power law form

$$Q = C(\Delta P)^N$$

where C and N are constants. These values were regressed by the method of weighted least squares (CGSB 1986) to determine the best values of C and N because ln(Q) vs ln(AP) is a linear relation. Values of Q can then be estimated for selected values of AP. The cfm50 value was calculated using the above equation and 50 Pa as the value of AP.

Throughout this section, sample (unweighted) statistics rather than regional (weighted) values are presented,

6.2 RESULTS

As shown in Table 6.1, the average sample pre-weatherization air leakage was 3468 cfm50 for the control houses and 3295 cfm50 for the weatherized houses. The two groups were statistically the same at a 0.05 level of significance. Distributions of pre-weatherization air leakages are shown in Fig. 6.1. The distributions of the two groups were generally similar, with the majority of the houses (69% of the control houses and 78% of the weatherized houses) having air leakages between 1500 and 4500 cfm50.

Pre-weatherization air leakages were less than 1500 cfm50 in 11% of the control houses and 4% of the weatherized houses. Houses in the northeast with air leakages between 1000 and

(a)

(b)

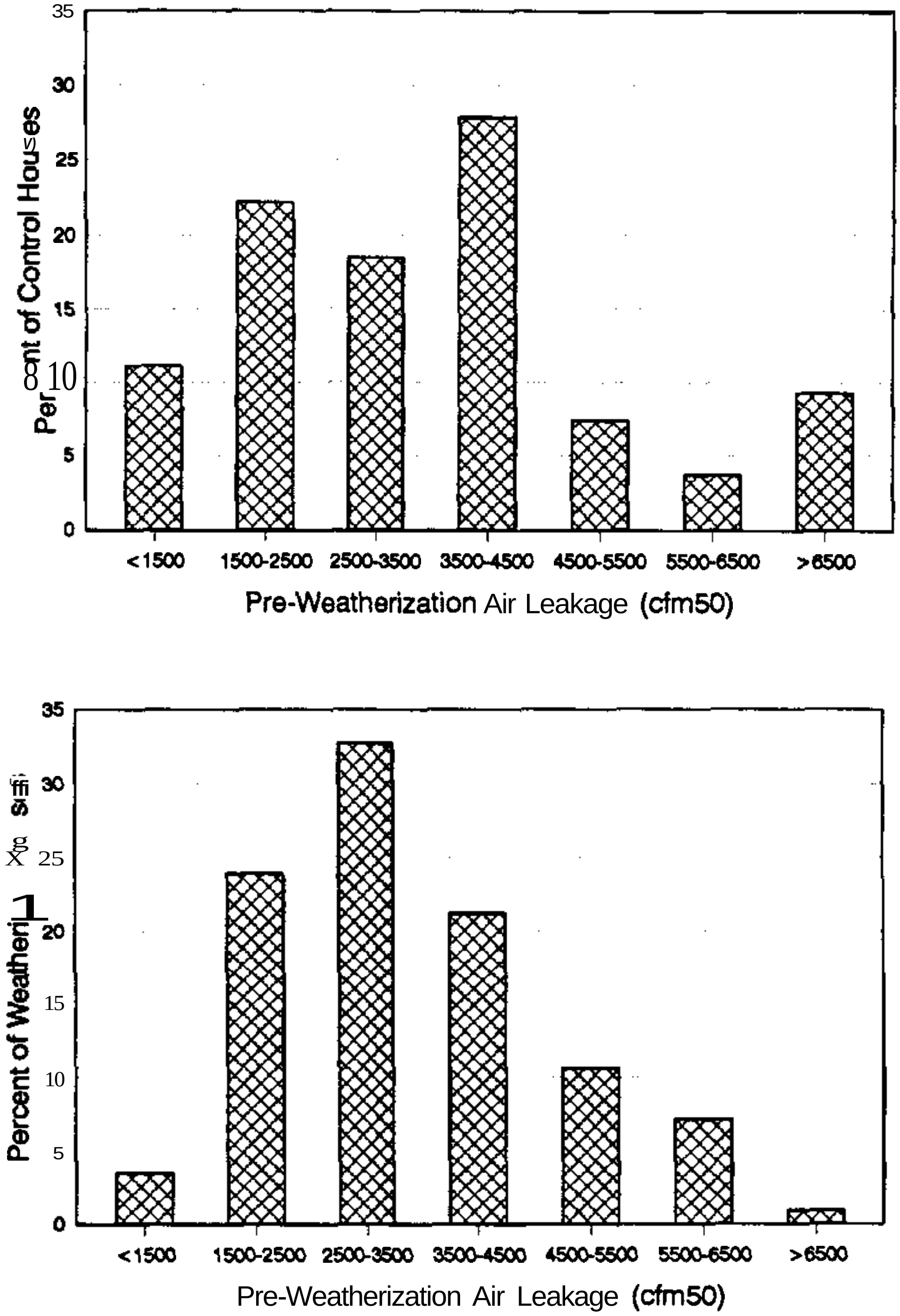

Fig. **6.1.** Distribution of **pre-weatherization** air leakages for the control (a) and **weatherized (b)** houses. For the control **houses,** the mean was 3468 **cfm50** and the standard deviation was **1735.** For the weatherized houses, the mean was 3295 **cfm50** and the standard deviation was 1263.

1400 cfm50 are generally considered to be tight (Tsongas 1993), requiring no infiltration reduction work[18]. Any infiltration reduction work performed on such houses would generally achieve small reductions and could potentially cause indoor health and moisture problems.

On the other hand, 9% of the control houses and only 1% of the weatherized houses had pre-weatherization air leakages greater than 6500 cfm50. These houses have severe air leakage problems that should benefit considerably from air-sealing work.

Weatherization work performed under the study achieved statistically significant reductions in air leakage. Table 6.1 shows that the average sample air-leakage reduction was 164 cfm50 for the control houses and 570 cfm50 for the weatherized houses. The average control house reduction was not statistically different from zero at a 0.05 level of significance; the average weatherized house reduction was statistically different from zero and from the control house reduction at this same confidence level.

The distribution of air-leakage reductions for both the control and weatherized houses is shown in Fig. 6.2, and air-leakage reductions are plotted versus prc-weatherization values in Fig. 6.3. A majority of the control houses had reductions between -500 and 500 cfm50, with 43% of the control houses having negative reductions and 57% having positive reductions.[19] Figure 6.3(a) shows this relatively even distribution of positive and negative reductions for the control houses. Figure 6,3(a) also shows that the pre-weatherization air leakage was not a determining factor in the sign of the reduction. Changes in air leakages for the control houses were expected to be more closely distributed around zero because no weatherization work was performed in them. Analysis was performed using the refined data set to ensure that data quality did not

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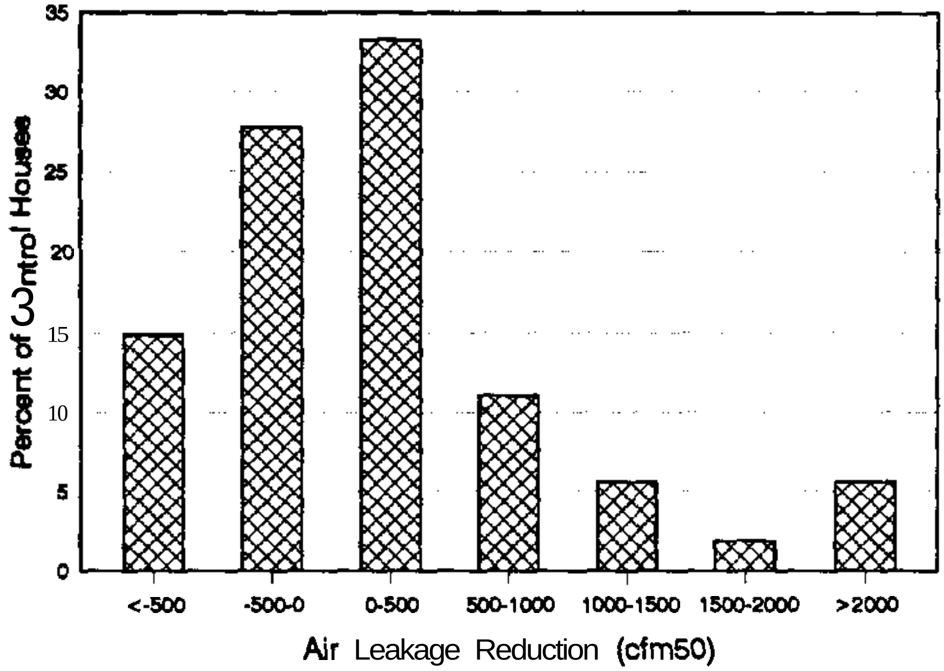
[18]This range assumes five or fewer occupants live in the house, normal shielding, and a living area less than 1610 ft^2. The range is higher for more occupants, better shielding, and larger living areas.

[19]Similar results are reported for control houses from other field tests (Ternes et al. 1991), although the reductions are more closely distributed around zero than they are here. On the other hand, consistent air leakages can be measured as demonstrated in other field tests (Ternes, Wilkes, and McLain 1993).

(a)



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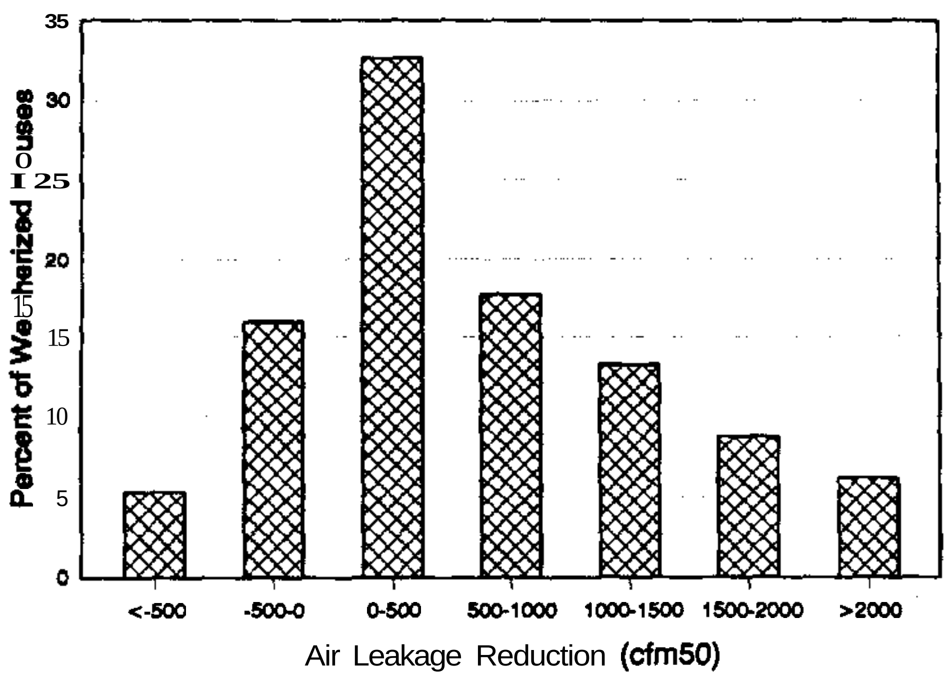
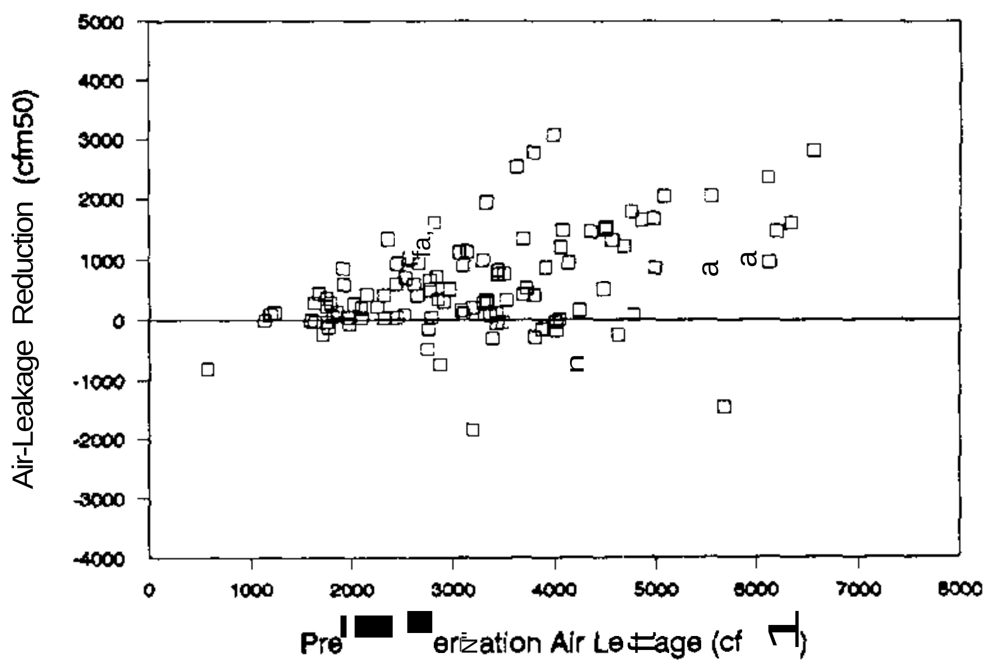


Fig. 6.2. Distribution of air-leakage reductions in the control (a) and weatherized (b) houses. For the control houses, the mean was 164 cfm50 and the standard deviation was 1099. For the weatherized houses, the mean was 570 cfm50 and the standard deviation was 821.

(a)



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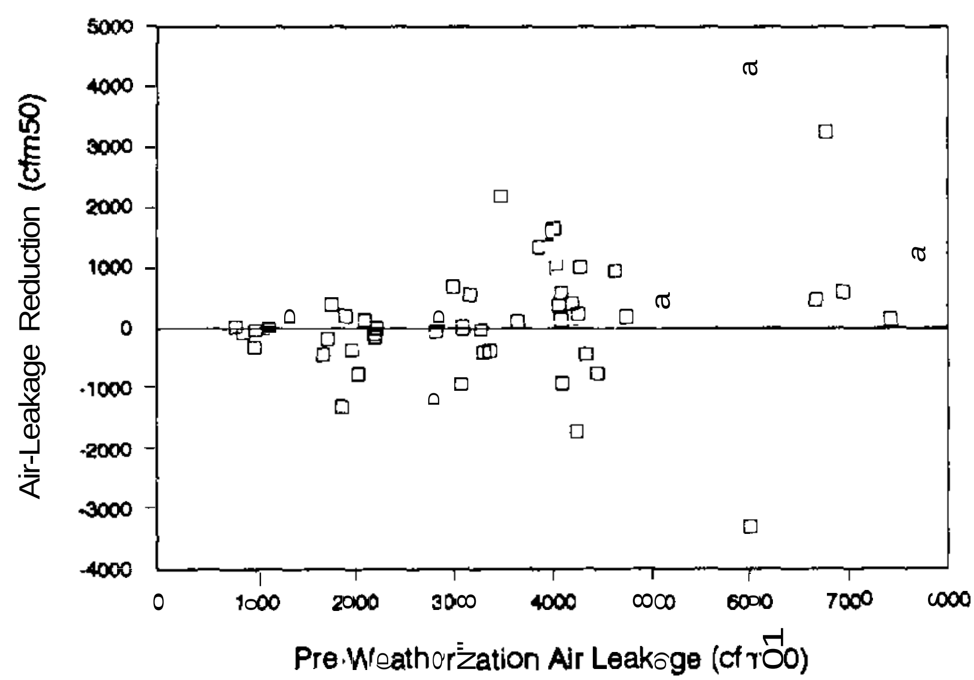


Fig. 6.3. Comparison of [redacted] leakage [redacted]uctions of the co[redacted] (a) and weatherized (b) houses to pre-weatherization air [redacted]ges.

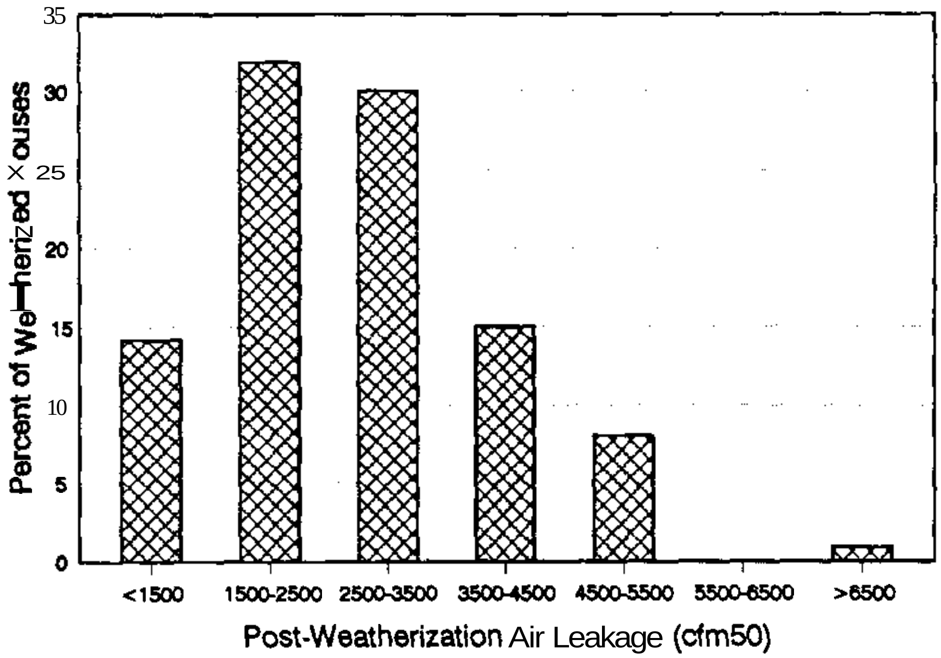


Fig. 6.4, Distribution of **post-weatherization** air leakages for the **weatherized houses. The mean** was 2725 **cfm50** and the standard deviation was **1165.**

contribute to this behavior. Changes observed for individual houses could be due to random measurement errors, although the test procedure in Appendix D was intended to minimize this.

About a third of the weatherized houses had relatively small air-leakage reductions (0 to 500 cfm50) and about a third had reductions between 500 and 1500 cfm50. Negative reductions were still experienced in 21% of the houses, mainly between 0 and -500 cfm50.[20] The shift to lower air leakages is evident in comparing the distribution of post-weatherization values (Fig. 6.4) to the pre-weatherization distribution shown in Fig. 6.1(b). Following weatherization, 76% of the weatherized houses had air leakages less than 3500 cfm50, while 60% did before weatherization. As shown in Fig. 6.3(b), the air-leakage reductions of the weatherized houses are somewhat dependent on pre-weatherization air leakages, although significant scatter does exist. Generally, small reductions were achieved for houses with pre-weatherization air leakages below 2000 cfm50.

[20]Previous field studies (Ternes et al. 1991, Ternes and Levins 1992) report few weatherized houses with negative reductions.

The effect of the following four factors on air-leakage reductions achieved in the weatherized houses was investigated, with results summarized in Table 6.2: use of a blower door to perform infiltration reduction work, presence of a forced-air distribution system in the house, installation of any type of wall insulation, and installation of high-density wall insulation. In all cases, average pre-weatherization air leakages were statistically the same for houses with the factor as without. This result implies that

- Houses weatherized using a blower door were not leakier than other houses to begin with (leaky houses did not receive preferential treatment).
- Houses with forced-air distribution systems did not have natural infiltration rates greater than houses with other distribution systems (the forced-air distribution system, when operating, may still affect house air leakage).
- Houses receiving wall insulation were not inherently leakier than houses that did not. This result does not address the question of whether houses without wall insulation were more leaky than houses with insulated walls because all houses without wall insulation did not necessarily receive this measure.

On average, air leakage reductions were 240 cfm50 greater in houses in which blower doors were used in sealing work compared to houses not receiving this treatment. Similarly, reductions were 175 cfm50 greater in houses receiving wall insulation, and 300 cfm50 greater in houses receiving high-density wall insulation. Houses with forced-air distribution systems did not have greater air leakage reductions than houses without forced-air distribution systems, despite the fact that air distribution systems are often leaky and contribute to total house leakage. None of these differences were statistically significant at a 0.10 level of significance (use of a blower door and installation of high-density wall insulation would just be significant at a 0.20 level of significance).

Table 6.2. Factors effecting air-leakage reductions in the weatherized houses

Factor	Number of houses in the sample	Pre-weatherization air leakage (cfm50)	Air-leakage reduction (cfm50)
Blower door used	88	3290	623
Blower door not used	25	3312	383
Forced-air distribution system present	56	3217	588
Forced-air distribution system not present	57	3372	552
Wall insulation installed	43	3271	678
Wall insulation not installed	70	3310	503
High density wall insulation installed	14	3253	833
High density wall insulation not installed	99	3301	533

7. HEATING SYSTEM MEASUREMENTS AND INSPECTIONS

Space-heating system steady-state efficiencies were measured at the beginning of the pre-weatherization period and at the end of the post-weatherization period following the measurement procedure provided in Appendix E. Additionally, a safety inspection of the space- and domestic water-heating systems was performed at the end of the post-weatherization period following the inspection procedure provided in Appendix F.

7.1 THE COMBUSTION OF FUEL OIL

An oil-fired heating system must both burn fuel oil efficiently and transfer the heat generated from combustion to the living area in order to efficiently heat a dwelling. The main chemical components of fuel oil are carbon and hydrogen (about 85% and 15% by weight, respectively). An efficient combustion process requires that fuel oil mix with oxygen from air and burn completely so that the products of combustion are carbon dioxide and water. Any inefficiency in the combustion process results in unburned fuel oil, soot (carbon), and carbon monoxide. Their presence reduces the amount of heat produced per unit of fuel oil delivered to the heating system and also creates potential health, safety, and operational problems.

The burner nozzle breaks the stream of liquid fuel into a spray of very small diameter droplets (large surface area per unit volume) so that the fuel may be more easily vaporized, mixed with oxygen from the air, and burned. Insufficient mixing of oxygen and fuel causes incomplete combustion. Since air is the source of oxygen for the combustion process, those components of air, such as nitrogen and argon, which do not enter into the combustion process actually inhibit combustion by lowering the temperature at which the reaction takes place. This means that the amount of excess air — that amount of air above the theoretical quantity necessary to burn all the fuel to carbon dioxide and water — should be minimized. Experience dictates that 40% is usually the optimum amount of excess air to be mixed with fuel oil to ensure proper combustion (Alliance to Save Energy 1985).

Heat produced as fuel oil is burned is removed from the hot combustion gas by a heat exchanger in order to heat a dwelling. Any soot formed during the combustion process reduces

Table 7.1. Description of smoke number

Smoke number	Burner performance
0-1	Excellent — Little, if any, sooting of furnace or boiler surfaces.
2	Good — May be slight sooting with some types of furnace or boiler but little increase in flue gas temperature.
3	Fair — Substantial sooting with some types of furnace or boiler and will require cleaning more than once a year on most types of furnace or boiler.
4	Poor — This is a borderline smoke — some units may soot only moderately, others may soot rapidly.
5	Very Poor — Heavy sooting in all cases — may require cleaning several times during the season.
6-9	Extremely Poor — Severe and rapid sooting — may result in damage to stack control and reduce overfire draft to danger point.

combustion efficiency and may attach to the heat exchanger to further reduce the transfer of heat to a dwelling. Any heat not removed from the combustion gas is essentially wasted by going up the chimney, although some heat is needed to vaporize the fuel oil for combustion and to form a draft to vent combustion gases.

The steady-state efficiency (SSE) measures both how completely a fuel burns and how well the heating system removes heat from the combustion gases under steady-state operation. Theory dictates that about 13% of the heat generated in the combustion process is needed for proper operation of a non-condensing draft-vented fuel-oil heating system, so that 87% is the maximum obtainable SSE for this type of system (Alliance to Save Energy 1985). The annual fuel utilization efficiency (AFUE) differs from the SSE in that it also includes cycling losses.

The SSE of an oil-fired furnace is determined by measuring the percent oxygen (or percent carbon dioxide) in the flue gas, the net stack temperature, and the smoke number. The first two measurements can be used with tables derived from combustion stoichiometry (see Table J.1) to determine the SSE assuming complete combustion. This efficiency must be adjusted by the smoke number (a number on a scale from 0 to 9) to account for incomplete combustion. A description of the smoke number is provided in Table 7.1 (Bacharach). Adjustments to the steady-state efficiency are provided in Table J.1.

7.2 CLEAN AND TUNE-UP SERVICE

A clean and tune-up was a measure performed on many heating systems. This service is suppose to address the steady-state efficiency, seasonal efficiency, reliability, and safety of the heating system. A fully trained oil-burner technician should clean the nozzle and heat exchanger, assure that the system is functioning and venting properly, and then tune-up the system so that it operates at its optimum SSE with minimum smoke. The tune-up should be performed while monitoring the SSE and is accomplished through adjustments to the air supply, burner, etc. The technician should then measure the final SSE and smoke value. The Alliance to Save Energy (1985) recommends as a retrofit goal an SSE of 80%, an oxygen level in the flue gas of ≤ 7%, and a smoke number of ≤ 1.

The technician should adjust fan limit switches to achieve maximum seasonal efficiency. The technician should also correct any malfunctions with the system and/or perform necessary repairs (e.g., cad cells, ignitors, limit switches, and barometric dampers) to address system reliability and safety.

A sample group was selected containing all houses which did not receive a new heating system or a new burner in order to determine the effect of clean and tune-up services on SSE and other combustion-related parameters of oil burners. Each heating system had to have valid SSE data for both pre- and post-weatherization periods in order to be included in the sample. A total of 208 houses were in the sample: 72 control houses and 136 weatherized houses. None of the control houses received a clean and tune-up, while 71 of the 136 weatherized houses received a clean and tune-up.

All measured SSEs reported in this section were adjusted for smoke number levels to correct table readings for incomplete combustion. Specifications for the analyzers used to perform the measurements state that they were accurate to within ±0.25% of the oxygen reading and to within 1% of the temperature reading. Based on the instrument specifications and Table J.1, SSE measurements readings should be within ±1% of the true value if procedures were properly followed. A potential source of error in the procedure involved interpolation errors when reading Table J.1.

Table 7.2 contains a summary of the unweighted sample data for all heating-system types and various subsets of the houses. Tables J.2 and J.3 in Appendix J contain information on standard errors of the mean for the measured SSEs.

The weatherized houses receiving a clean and tune-up were originally less efficient and more in need of a tune-up than weatherized houses not receiving this service. The average value of the SSE at the start of the pre-weatherization period was 75.0% for the control houses, 77.2% for the weatherized houses receiving no clean and tune-up, and 75.0% for the weatherized houses receiving a clean and tune-up. Distributions of the pre-weatherization SSEs for these groups are shown in Figs. 7.1(a), 7.2(a), and 7.3(a), respectively. Almost twice as many weatherized houses that did not receive a clean and tune-up had a SSE ≥80% compared to weatherized houses that did receive this service (37% compared to 18%, respectively). A t-test showed that the difference between the average pre-weatherization SSE values of weatherized houses receiving a clean and tune-up and weatherized houses not receiving this service was significant at a 0.05 level of significance.

The control houses, which received no clean and tune-up services, showed the greatest SSE increase of all three groups, and their distribution appeared to have much less variance than those of the weatherized groups. The average values of the SSE at the end of the post-weatherization period were 76.6% for the control houses (an average increase of 1.5 percentage points), 77.7% for the weatherized houses not receiving a clean and tune-up (an average increase of 0.5 percentage points), and 75.8% for weatherized houses receiving a clean and tune-up (an average increase of 0.8 percentage points). Distributions of the SSE changes for these groups are shown in Figs. 7.1(b), 7.2(b), and 7.3(b), respectively. Figure 7.2(b) shows that over half of the weatherized houses receiving a clean and tune-up increased in SSE from 0 to 4 percentage points, with a third of the total increasing from 2 to 4 percentage points; however, the SSE decreased in 21% of the houses by 2 to 14 percentage points! Figure 7.3(b) shows that about half of the weatherized houses not receiving a clean and tune changed in SSE within a -2 to 2 percentage point range. T-tests showed that SSE changes of the three groups were not significantly different from zero or each other at a 0.05 level of significance.

Table 7.2. Mean values of measured space-heating system performance parameters

(a) **ALL SYSTEMS (Forced Air, Hydronic, Steam, and Gravity)**

Type[1]	Number in sample	Adjusted steady-state efficiency			Smoke number		CO in flue gas (ppm)[2]	Age of heating system
		Pre	Post	Difference	Pre	Post		
WEATHERIZED	136							
No C&T	65	77.2	77.7	0.5	1.5	1.7	134	18
With C&T	71	75.0	75.8	0.8	2.2	2.1	73	24
CONTROL	72							
No C&T	72	75.0	76.6	1.5	2.2	1.7	89	20

(b) **FORCED AIR SYSTEMS**

Type[1]	Number in sample	Adjusted steady-state efficiency			Smoke number		CO in flue gas (ppm)[2]	Age of heating system
		Pre	Post	Difference	Pre	Post		
WEATHERIZED	65							
No C&T	32	77.7	77.6	-0.1	1.1	1.3	84	14
With C&T	33	75.9	76.3	0.4	2.1	2.2	80	20
CONTROL	16							
No C&T	16	76.5	77.7	1.2	1.2	0.9	64	10

(c) **HYDRONIC BOILER SYSTEMS**

Type[1]	Number in sample	Adjusted steady-state efficiency			Smoke number		CO in flue gas (ppm)[2]	Age of heating system
		Pre	Post	Difference	Pre	Post		
WEATHERIZED	45							
No C&T	18	79.1	78.9	-0.2	1.2	1.4	96	13
With C&T	27	76.0	76.9	0.9	2.3	2.0	56	22
CONTROL	44							
No C&T	44	74.9	76.6	1.7	2.4	1.7	105	21

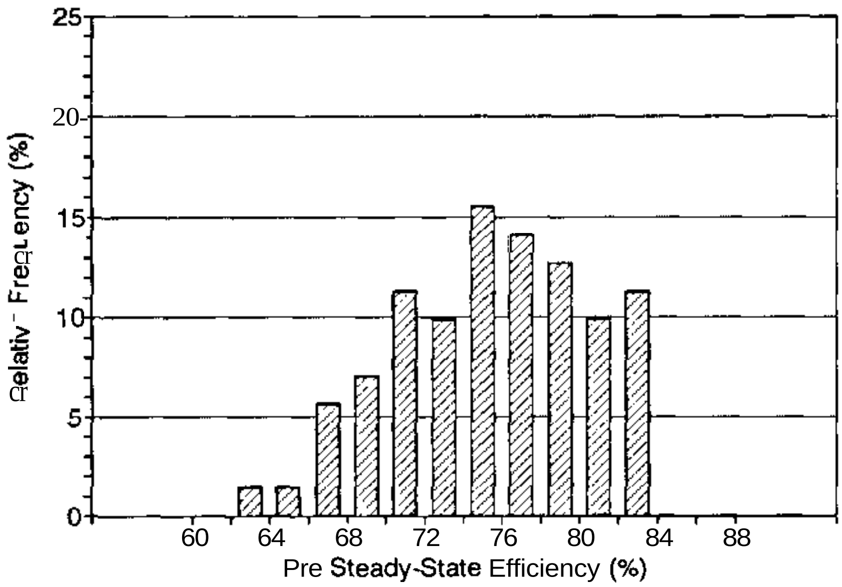
(d) **SYSTEMS WITH FLAME RETENTION BURNERS**

Type[1]	Number in sample	Adjusted steady-state efficiency			Smoke number		CO in flue gas (ppm)[2]	Age of heating system
		Pre	Post	Difference	Pre	Post		
WEATHERIZED	66							
No C&T	40	79.0	79.5	0.6	1.2	1.1	111	8
With C&T	26	77.2	78.4	1.2	1.7	1.5	63	20
CONTROL	34							
No C&T	34	76.7	78.8	2.0	1.7	1.2	67	13

[1]C&T — clean and tune-up.

[2]Measurements of carbon monoxide (CO) in the flue gas were only taken at the end of the heating season.

(a)



(b)

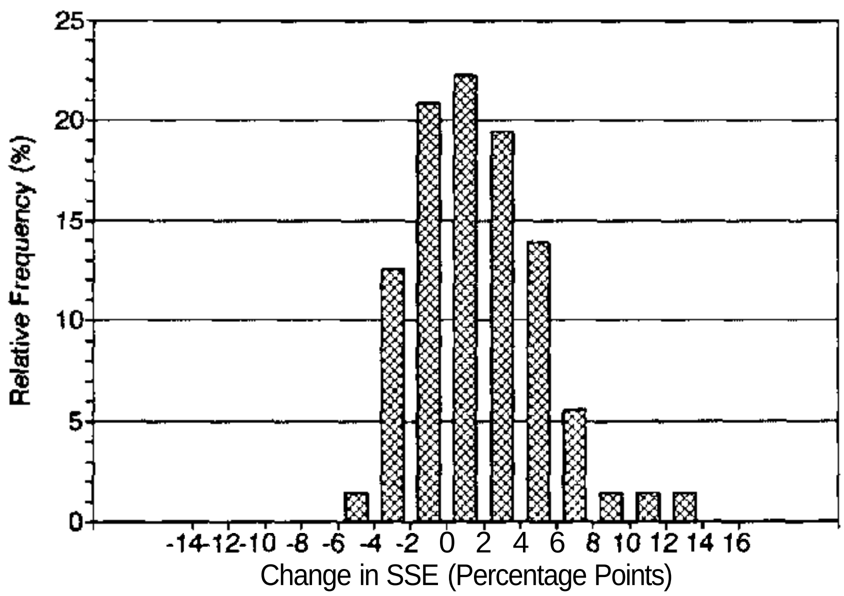
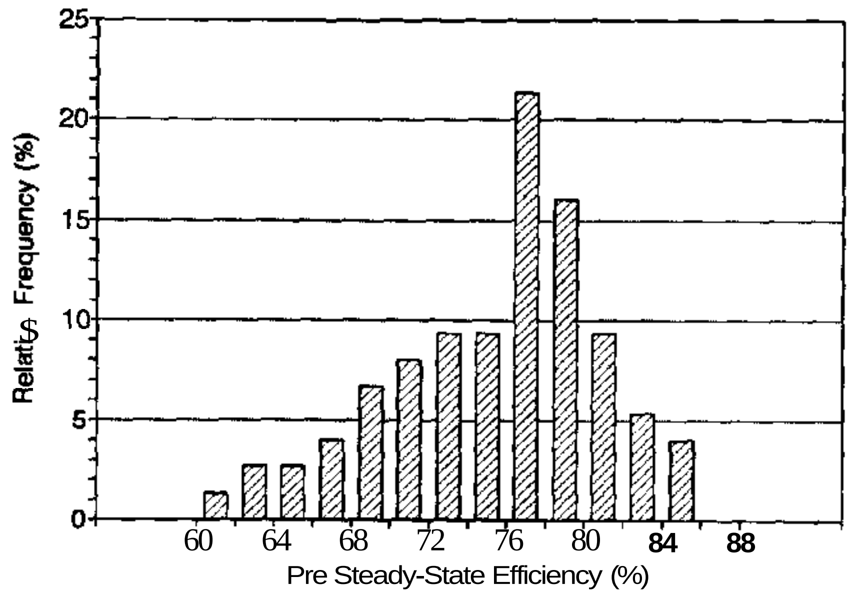


Fig. 7.1. Control houses (none of which received a clean and tune-up) — Distribution of pre-weatherization adjusted steady-state efficiency (a) and efficiency change (b). The mean pre-weatherization steady-state efficiency was 75% and the standard deviation was 53. The mean efficiency change was +1.5 percentage points and the standard deviation was 3.7.

(a)



(b)

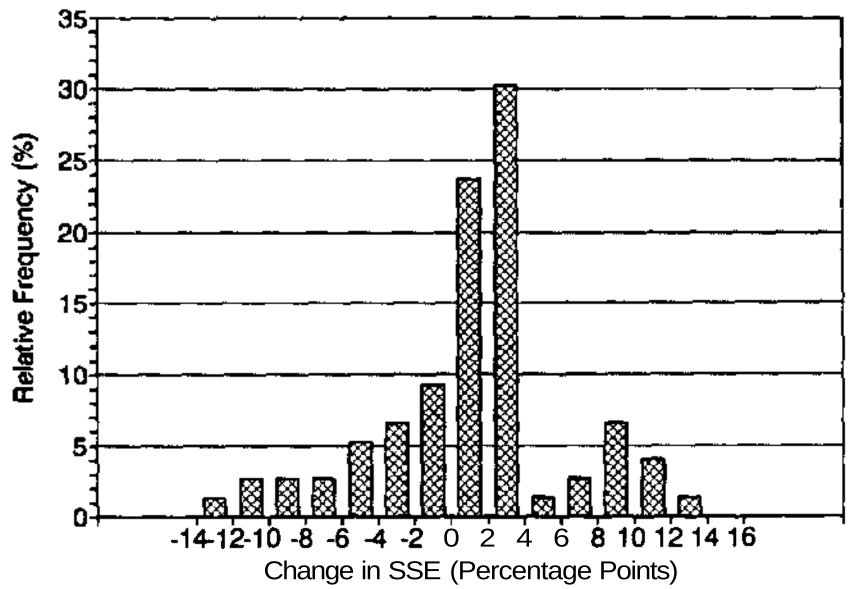
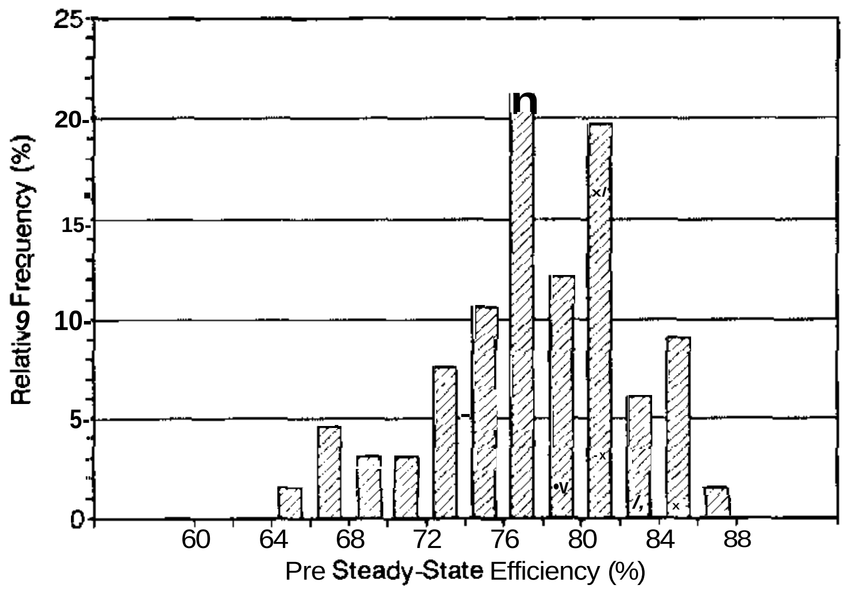


Fig. 7.2. Weatherized houses receiving a clean and tune-up — Distribution of pre-weatherization adjusted steady-state efficiency (a) and efficiency change (b). The mean pre-weatherization steady-state efficiency was 75.0% and the standard deviation was 6.0. The mean efficiency change was +0.8 percentage points and the standard deviation was 5.0.

(a)



(b)

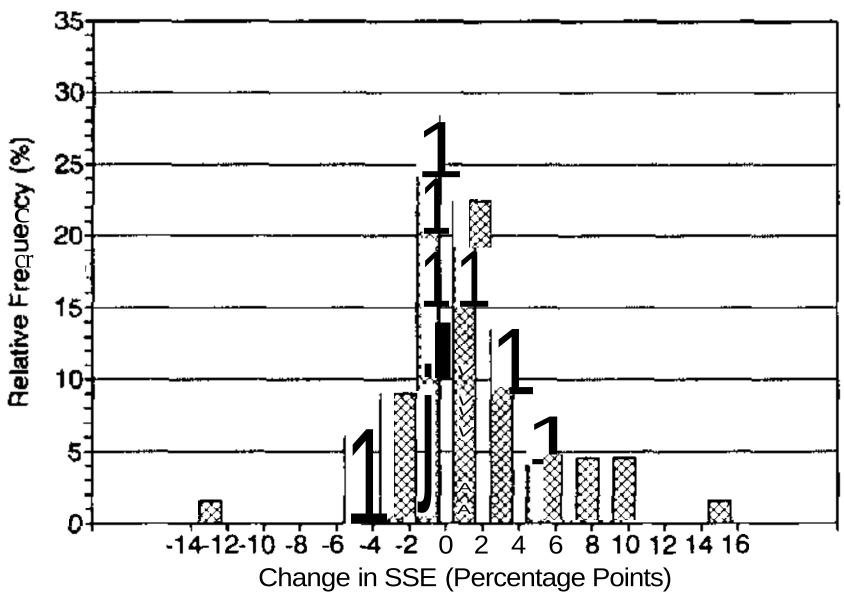


Fig. 73. Weatherized house not receiving a clean and tune-up — Distribution of **pre-weatherization** adjusted steady-state efficiency (a) and efficiency change **(b).** The mean pre-**weatherization steady-state efficiency** was **77.2%** and the standard deviation was 6.1. The mean efficiency change was **+0.5** percentage points and the standard deviation was 4.3.

Tables 7.2(b) and 7.2(c) contain data for the two most common subsets of Table 7.2(a): forced-air furnaces and hydronic boilers, respectively (gravity furnaces and steam boilers are remaining systems that are not included). These tables show little difference in performance improvements from clean and tune-up services between forced-air furnaces and hydronic boilers.

Figures 7.4 - 7.6 offer more insight into the SSE measurements and the effectiveness of clean and tune-up services. These figures are plots of pre-weatherization SSE versus change in SSE for control houses, weatherized houses with clean and tune-up, and weatherized houses without clean and tune-up, respectively. These figures all show a general trend (the R^2 values were low at about 0.2): the measured change in SSE was greater for sites with lower SSEs at the beginning of the heating season. All three plots show that the change in SSE was usually negligible or negative if the pre-weatherization SSE was greater than about 77%, whether or not a clean and tune-up had been performed. Similarly, about a 3 percentage point improvement was obtained at sites with a pre-weatherization SSE of 70%, whether a clean and tune-up was performed or not. Ternes et al. (1991) found the same type of behavior in a study dealing with gas space-heating systems in New York state.

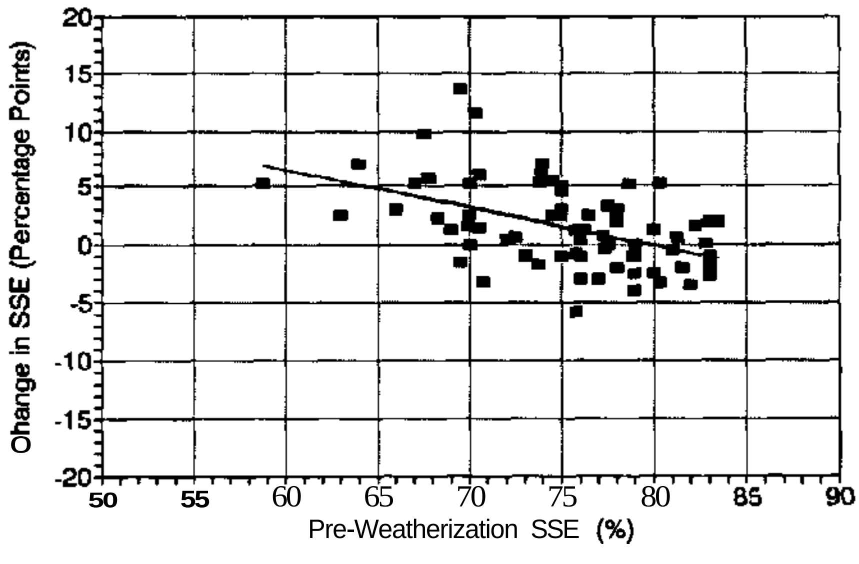


Fig. 7.4. Control houses — Comparison of the change in adjusted steady-state efficiency to the pre-weatherization efficiency.

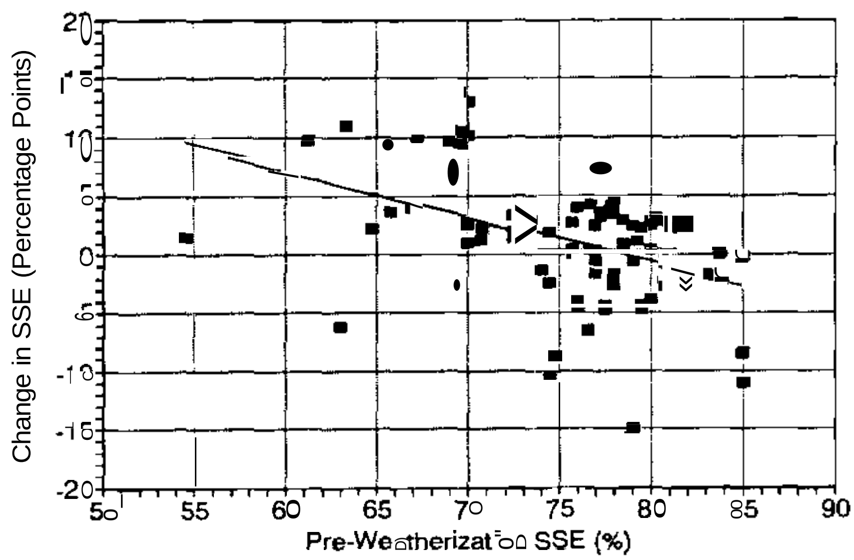


Fig. 7.5. Weatherized houses receiving a clean and tune-up — Comparison of the change in adjusted steady-state efficiency to the pre-weatherization efficiency.

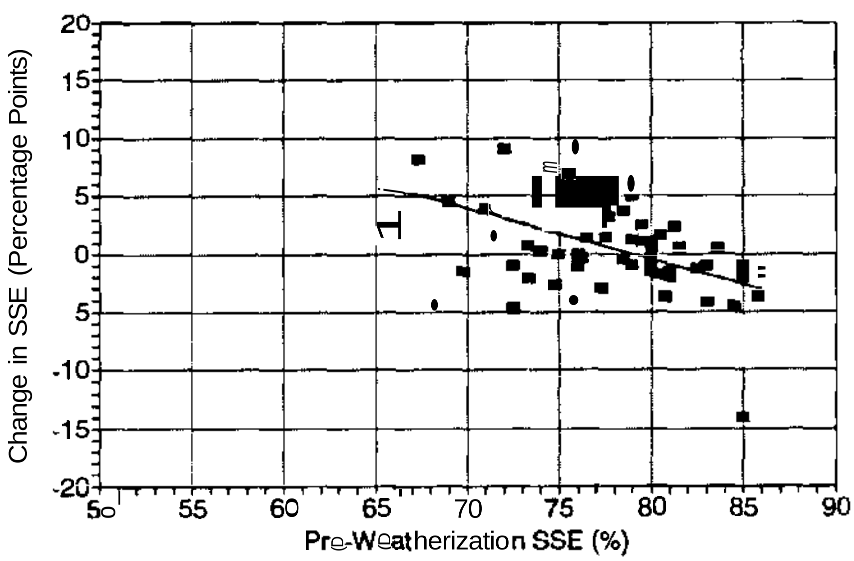


Fig. 7.6. Weatherized houses not receiving a clean and tune-up — Comparison of the change in adjusted steady-state efficiency to the pre-weatherization efficiency.

The results for the weatherized houses receiving a clean and tune-up, interpreted by themselves, indicate that clean and tune-ups should be performed only when pre-weatherization efficiencies are less than 70%; clean and tune-ups consistently increased steady-state efficiencies only when pre-weatherization efficiencies were less than 70%. The scattered results and low average increases in SSE obtained from clean and tune-ups performed at houses with higher pre-weatherization efficiencies suggest that clean and tune-ups are not long lasting (our SSE measurements were made at the end of the heating season), clean and tune-ups are not done properly, or systems in these houses are already operating at their maximum efficiency. The results from the control houses and weatherized houses not receiving a clean and tune-up indicate that clean and tune-ups were not the cause for efficiency increases. This suggests that clean and tune-ups should perhaps not be performed with expectations of improved SSEs.

The current SSE must be measured in order to decide whether or not a system should be cleaned and tuned. The cost of the clean and tune-up is rather insignificant once a burner technician is on site and has made the initial SSE measurement. An agency auditor, however, could measure the SSE as part of an audit and avoid the cost of having a burner technician make a special trip to decide whether or not to conduct a clean and tune-up. Indeed, this situation occurred in many of the agencies in our sample. It should be remembered that, in addition to increasing the SSE, a clean and tune-up might improve the seasonal performance of an oil system and assure that a system is operating properly, reliably, and safely.

Smoke is a primary sign of incomplete combustion and fouling. Smoke numbers averaged between 1.5 and 2.2 in the three groups of houses analyzed before weatherization (Table 7.2a). Average smoke numbers improved little in the weatherized houses receiving a clean and tune-up, and actually improved the most in the control houses.

The Alliance to Save Energy's goals for performance following a clean and tune-up were generally not obtained. Referring to the goal of 80% SSE with a flue gas containing $\leq$ 7% oxygen and a smoke number $\leq$ 1, 3 of the 71 houses (4%) receiving a clean and tune-up service met the goal. Ignoring the $\leq$ 7% oxygen requirement, 12 of the 71 houses (17%) receiving a clean and tune-up service met the goal. However, the average pre-weatherization SSE value for this group of 12 houses was 80.3%, already above the 80% goal. If the desired smoke number requirement of ≤ 1 is also ignored, then 21 of the 71 homes (30%) had a final SSE of 80% or greater. However, 27 of 65 (42%) of the weatherized houses not receiving clean and tune-ups had a final SSE of 80% or greater.

Table 7.2(d) contains data for another subset of Table 7.2(a), systems with flame-retention burners. Not shown in Table 7.2 (but also of interest) is a subset consisting of systems without flame-retention burners. Systems with flame-retention burners were more efficient than systems without flame-retention burners. Average pre-weatherization SSEs were 77.2% vs 74.1% for weatherized houses receiving clean and tune-ups and 79.0% vs 73.9% for weatherized houses not receiving clean and tune-ups. These data confirm that a flame retention burner should be seriously evaluated on a cost effectiveness basis as a retrofit option compared to a conventional burner when a burner replacement is needed. All 20 new systems installed in this study contained flame-retention burners and all 11 new burners installed were also of the flame retention type. The changes in SSE for systems with flame-retention burners after a clean and tune-up were small.

73 HEATING SYSTEM SAFETY INSPECTIONS

The inspection performed on each heating system at the conclusion of each heating season was mostly visual, but some measurements were taken, such as time for spillage to stop, draft buildup time, and carbon monoxide measurements.

73.1 Visual Inspection

The visual inspection was mostly safety oriented. It consisted of checking the heating system externally, the distribution system, the fuel supply system, the chimney or venting system, the heating system internally, the operational peripherals of the heating system, and the domestic water-heating system. Table 73 contains the results of the inspections in a format where a "Yes" answer represents a passing evaluation and a "No" answer represents an unacceptable evaluation.

Figure 7.7 shows that, overall, the systems were relatively safe. This figure quantifies the results of the overall system evaluation inspections in a simple manner. The "percent passing

Table 7.3. Comparison of safety related **observations** between groups

Description of safety item	Weatherized homes			Control homes		
	Yes	No	Percent	Yes	No	Percent
HVAC EXTERNAL						
Vent Damper Present	61	153	28.5	27	77	26.0
Wiring Secure	196	17	92.0	93	11	89.4
Electrical Cutoff Switch Present	201	11	94.8	95	8	92.2
Fan Limit Switch Present	98	1	99.0	26	0	100.0
No Combustible Material Near Flue	166	42	79.8	85	14	85.9
No Asbestos Present on HVAC system	172	38	81.9	85	20	81.0
DISTRIBUTION SYSTEM						
Intentionally Heated Distribution System Structurally OK	35	4	89.7	22	3	88.0
Unintentionally Heated Distribution System Structurally OK	145	2	98.6	67	5	93.1
Not Heated Distribution System Structurally OK	10	2	83.3	0	1	0.0
No Asbestos on Distribution System	152	38	80.0	73	18	80.2
Return System Present	98	2	98.0	29	3	90.6
Return Air Filter Clean	48	40	54.5	12	12	50.0
FUEL LEAKS						
No Leaks in Fuel-Oil Supply Line	188	13	93.5	89	5	94.7
CHIMNEY SYSTEM						
Chimney Structurally Sound	191	12	94.1	93	5	94.9
Chimney Extends 2 Ft Above Roof	182	16	91.9	88	6	93.6
Chimney Top Clearance 10 Ft	173	17	91.1	85	6	93.4
No Chimney Leaks	175	19	90-2	81	12	87.1
No Thick Debris in Chimney	161	19	89.4	75	13	85.2
Flue Liner Present in Chimney	113	66	63.1	56	29	65.9
Barometric Damper Present	192	17	91.9	86	15	85.1
Barometric Damper Installed OK	171	18	90.5	75	10	88.2
HVAC INTERNALS						
No Visual Heat Exchanger Cracks	124	4	96.9	48	1	98.0
No Rue Gas Odor in House	133	11	924	57	5	91.9
HVAC PERIPHERALS						
Circulating Fan OK	115	2	983	35	0	100.0
Zone Valves OK	23	3	88.5	24	2	9Z3
No Furnace Leaks	87	13	87,0	54	5	91.5
Barometric Damper Works	146	18	89.0	62	9	87.3
Thermostat Works (On/Off)	178	4	97.0	92	0	100.0
DOMESTIC WATER-HEATING SYSTEM						
No Combustible Material Near Flue	61	9	87.1	24	4	85.7
Pressure Relief Valve Present	185	7	96.4	87	2	97.8

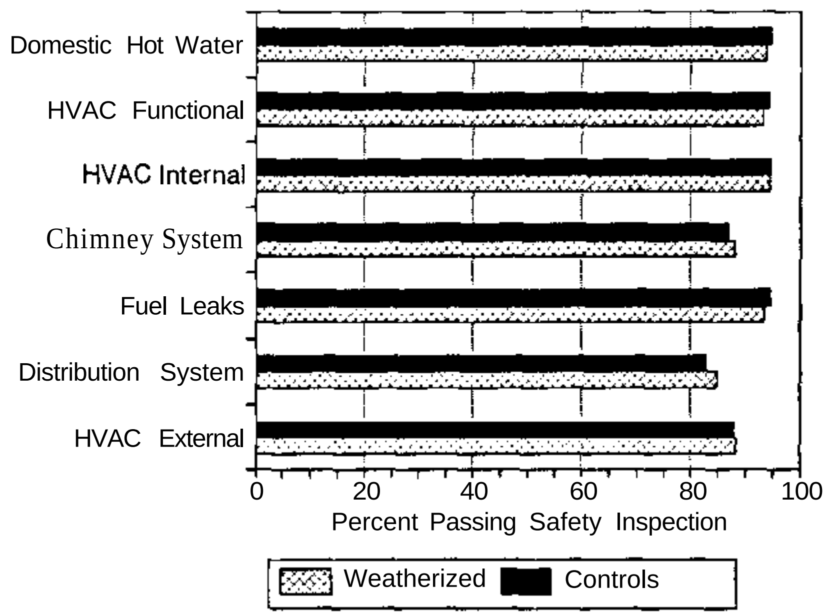


Fig. 7.7. Safety inspection results for the control and weatherized houses showing the percent of passing evaluations for each safety area covered by the inspection.

inspection" bars on the plot for both weatherized and control houses were calculated by summing the favorable responses for each of the seven areas covered by the inspection and dividing by the total number of responses (the total number of yes and no answers). The presence of a vent damper on the flue, which is predominately an energy-related item, was not included in Fig. 7.7. Dirty return air filters and the presence of asbestos (very little of it was friable) caused the distribution system area to have the lowest degree of safety while asbestos (again, very little friable) and the presence of combustible material near a flue caused the HVAC external area to have some safety deficiencies. These items were either not of immediate concern (in the case of asbestos) or more of a maintenance problem (in the case of dirty filters or combustible material near a flue). Thus, the lower results for these areas are not a major concern. The main area of concern was in the chimney system, where a lack of flue liners in chimneys appears to be more of a major problem. Flue liners can prevent potential fires and exhaust gas leakage problems, but are rather difficult and expensive to install properly.

Visual inspections showed little average difference overall in safety between control and weatherized houses. About 18% of the individual houses from each group passed all of the safety inspection items. However, the severity of problems can differ between groups. If a difference of five percentage points or greater between control and weatherized groups in any of the items in Table 7.3 is arbitrarily chosen to be significant, then one item in the HVAC external area (combustible material near the flue), three items in the distribution system area (distribution system structural problems in unintentionally heated and non-heated areas, and no return system present), and one item in the chimney system area (presence of a barometric damper) were the main areas where weatherized and control houses differed. All differences favored weatherized houses, indicating that the weatherized houses were safer than the controls.

732 Heating System Limit Settings

The safety inspection included checking the settings of fan operating (high and low limit) and cutout (maximum operating temperature limit) switches. Proper setting of these limit switches affects seasonal efficiency, as improper settings will result in lost heat going up the flue.

Results for forced-air heating systems were based on data from 28 control and 102 weatherized houses. All forced-air heating systems in both groups had fan operating and cutout switches present. Average switch settings for control and weatherized forced-air heating systems were essentially the same. Fan-on (upper-limit) settings for control and weatherized houses both averaged 137°F, while fan-off (lower-limit) settings averaged 99°F for control houses and 100°F for weatherized houses. Cutout switch settings averaged 197°F for control houses and 196°F for weatherized houses. Two control houses (7%) and two weatherized houses (2%) were noted as having potentially dangerous fan-on settings of 190°F to 200°F. The settings for these four houses likely decreased the seasonal efficiency of the units considerably and posed the potential problem of the systems not operating properly, since their settings were very close to the furnace cutoff settings.

Results for hydronic boilers were based on data from 52 control houses and 67 weatherized houses. The average operating temperatures for hydronic boilers was 164°F for both control and weatherized houses. Cutoff temperatures for control houses averaged 189°F, while weatherized houses averaged 190° F. Two (4%) hydronic boilers in control houses had operating temperatures of 200° F, while three (4%) boilers in weatherized houses were operating above 195°F. These five systems were operating at too-high a temperature for maximum efficiency and safety.

7.3.3 Spillage

Another potential safety problem can occur if a fossil-fueled heating system does not establish a proper draft after a short time because flue gas spills back into the furnace room. Besides containing soot and foul smelling gases, flue gases can also contain carbon monoxide, which can be deadly. Therefore, it is necessary to establish a draft in a fossil-fueled heating system as soon as possible. Table 7.4 contains measured fluedraft data for weatherized and control houses.

The average time for all heating systems to establish a draft was about 9 seconds. However, two control houses and one weatherized house took over 60 seconds to establish a draft, with one of each type requiring 180 seconds. Spillage appeared to stop at a pressure differential of about 0.01 in. of water (inside to outside) on a draft gauge. Forced-air furnaces were slower than hydronic boilers in the time necessary to stop spillage. On average, hydronic boilers established a draft in about 5 seconds, while forced-air furnaces took about 14 seconds to establish a draft.

Figure 7.8 shows the average fluedraft pressure as a function of time for all forced-air furnaces and all hydronic boilers. Stronger drafts were established by hydronic boilers for the first three minutes, at which time data collection was stopped. Drafts of 0.02 to 0.06 inches H_2O are usually recommended to ensure that there is continuous negative pressure in the combustion system without creating excess draft which will decrease efficiency (Bacharach).

73.4 Carbon Monoxide Measurements

Another part of the safety inspection involved taking measurements of carbon monoxide 5 ft from furnaces, in living rooms, in kitchens, and from hot-air registers. Carbon monoxide is a

Table 7.4. Draft pressures (in. of water)

CONTROL HOUSES

Type of heating system	Size of sample	Time from ignition (seconds)					Time to stop spillage (seconds)
		0	30	60	120	180	
Forced air	22	0.002	0.020	0.022	0.023	0.021	16.7
Gravity	3	0.007	0.037	0.040	0.043	0.045	1.3
Steam boiler	11	0.008	0.030	0.037	0.036	0.037	15.0
Hydronic boiler	46	0.009	0.031	0.030	0.032	0.033	4.1
Unspecified	3	0.002	0.020	0.033	0.035	0.035	3.0
All combined	85	0.007	0.028	0.029	0.031	0.031	8.1

WEATHERIZED HOUSES

Type of heating system	Size of sample	Time from ignition (seconds)					Time to stop spillage (seconds)
		0	30	60	120	180	
Forced air	73	0.003	0.019	0.020	0.022	0.022	12.5
Gravity	3	0.002	0.012	0.016	0.015	0.018	4.0
Steam boiler	21	0.004	0.030	0.032	0.035	0.039	6.8
Hydronic boiler	57	0.006	0.027	0.030	0.028	0.029	6.1
Unspecified	4	0.008	0.025	0.030	0.030	0.039	0.5
All combined	158	0.004	0.024	0.025	0.026	0.027	9.2

dangerous indoor air pollutant because it is colorless, odorless, and readily absorbed by blood in the lungs. Carbon monoxide can cause headaches, nausea, and death. Carbon monoxide is produced in a home in combustion processes occurring in heating systems, fossil-fuel cooking, and smoking.

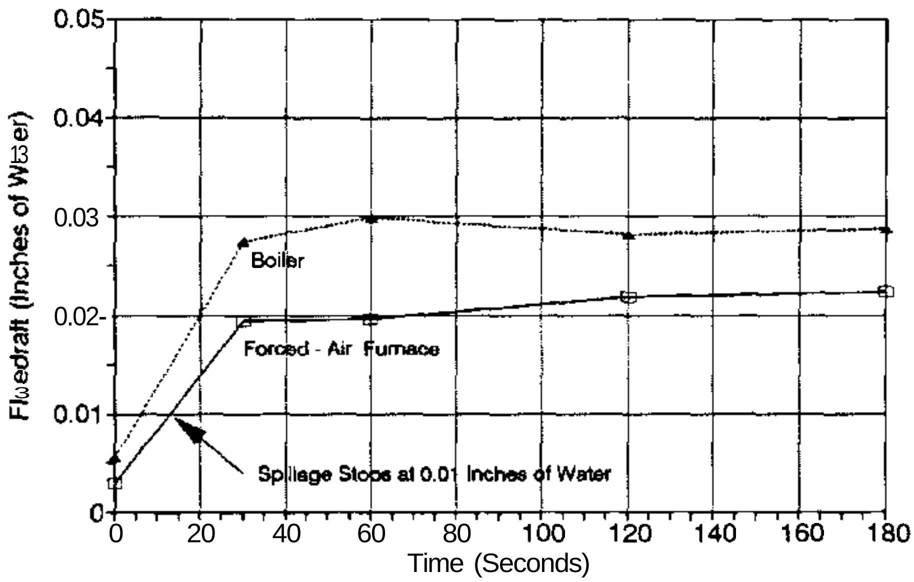


Fig. 7.8. Comparison of **the** average measured draft to time for forced-air furnaces and **hydronic boilers.**

Standards and guidelines for exposure to carbon monoxide are summarized in Table 7.5 (Bacharach). The Office of Occupational Safety and Health Administration (OSHA) mandates a maximum limit of 35 ppm for an 8-hour period. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 1989) recommends a maximum 8-hour carbon monoxide concentration of 9 ppm in a living space. Examination of the available guidelines indicate that actions such as better venting of an area or removing/abating the carbon monoxide source should be taken as soon as possible if a level of 10 ppm or more is present, especially for long-term exposure.

Table 7.6 contains a summary of the carbon monoxide measurements. No houses had an appreciable carbon monoxide problem (carbon monoxide level ≥ 10 ppm) at the end of the heating season. Differences between control and weatherized houses were minor.

Table 7.5. Standards and guidelines for exposure to carbon monoxide

Concentration of carbon monoxide 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 hour, 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.

Reference: Bacharach

Table 7.6. Results of carbon monoxide measurements

Measured carbon monoxide concentration (ppm)	Total number of houses	
	Weatherized	Control
5 ft from space-heating system:		
5 - 10ppm	18	7
10 - 15 ppm	2	2
15 - 20 ppm	2	0
>20 ppm	0	0
Living room:		
5 - 10 ppm	3	0
> 10 ppm	0	0
Kitchen:		
5 - 10 ppm	1	3
>10 ppm	0	0
Hot air register:		
5 - 10 ppm	1	0
> 10 ppm	0	0

8. OCCUPANT FEEDBACK

An adult occupant of each household was interviewed at the end of each heating season to obtain feedback as to how the occupant(s) felt about the weatherization process and also to gather information about occupant behavior and status. Sample questionnaires used for the control and weatherized house are contained in Appendix B. Some of the input from these questionnaires has already been presented in Sect. 3, which dealt with occupant and house characteristics.

Table K.1 contains responses from the occupants. The reader should keep in mind when reading this section that the responses are based on the occupant's perception of a question or condition, and may or may not agree with what actually occurred or was present.

8.1 INDOOR TEMPERATURES

The average indoor temperature levels reported by the occupants when a house was occupied was 69°F. The average measured temperature for all houses during both periods was about 70°F (see Table 5.3). Therefore, measured and perceived temperatures were not too far apart, with measured temperatures being about a degree or so higher than perceived temperatures.

Of the 198 responses from weatherized houses, 106 of 198 (53%) said they regularly changed the temperature in their house during the day in the pre-weatherization period, and 100 of 195 (51%) said they changed it during the post-weatherization period. Control house responses were similar: 54 of 96 (56%) said the temperature was changed during the day in the pre-weatherization period, and 53 of 96 (55%) said the temperature was changed in the post-weatherization period. Setbacks of temperatures reported by the occupants when a house was unoccupied or when the occupants were sleeping averaged about 5°F.

8.2 NO-HEAT PROBLEMS

Figure 8.1 depicts the number of no-heat problems for each period. The figure shows a definite decline in no-heat problems from pre- to post-weatherization periods, except for control house utility cutoffs. About 16% of control and weatherized households had problems at one or more times in the pre-weatherization period with not being able to operate their heating systems because of mechanical problems. About 13% of the households did not have any fuel oil at some time during the pre-weatherization period. Mechanical problems decreased during the post-weatherization period (12% of control and weatherized households had problems), while running out of fuel oil decreased to 11% for weatherized houses and 8% for control houses. A utility stopped service because of failure to pay bills in about 5% of all houses during each period.

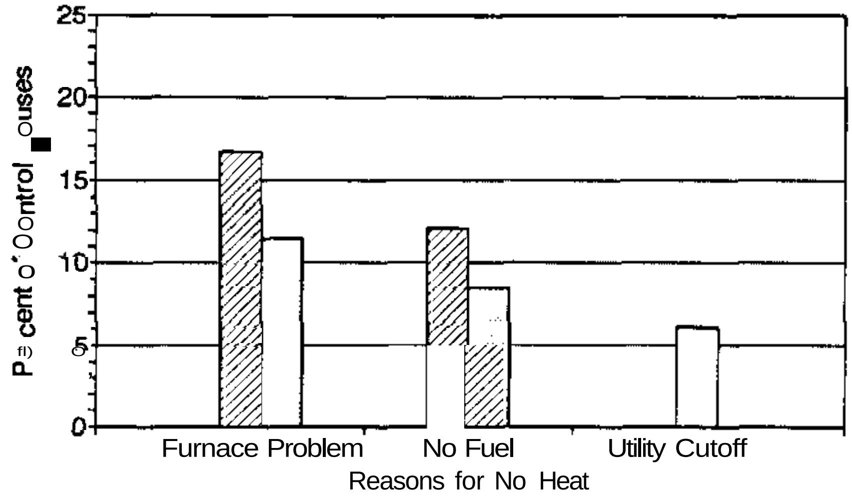
The total duration of no-heat days, obtained by summing the products of occurrences times duration, decreased substantially (by 84%) for weatherized houses, from 196 days for the pre-weatherization period to 31 days for the post-weatherization period. Control houses went from 57 to 26 total no-heat days (a 54% decrease) during the same period.

83 OTHER INDOOR CONDITIONS

Occupants were asked to rate various indoor conditions (comfort, draftiness, health, and safety,) and heating affordability on a scale of 1 to 7, where 1 was poor and 7 was very good. Figure 8.2 summarizes the results. As expected, the control house responses to each category did not change significantly from the pre-weatherization period to the post-weatherization period. The weatherized house perceptions all improved after weatherization. The average value of the control house responses were higher than the weatherized house responses for all categories in the pre-weatherization period, which could illustrate some bias to the weatherized group responses — they were thankful for the weatherization work and wanted to make us feel good. Nevertheless, weatherized house responses were higher than control house responses in the post-weatherization period, indicating improved satisfaction from weatherization.

The areas of health and safety were the only areas both groups thought were acceptable before weatherization, although weatherized houses still underwent about a one grade point

(a)



(b)

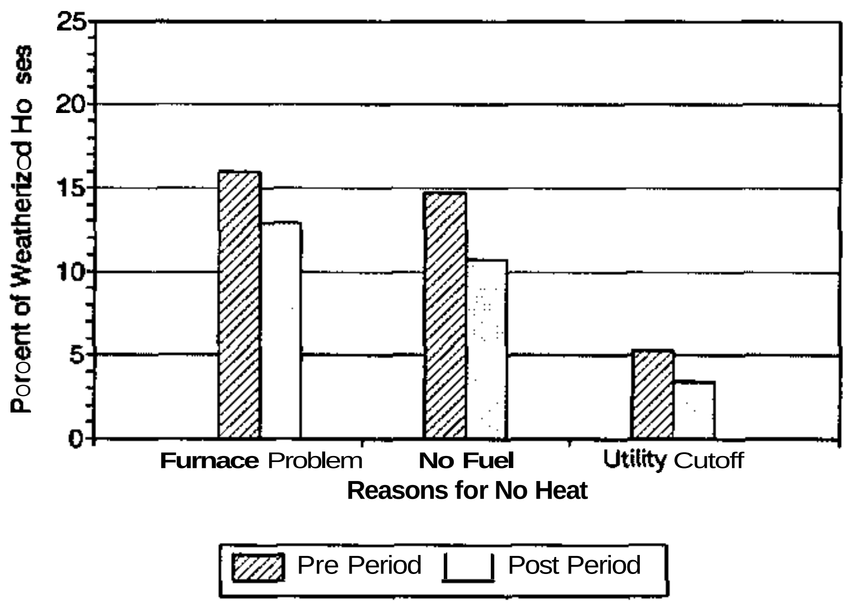


Fig. 8.1. Percentage of control (a) and weatherized (b) houses experiencing different types of no-heat problems before and after weatherization.

increase after weatherization. Most people thought their homes were expensive to heat in the pre-weatherization period; occupants of weatherized houses felt that costs were much more reasonable after weatherization (scores increased two grade points to become quite acceptable after weatherization). Comfort, and especially draftiness, were also improved after weatherization according to weatherized home responses.

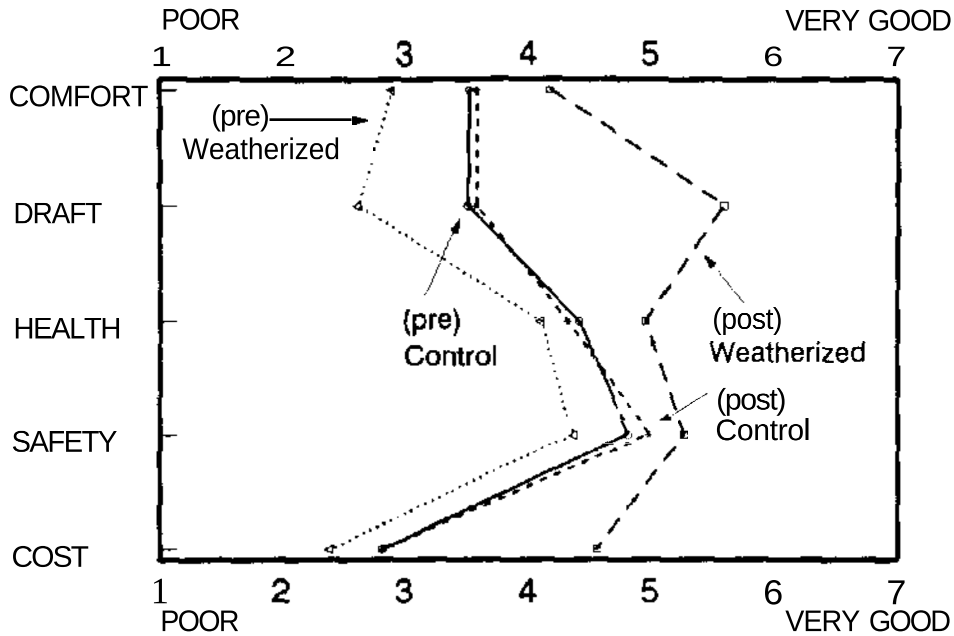


Fig. 8.2. Average rating provided by the occupants on indoor conditions and heating affordability before and after weatherization. A scale of 1 to 7 was used, where 1 was poor and 7 was very good.

Figures K.1-5 are distribution plots showing how the occupants rated conditions in their houses in pre- and post-weatherization periods. These plots indicate that weatherization definitely increased the general comfort and heating affordability of a house. Table G.5 adds validity to this statement, as the number of weatherized houses using any auxiliary heat decreased by 10 percentage points (from 57% to 47%) after weatherization, while the number of control houses only decreased by 3 percentage points (from 53% to 50%).

9. PROGRAM COSTS

Information on program costs to weatherize 218 of the 222 weatherized houses monitored during the study was collected from the local weatherization agencies using the Fuel-Oil Study Weatherization Information Survey provided in Appendix C. Estimates of average costs to weatherize single-family fuel-oil heated houses for the northeast region as a whole are presented in this section. All analyses performed in this section were weighted to be consistent with the regional fuel-oil savings calculated in Sect. 5.

Total program costs were divided into installation costs and overhead and management costs (see Table 9.1) to allow cost-effective analyses to be performed from installation, program, and societal perspectives in Sect. 10. Installation costs included the actual costs for (1) materials installed in the houses and (2) labor required to install the materials and perform other energy-efficiency-improvement work on the house.[21] Overhead and management costs include all other costs associated with providing the weatherizatmon services. These expenses were divided into installation-related overhead and program management categories. Installation-related overhead expenses for contractors were estimated to be 15% of total billed cost. Installation labor costs for contractors were then calculated by subtracting material and overhead costs from the total billed cost. State expenditures for implementation of the Program were not included in the overhead and management costs presented in this section.

Previous researchers have had difficulty interpreting cost information as maintained by the local weatherization agencies because of the variety of funding sources, recordkeeping systems, cost categories, cost formats, and definitions. We chose and defined our cost categories (Table 9.1) in order to collect consistent and accurate information from the local weatherization agencies. These categories drew a logical distinction between installation costs that occurred on-site and noninstallation, or overhead and management, costs.

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[21] Although travel time is often considered an installation-related overhead item, costs for time spent traveling to the job site were included as installation labor costs because of limitations in the collected expenditure information.

Table 9.1. Cost categories used in this study

Installation Costs:
Labor
Material
Overhead and Management Costs:
Installation-Related Overhead:
Vehicles
Equipment
Field Supervision
Insurance
Training
Contractor profit
Program Management:
Intake and eligibility
Audits and assessments
Final Inspections
Contractor and crew management
Program administration
Program evaluation

Our cost categories were fairly consistent with those that might be used by a typical local weatherization agency to report total program costs:

- labor,
- materials,
- administration,
- training and technical assistance,
- program support, and
- liability insurance.

Our definition of material cost is the same as a typical weatherization agency. The last four categories listed for a typical agency are included under our definition of overhead and program management costs. The major difference between our cost categories and those for a typical agency is the costs included in the labor category. Our labor costs did not include provisions for

Table 9.2. Average costs

Cost type	Program years 1991 and 1992			Program year 1991			Program year 1992		
	In-house	Contractor	Total	In-house	Contractor	Total	In-house	Contractor	Total
Installation:									
Material	245	500	745	160	619	779	330	380	710
Labor	194	253	447	141	315	456	248	191	439
Total	439	753	1192	301	934	1235	578	571	1149
Overhead and management			627			707			562
Total			1819			1942			1711

performing tasks other than the installation of measures; audit and inspection functions, for example, were not included in our definition of labor costs although they might be present in the labor costs reported by a local weatherization agency.

9.1 INSTALLATION COSTS

Table 9.2 shows that the **regionwide** mean value for installation costs was **$1192** for program years 1991 and 1992 combined. Material costs for these years were $745 for an average house weatherized, and labor costs were $447. Installation costs and their breakdown into material and labor costs were consistent for each program year. Expenditures by in-house crews and contractors were significantly different in program year 1991 but the same in program year 1992, indicating a more predominant use of contractors in the first year.

Installation costs for an individual house differed substantially from the average value of $1192. The distribution of installation costs is shown in Fig. 9.1. Installation expenditures were between $600 and $1500 in 58% of the houses. Installation expenditures were less than $300 on 3% of the houses, and more than $2400 on 6%, The minimum expenditure was $15 and the maximum was $4383, House costs may appear higher than DOE program allowances because other sources of funds could also have been used (see Sect. 9.3).

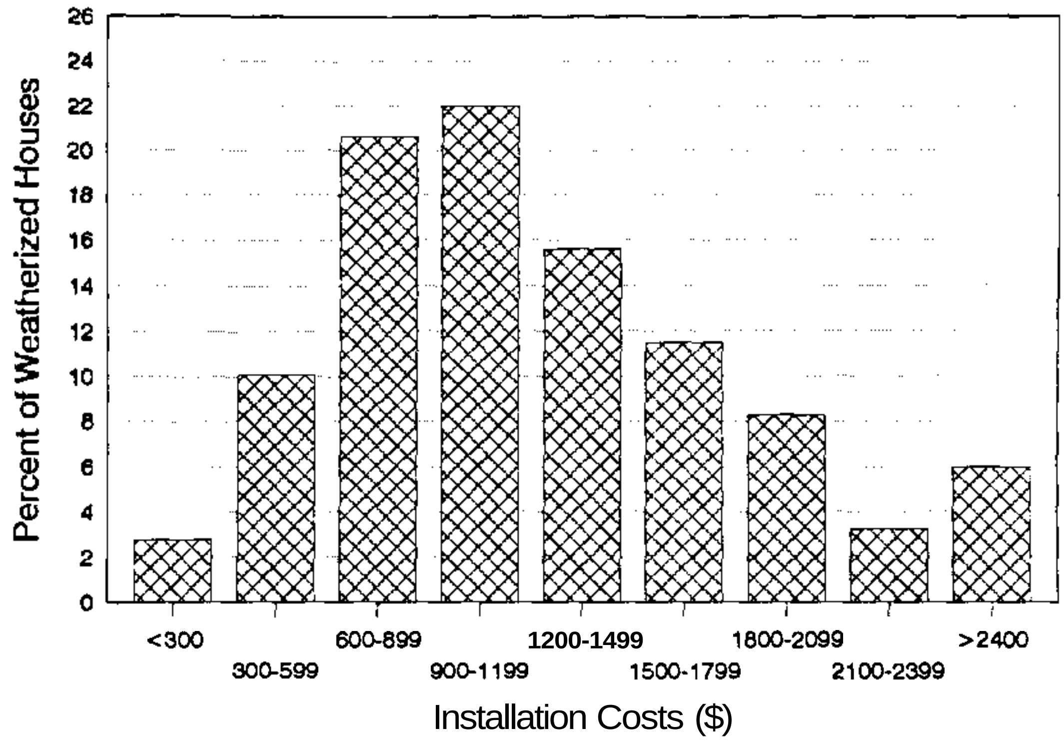

Fig. 9.1. Distribution of installation costs. Thc sample mean was $1253 and the sample standard deviation was 706.

Contractor expenditures accounted for 63% of the average installation costs. Additionally, houses in which weatherization work was performed by just in-house crews had average expenditures $350 lower than houses in which only contractors were involved (Fig. 9.2). As previously stated in Sect. 4.2, weatherization activity in the house was performed completely by in-house crews in 27% of the houses, activity was performed completely by contractors in 55% of the houses, and both in-house crews and contractors performed the work in the remaining houses. In houses in which both crew types were involved, about 75% of the expenditures were by the in-house crew. Higher costs associated with contractors were likely due to differences in the measures performed by contractors, and do not imply that contractors were inherently more expensive than in-house crews. Contractors performed high-cost measures such as space-heating system measures and standard wall insulation more frequently than in-house crews.

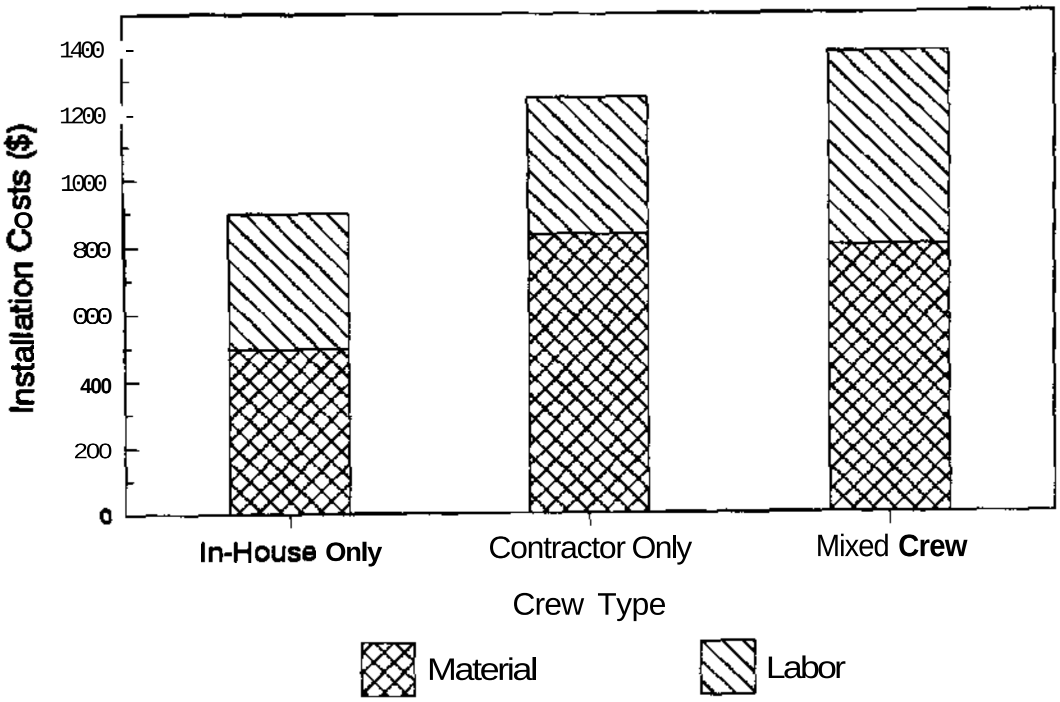

Fig. 9.2. Installation costs for houses subdivided by type of crew performing the weatherizations.

Figure 9.3 shows a cost breakdown of materials for an average weatherized house.[22] Insulation materials accounted for a third of the total material expenditure. Material costs for air leakage, window and door, and space-heating system measures were approximately equal (12% - 18%). Expenditures on domestic water-heating system materials were rather small, being only *2%* of the total material costs.

[22]Material cost information was obtained directly from the local weatherization agencies and was based upon their records. Some inconsistencies associated with the breakdown of material costs into the respective cost categories remained following close examination of the data, comparison of measures installed to cost allocations, and discussions with the agencies. Total material costs were accurate. Total insulation and space-heating system material costs were also correct, but were not always properly divided into subcategories. The main difficulty was that material costs for air leakage measures, window and door measures, and other energy-efficiency work were often intermixed because of the ambiguity in identifying the correct category for some work.

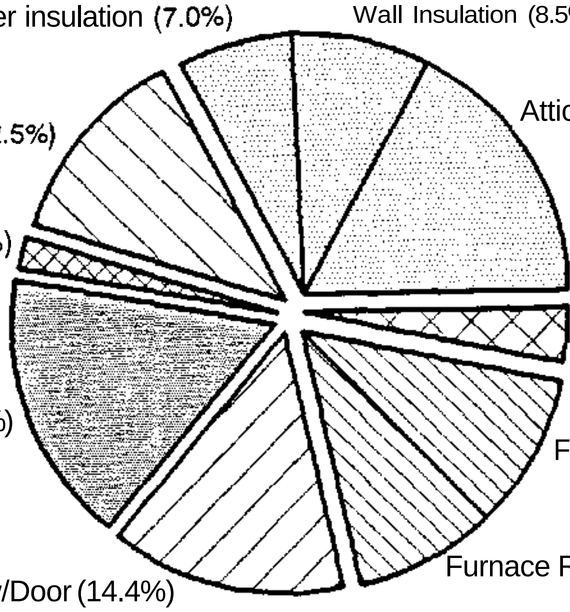

Fig- 93. Material cost breakdown for an average weatherized house (average material cost for a house was $710).

9.2 OVERHEAD AND MANAGEMENT COSTS

We estimated an overage overhead and management cost of $627 per house to weatherize a single-family fuel-oil heated house in the northeast region. This cost included $438 for program management, $59 for in-house crew installation-related overhead, and $130 for contractor installation-related overhead. We estimated an average overhead and management cost of $557 per house for houses in which only in-house crews performed weatherization work, and $651 for houses in which contractors performed work either alone or with in-house crews. As shown in Table 9.2, there was a $145 difference in the overhead and management cost estimated for the two program years separately.

Considerable judgement was required to perform the analysis of the overhead and management costs; consequently, the listed values should be interpreted as approximate values that best indicate order of magnitude, especially in considering the breakdown into installation-related overhead and program management costs and comparisons by crew type and program years.[23] In performing the analysis, two local weatherization agencies were dropped because they did not report program management costs[24], and another two were dropped because their reported program management costs were unrealistically low ($62) or high ($1142). Program management costs for agencies using only contractors to perform the weatherization work were likely more accurate than when in-house crews were used because costs paid to the contractors were usually easily obtainable. Average program management costs were probably less than reported above, and average in-house crew installation-related costs were probably higher, for the following reasons:

- In-house crew installation-related overhead expenses were not reported for five agencies using in-house crews. We assumed these costs were included with program management costs.

- In-house crew installation-related overhead costs were set to zero for two agencies. For these two agencies, the overhead costs and program management costs were both very high. The overhead costs were set to zero because we assumed the overhead costs were already included with the reported program management costs.

93 SOURCES OF FUNDING

Local weatherization agencies rely on a number of different funding sources to perform weatherizations. These include the DOE Weatherization Assistance Program, Petroleum Violation Escrow (PVE) funds, the Low-Income Heating Energy Assistance Program (LIHEAP) operated by the Department of Health and Human Services, and various foundation, state, and utility programs. Although most funds followed Program rules, funds with fewer restrictions could also have been used. For single-family fuel-oil heated houses weatherized in the northeast region,

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[23]In order to perform a rigorous study of overhead and management costs, we believe that an "audit" team would need to work directly and on-site with local weatherization agencies to collect the necessary cost data rather than rely on agencies completing forms. Collecting complete, consistent, and understandable information on overhead and management costs is complicated because variations exist in terminology and accounting systems used by the agencies, different programs offered by the agencies often become integrated with one another, and the diversity of funding sources often overlap.

[24]The multitude of funding sources for one local weatherization agency made it impossible for us to even help them make an estimate of program management costs.

73% of the installation costs were provided by the DOE Weatherization Assistance Program and PVE.[25] These figures were consistent with results obtained by Mihlmester et al. (1992), which indicate that local weatherization agency direct financial support for weatherization and other energy programs is broken down on a national basis as follows: 31% DOE Weatherization Assistance Program, 29% PVE, 18% LIHEAP, and 22% other.

Average per house installation expenditures increased as the percent of total house costs covered by DOE Weatherization Assistance Program funds decreased. Average costs were $1114 in houses receiving just DOE Weatherization Assistance Program funds, $1227 in houses where DOE Weatherization Assistance Program funds covered 50% or more of the total, and $1417 in houses where DOE Weatherization Assistance Program funds covered less than 50% of the total. This result was consistent with expectations because funding sources other than DOE Weatherization Assistance Program funds were often used to install measures that were not allowed under DOE Weatherization Assistance Program guidelines (such as space-heating system replacements).

In examining the results presented in this section, it should be noted that funding sources used by local weatherization agencies are not always consistent throughout the year. Some agencies use different funding sources for different parts of the year because of the time when funds are received (for example, spending DOE Weatherization Assistance Program and PVE funds the first half of the year and state and LIHEAP money the second half of the year). Other agencies are able to spend their funds evenly over the year, allowing a mix of funding sources to be applied to individual houses. Agencies reported that no DOE Weatherization Assistance Program funds were spent in 18% of the houses weatherized under the study. In all cases, though, agencies stated that houses were treated equivalently despite the funding sources available at the time of weatherization. Thus, the results presented in this section are a snapshot of the funding sources used when weatherizations were performed in January of each program year.

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[25] In responding to funding source questions, we believe the local weatherization agencies considered PVE funds to be equivalent to Weatherization Assistance Program funds.

10. COST EFFECTIVENESS

The cost effectiveness of weatherization measures was estimated using simple payback and benefit-to-cost ratio. Standard formulas for these indicators were used along with regional estimates of fuel savings, published regional fuel prices, installation costs, and overhead and management costs. Lifetimes of installed energy conservation measures are critical to such evaluations; therefore, analyses using a range of values are presented, with best estimates for lifetimes noted. Also critical is the discount rate reflecting the time value of money and fuel-oil price escalation rates.

Measured input values used to calculate simple paybacks and benefit-to cost ratios were a regional net average fuel-oil savings of 160 gallons/year (recall that net savings is our best estimate of the savings achieved under the Fuel-Oil Study and is the average gross savings of the control houses subtracted from the average gross savings of the weatherized houses), an average regional installation cost of $1192, and an average overhead and management cost of $627. Fuel-oil savings were converted to regional dollar value estimates using a fuel-oil cost of $1.01/gallon (the average regional fuel-oil cost in the northeast during the study). A "real" discount rate of 4.7% and a fuel escalation rate were used in the calculation of benefit-to-cost ratio as recommended by the Department of Commerce for the year 1991[26] (Lippiat and Ruegg 1990).

10.1 SIMPLE PAYBACK

The easiest method used to assess the cost effectiveness of a program is known as the simple payback method. It is often used to obtain a rough estimate of cost effectiveness. In this method, the incurred cost is simply divided by the obtained savings or benefits. We used only installation costs, overhead and management costs, and energy saving benefits for these calculations.

[26] A "real" discount rate is set annually by DOE for evaluating Federal energy conservation and renewable energy projects. The "real" discount rate for 1991 was set at 4.7%; this was equivalent to a market rate of 8.4% and was based on long-term treasury bond rates averaged over the previous 12-month period.

Dividing the annual installation costs of $1192 by the annual net savings of $162 resulted in a simple payback of 7.4 years. This means that the average lifetime of installed measures must be at least 7.4 years if the program is to be cost effective, based on the foregoing assumptions. By adding overhead and management costs of $627 per house to the installation costs, the average Program cost per house was $1819. Dividing $1819 by $162,34 results in a simple payback of 11.2 years.

Both of these simple payback values imply that the weatherization work performed under the Program in single-family fuel-oil heated houses in the northeast was cost effective because reasonable lifetime estimates for weatherization measures are greater than these payback periods.

10.2 BENEFIT-TO-COST RATIO

Benefit-to-cost ratio is a cost-effectiveness indicator that compares the discounted lifetime benefits obtained from the Program to the costs of achieving them. A number of inputs are usually needed in addition to Program costs and benefits: a discount rate that reflects the time value of money, fuel-oil price escalation rate, and expected lifetimes of the conservation measures. A program is cost-effective whenever the benefit-to-cost ratio is greater than or equal to unity.

This section examines the benefit-to-cost ratio from three perspectives. An installation perspective is defined to consider only energy savings benefits and on-site installation costs. This perspective is the most narrowly defined. It provides insight into how well the measures performed based on their primary function (i.e., to save energy) without considering the indirect costs required to operate a program. A program perspective is defined to consider energy savings benefits and the total costs required for weatherization (installation costs combined with overhead and management costs). The program perspective is the most conservative estimate of program cost effectiveness. A societal perspective was developed to consider the broadest definitions of benefits and costs: benefits include energy and nonenergy benefits, and costs include installation, overhead, and management expenses.

Nonenergy (or societal) benefits can result from the weatherization activity performed under the Program. A quantitative value for these nonenergy benefits is not as simple to estimate

Table 10.1. **Cost-effectiveness** estimates

Effective measure life (years)	Benefit-to-cost ratio		
	Installation perspective	Program perspective	Societal perspective
10	1.25	0.82	1.35
15	1.79	1.17	1.71
20	2.26	1.48	2.01
25	2.65	1.74	2.27

as are the energy savings and costs associated with weatherization. Nonenergy benefits can be grouped into five major categories:

- preservation of affordable housing,
- comfort, health, and safety impacts,
- impacts on household budgets,
- employment and economic impacts, and
- environmental externality impacts.

Brown et al. (1993) extensively examined nonenergy impacts of low-income weatherization and concluded that the average net present dollar value of nonenergy impacts for the Program in 1989 was $976 per weatherized house. Additional benefits that could not be assigned a dollar value include: thermal comfort improvements, indoor air quality, benefits of increased nonenergy expenditures, and savings associated with fewer residential moves.

Table 10.1 summarizes the results of the benefit-to-cost ratio calculations performed. These results are plotted in Fig. 10.1.

The program is cost effective from all three perspectives under the conditions analyzed except for the program perspective assuming a 10-year lifetime for the measures. The Program is cost effective from the societal and installation perspectives assuming measure lifetimes as low as six and eight years, respectively. The Program is cost effective from a program perspective when measure lifetimes exceed 12.5 years.

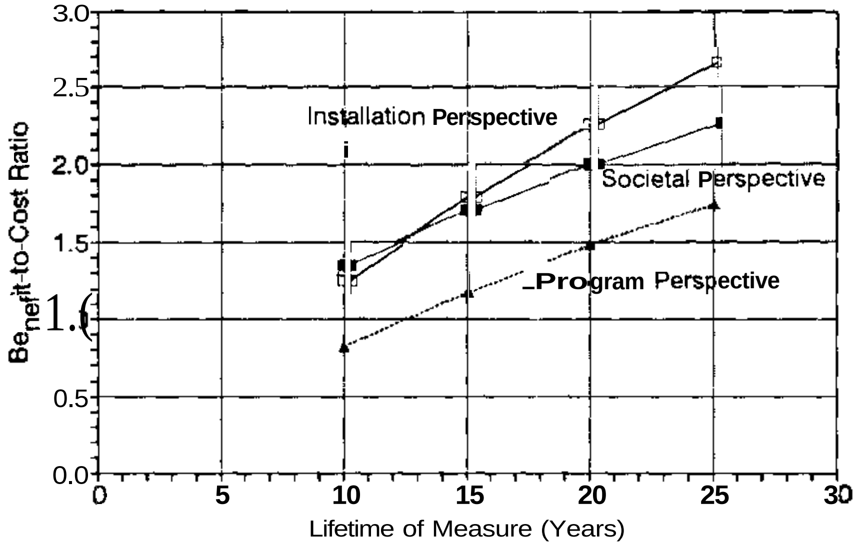


Fig. 10,1. Comparison of benefit-to-cost ratios to measure lifetimes.

Estimated lifetimes for the various weatherization measures installed in the study houses range from 1 to 5 years for caulking to 30 plus years for insulation, with 20 years being a fair average for all measures combined (Brown et al. 1993). A 20-year estimated life results in a benefit-to-cost ratio of 2.26 from an installation perspective, 2.01 from a societal perspective, and 1.48 from a program perspective. All three estimates show that the Weatherization Assistance Program is indeed cost effective for houses heated with fuel oil in the northeast.

11. FACTORS ASSOCIATED WITH SAVINGS

An analysis conducted to determine which measures provided the most savings in this study was difficult. Many different measures and procedures were applied to or performed on the tested single-family fuel-oil-heated houses. The houses had many different construction characteristics and occupant types. Identical measures often perform differently with different types of houses or different conditions existing in the same type of house. For instance, six inches of attic insulation will be more beneficial when added to a house with two inches in the attic rather than eight inches in its attic. Also, a sophisticated setback thermostat installed in a house with an occupant who does not understand its workings may result in no savings and a great deal of frustration for the occupant.

Sample houses for this study were randomly chosen to determine the energy savings of the Program rather than to determine the cause of the savings. In order to determine factors affecting savings, houses would have been selected based on individual measures and selected combinations of measures received. For example, almost all houses in our sample received standard caulking and weatherstripping, making it impossible to study this measure. Also, the sample size was too small and not sufficiently randomly distributed to study the large number of combinations of measures installed, house characteristics, procedures, etc. Another item to note is that inspections were conducted on the test houses after weatherization had been accomplished and not before. Thus, detailed information is available on conditions existing in a house after weatherization was done, but not before weatherization.

Data presented and analyzed in this section were taken from a subset of the original database. An arbitrary requirement for inclusion in the subset was that all fuel-oil consumption coefficients of determination (R^2) be 0.7 or above for both pre-weatherization and post-weatherization periods. This criterion reduced the weatherized sample from 193 houses to 149 houses, but we felt that it allowed more accuracy in the analysis. The mean pre-weatherization consumption for this subgroup was 930 gallons/year, and the mean gross savings was 162 gallons/year with no control house adjustment. A discussion of control house data is not included in this section since control houses had no weatherization work done on them. Analyses were performed on a house basis (Sect. 11.1) and an agency and state basis (Sect. 11.2),

11.1 HOUSE LEVEL ANALYSIS

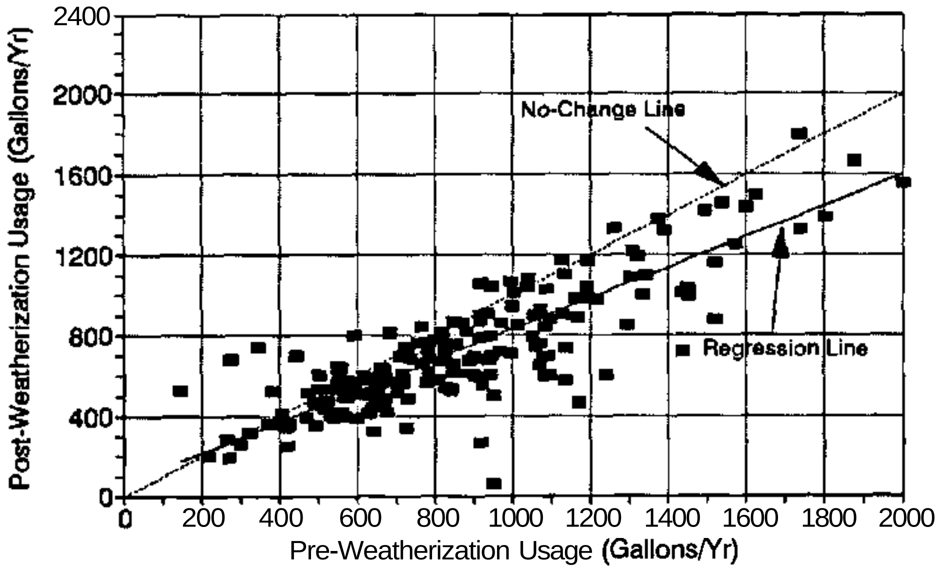
"Independent" or "two-sample" t-tests on the equality of two means (space-heating fuel-oil savings in this study) were performed to study the importance of selected measures, procedures, and occupant and dwelling characteristics. The mean savings of houses receiving a particular measure or procedure, for example, was compared to the mean savings of the remaining houses (those not receiving the particular measure or procedure) to determine if a statistically significant difference existed. The significance of the difference depends upon the magnitude of the difference, the standard deviations of the means, and the size of each sample. The mean savings of the houses are listed in the appropriate tables in this section by the factors studied, along with their mean pre-weatherization consumption and the significance of the difference.

11.1.1 Pre-Weatherization Consumption and Savings

One factor which previous evaluations (Ternes et al. 1991, and Ternes and Levins 1992) have shown to be associated with savings in many programs is the level of energy consumption before any weatherization measures are performed on a house. Figures 11.1(a) and (b) plot the pre-weatherization fuel-oil consumption against the post-weatherization fuel-oil consumption for each weatherized house. Figure 11.1(b) differs from 11.1(a) in that it normalizes the annual consumptions for each house by the heated area of the house. Regression lines on these figures (the R^2 values are on the order of 0.2) indicate that post consumptions are, on average, lower than pre consumptions. Figure 11.1(b) predicts an expected savings of 20% in a household with a pre-weatherization fuel-oil usage of 1 gallon/square foot/year. A crossover of the regression and no-change lines in Figs. 11.1(a) and (b) at low consumptions is not unexpected. Pre- and post-weatherization consumptions should be about equal to each other in houses with low pre-weatherization consumption because these houses likely received few conservation measures.

Figures 11.2(a) and (b) compare fuel-oil savings to pre-weatherization consumptions. The regression lines show that there is a trend for savings to be greater in houses with high pre-weatherization consumption and high pre-weatherization consumption per unit floor area. The R^2 value of each regression line is on the order of 0.2, so pre-weatherization consumption explains only a small amount of the variation in savings.

(a)



(b)

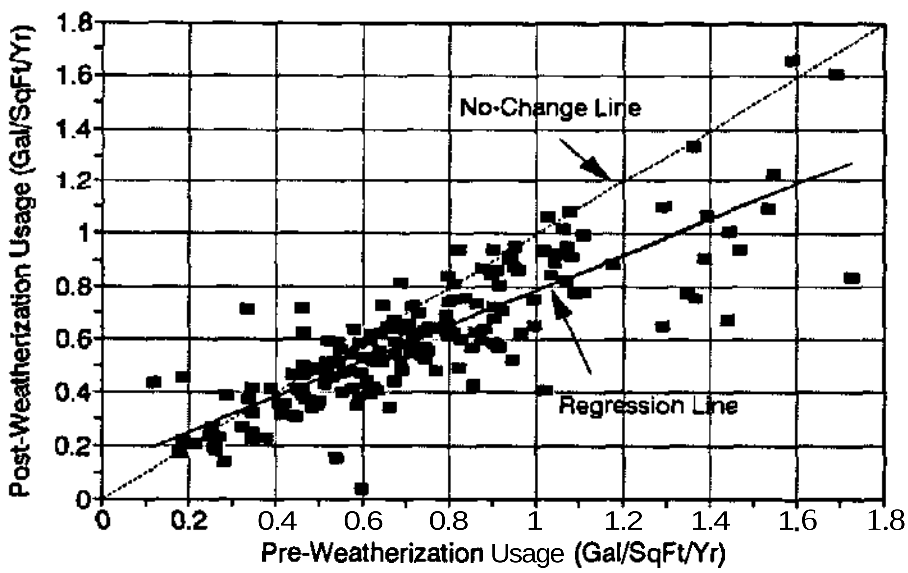
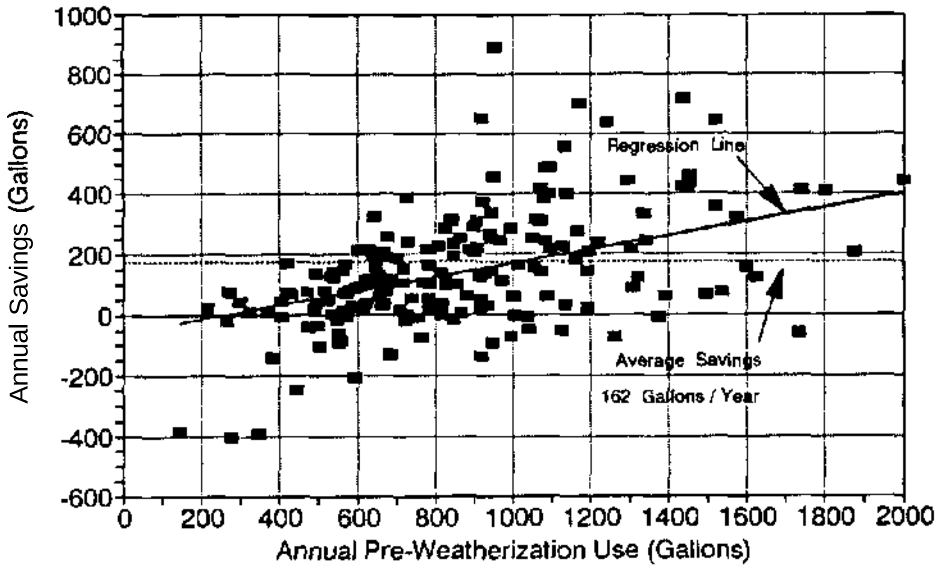


Fig. 11.1. Comparison of annual **pre-weatherization fuel-oil** consumption to **post-**weatherization consumption for the weatherized **houses.**

(a)



(b)

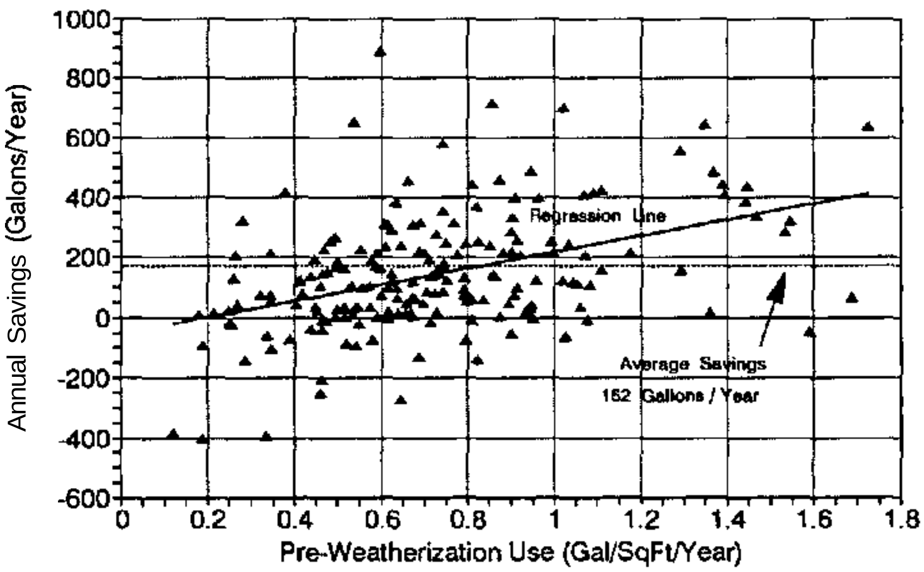


Fig. 11.2. Comparison of fuel-oil savings to pre-weatherization fuel-oil consumption for the weatherized houses.

Table 11.1. **Effect** of cost of **weatherization** on **savings**

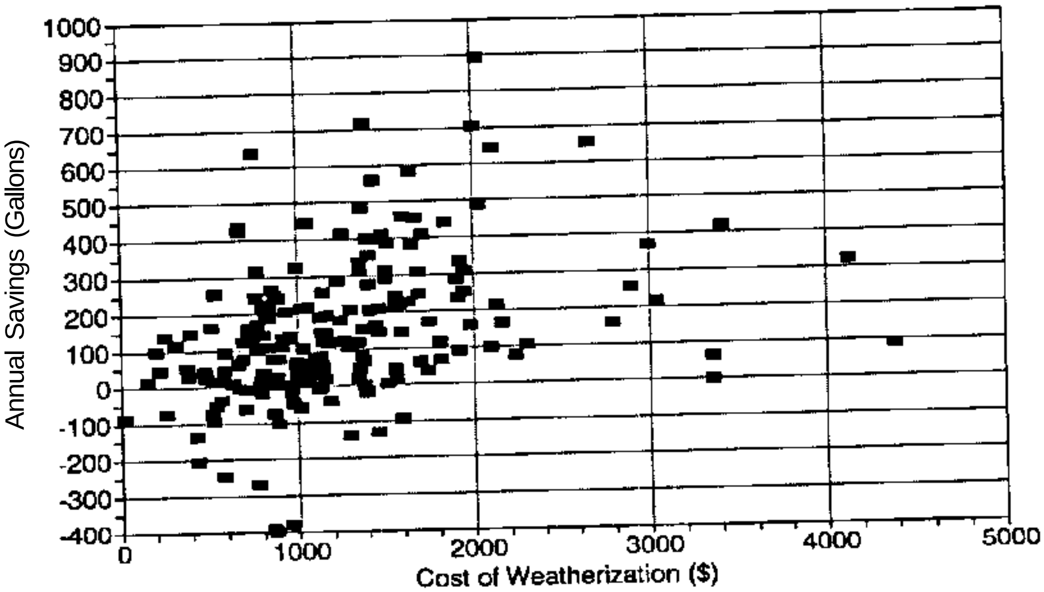
Group	Average cost of weatherization	Number of houses	Pre-weatherization usage (gallons)	Annual savings (gallons)	Annual savings (%)
All	$1270	147	934	164	17.5%
< $1200	$821	82	859	102	11.8%
> $1200	$1837	65	1028	241	23.4%

11.1.2 Weatherization Cost and Savings

The association between the cost to weatherize a house and the savings obtained by that house is examined in this section. All costs used in this discussion are installation costs (only for labor and materials) and do not include overhead and management costs. Table 11.1 contains sample data (not weighted data) from those houses with available cost data and also with consumption R^2 values 0.7 or greater for both pre-and post-weatherization periods. The houses are separated into three groups in the table — all houses, those houses on which $1200 or less was spent for weatherization during the weatherization process, and those on which more than $1200 was spent. The cutoff of $1200 was chosen because the mean regional installation cost was $1192 (see Table 9.2).

T-tests between the average savings for those houses on which less than $1200 was spent and those houses on which more than $1200 was spent show that there is a statistically significance difference (at a >0.001 level of significance) between the savings of the two groups. The houses on which more than $1200 was spent saved more than twice as much fuel oil as the other group. The houses receiving the higher expenditures also used more fuel-oil in the pre-weatherization period (at a 0.006 level of significance) than the other group. This suggests that the money spent to weatherize houses was on average spent properly because the most needy houses (the largest consumers) received more than the more efficient houses.

(a)



(b)

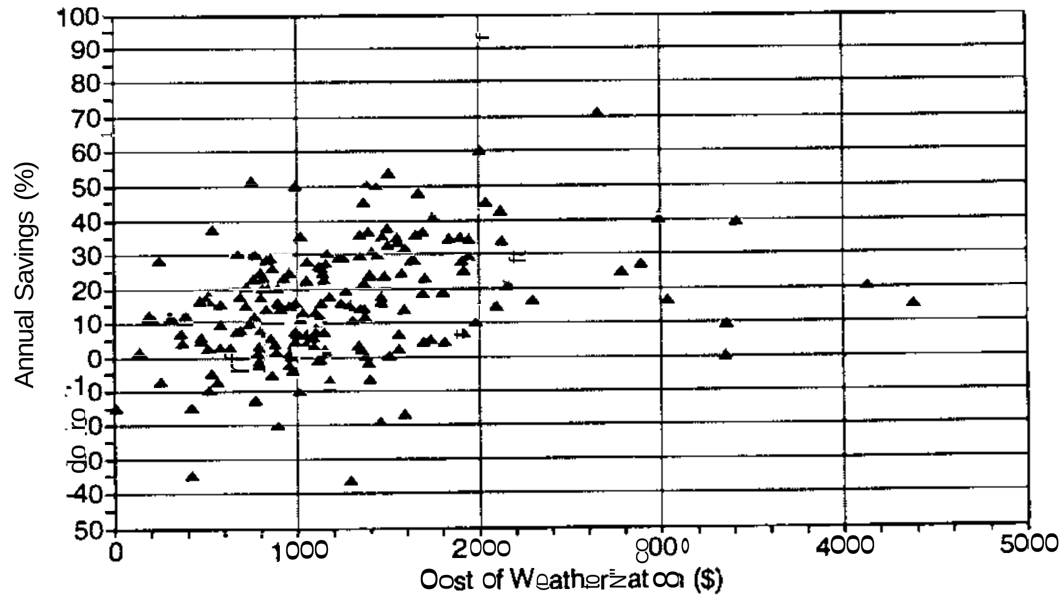


Fig. 11.3. Effects of cost of weatherization on meas [redacted] il savings.

Table **11.2.** Energy savings by occupant and dwelling characteristic

	Pre-weatherization consumption (gallons/year)	Savings (gallons/year)	Number of dwellings	Significance level
Owners/Renters				—
Owned	899	146	110	
Rented	944	250	15	
Elderly Occupants				—
1 or more	972	179	60	
None	902	150	89	
Handicapped Occupants				—
1 or more	911	138	27	
None	934	167	122	
Type of Housing				—
Single story	790	137	56	
Two stories	1015	177	93	

* means that differences in savings are different from zero at the 0.05 level of significance.
— means that differences in savings are not significantly different from zero.

Figures 11.3(a) and (b) show the effects of weatherization expenditures on the annual gallons saved and percent savings, respectively. The figures generally agree with the conclusions drawn from the table.

11.13 Occupant and Dwelling Characteristics **Associated** With Savings

The effect of four occupant and dwelling characteristics on the savings obtained from weatherization were investigated: **ownership,** occupancy by an elderly or handicapped person, and number of stories in the house. The results are contained in Table **11.2,** which shows that the four factors were not associated with higher-than-average savings. Other characteristics discussed in Sect. 3 that may be associated with savings include number of occupants, change in occupancy, family income, heated floor area, and age of the house. The effect of these factors remain to be investigated.

11.1.4 Energy Savings Associated with Installed Measures

Average measured savings in houses receiving a particular measure during weatherization were compared to the remaining houses to determine the savings associated with the particular measure. Table 11.3 contains a summary of the average measured savings in houses receiving a particular measure during weatherization. Measures were divided into six different major groups in the table, but the measures were not differentiated here as being installed by an in-house crew or by a contractor. Figure 11.4 shows mean savings for houses receiving insulation, air-leakage control, structural, and space-heating system measures.

The reader should bear in mind that several different measures were usually installed in a house. The savings shown are for the house with the specific measure in question plus all other measures that may have been installed. It is not possible to precisely estimate how much energy is saved by a single measure based on the analysis presented here for several reasons. First, the particular measure being examined may not be the cause of a significant difference in energy savings because measures can be co-related (see discussion of attic ventilation in this section). Second, all weatherized houses did not start out at the exact same condition (some already had attic insulation and some didn't, etc).

Using a blower door for sealing was the only air-leakage control measure that showed statistically significant (0.05 level of significance) higher-than-average savings. Houses receiving this treatment also appeared to have higher-than-average pre-weatherization consumptions . No statistically significant differences existed between houses receiving general caulking, distribution system work, or other infiltration reduction techniques and houses not receiving these measures, although houses that had distribution system leaks addressed had the highest mean savings.

Houses in which new attic insulation (where none was previously installed), normal wall insulation, and high-density wall insulation were added had statistically significant, higher-than-average savings. Houses receiving new attic insulation had pre-weatherization consumptions greater than average, while houses receiving wall insulation were about average. Pre-weatherization consumptions of houses receiving and not receiving wall insulation may not have

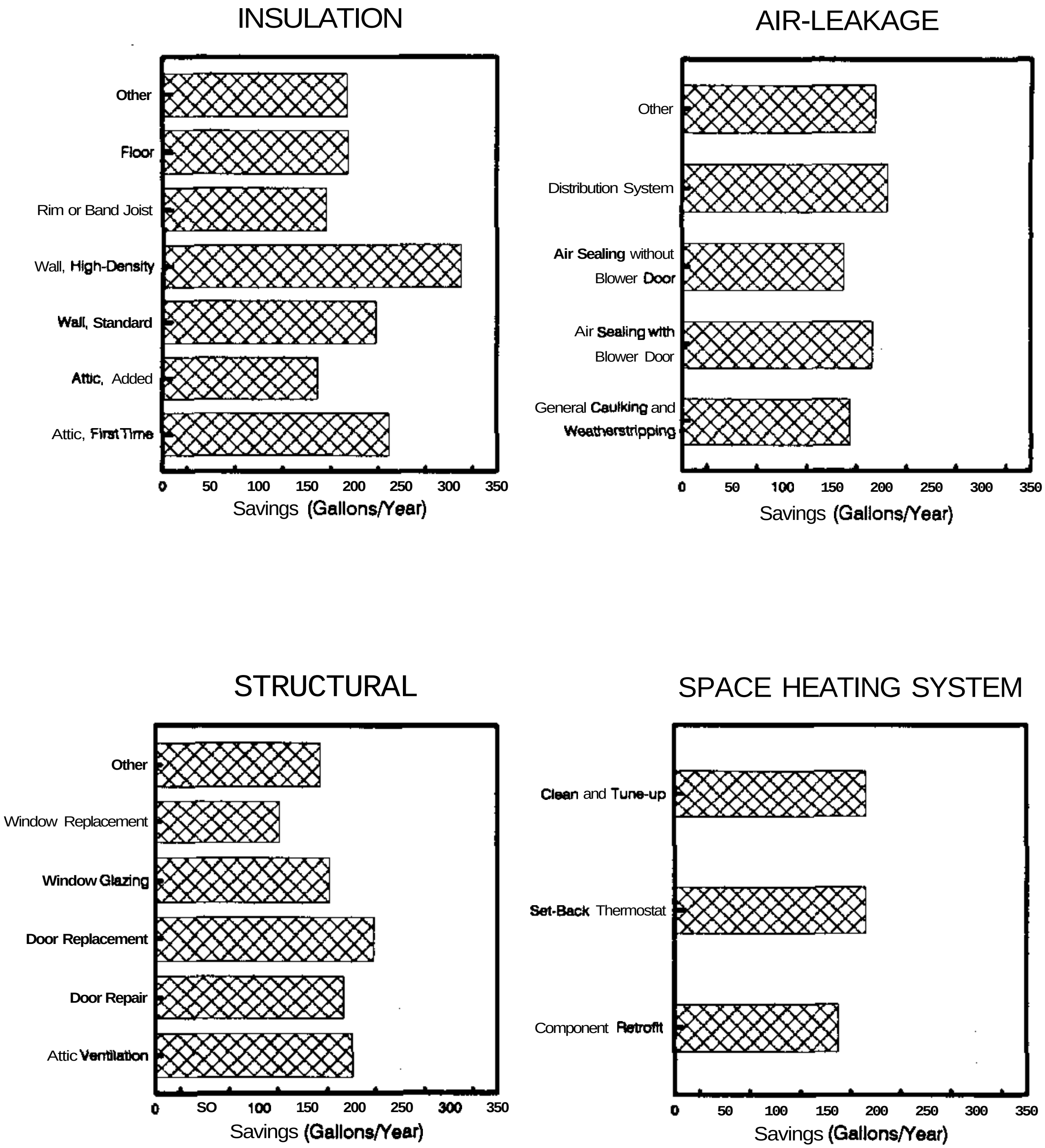


Fig. 11.4. Mean fuel-oil savings for houses receiving selected insulation, air-leakage, structural, and space-heating system measures.

Table 11.3. House-level energy savings associated with selected measures

Houses receiving measures including:	Annual pre-weatherization consumption (gallons)	Annual savings (gallons)	Number of dwellings	Significance level
All Houses	930	162	149	
Air Leakage				
General caulking	936	168	136	—
Air sealing without a blower door	919	162	77	—
Air sealing with a blower door	1041	193	40	*
Distribution system	952	206	26	—
Other	924	195	31	---
Insulation				
Attic insulation, first time	1032	237	54	*
Attic insulation, added	829	165	55	—
Wall insulation, standard	970	223	42	*
Wall insulation, high-density	965	313	16	*
Rim or band joist insulation	1012	171	32	—
Floor insulation	970	194	58	—
Other	986	193	33	—
Windows and Doors				
Storm window(s)	951	154	46	—
Storm door(s)	784	30	7	*
Window films of shades	–	–	0	—
Other	795	71	6	—
Space-Heating System				
Clean and tune-up	998	191	63	—
New system	1031	305	5	*
Set-back thermostat	972	190	9	---
Component retrofit	996	163	9	—

* means that differences in savings are different from zero at the 0.05 level of significance.
— means that differences in savings are not significantly different from zero.

Table 11.3. **House-level** energy savings associated with selected measures (continued)

Houses receiving measures including:	Annual pre-weatherization consumption (gallons/year)	Annual savings (gallons)	Number of dwellings	Significance level
Water Heating Measures				
Tankinsulation	843	171	43	—
New system	953	456	1	—
Pipe insulation	914	166	80	—
Temperature reduction	1019	219	22	—
Low-flow showerhead	923	214	15	—
Other	982	160	18	—
Structural Measures				
Attic ventilation	938	203	71	*
Roof	743	125	5	—
Doors	959	190	34	—
Doors replacement	968	222	24	—
Windows glazing	933	177	89	—
Window replacement	1014	126	26	—
Walls	997	185	9	—
Floor	755	157	2	—
Other	838	168	53	—

* means that differences in savings are different from zero at the 0.05 level or greater.
— means that differences in savings are not significantly different from zero.

been as different as one would expect because some houses needing wall insulation still did not receive this measure.

Houses receiving the addition of storm doors had statistically significant, lower-than-average savings (30 gallons/year). This does not imply that storm doors increase fuel-oil consumption. The pre-weatherization consumption of houses receiving a storm door were much lower than average, indicating that the houses were already relatively efficient. Storm doors may have been installed in these houses because other, more effective measures were already in place. Additionally, measures other than storm doors that save more significant amounts of energy may not have been installed with the storm doors. There were only seven houses receiving storm doors, so the results may possibly be viewed as being inconclusive because of the small sample size. Savings for houses receiving all other window and door measures such as adding storm windows were not statistically different from houses not receiving these measures.

The only space-heating system measure associated with statistically significant, higher-than-average savings was replacement of the entire heating system. Houses receiving this measure saved 305 gallons/year, or about twice the average of all houses. A small sample size of five units may add some uncertainty to this result. This measure was expensive, typically costing about $2000 to $2500 to complete. Houses receiving a new system had higher pre-weatherization consumptions than average; in fact, houses receiving any space-heating system measure generally had higher-than-average pre-weatherization consumptions.

None of the domestic water heating measures were associated with statistically significant higher-than-average savings. Houses receiving hot-water temperature reduction, though, had high pre-weatherization consumptions and high savings.

Attic ventilation was the only structural measure (i.e., those measures which are either energy related, such as replacing broken window glass, or are necessary in order to enable other energy-related repairs to be accomplished) associated with statistically significant, higher-than-average savings. Obviously, attic ventilation by itself cannot bring about such improved savings, so it must be correlated with some other variable like attic insulation. Discussions with weatherization agency employees confirmed that an attic was often not vented if it did not have any insulation in it. Attic ventilation, if none existed, was usually added when new attic insulation was installed. A check of 54 houses receiving new attic insulation showed that 43 (80%) of them also received attic ventilation.

A Pearson chi-squared analysis was conducted among those measures shown to be associated with statistically significant, higher-than-average savings — new attic insulation, standard

Table 11.4. Correlations between measures associated with statistically **significant, higher-than-average** savings based on the Pearson **chi-square statistic**

Measure	New attic insulation	Standard wall insulation	High-density wall insulation	Air sealing using a blower door	Attic ventilation	New storm door	New heating system
New attic insulation		√	X	V	V	-	-
Standard wall insulation	V		X	X	V	-	-
High-density wall Insulation	X	X		V	X	-	-
Air sealing using a blower door	V	X	V		X	-	-
Attic ventilation	√	V	X	X		-	-
New storm door	-	-	-	-	-		-
New heating system	-	-	-	-	-	-	
Occurrences	3	2	1	2	2	0	0

Notes: V means that measures show a correlation at the 95% confidence level.
X means that measures do not show a correlation at the 95% confidence level.
\- means that the sample is too small to form a definitive decision.

wall insulation, high-density wall insulation, air sealing using a blower door, attic ventilation, new storm doors, and a new heating system — in order to ascertain which measures might be co-related with each other. Table 11.4 shows that new storm doors and new heating systems were not installed in sufficient houses during weatherization to show a definitive co-relation with any of the other measures associated with higher-than-average savings. New attic insulation is directly co-related with three of the remaining four variables (including attic ventilation); standard wall insulation, air sealing using a blower door, and attic ventilation are directly co-related with two variables each; and high-density wall insulation is directly co-related with only air sealing using a blower door. It is difficult to say which variable(s) contribute directly to higher-than-average savings because of the extensive correlation among the variables.

11.1.5 Energy Savings Associated with Delivery Procedures

The term "delivery procedures" encompasses pre-installation, installation, and post-installation procedures that were followed or utilized in order to decide what weatherization activity to perform on a house, how to do it, and how to inspect installed measures when the job was completed. Table 11.5 divides these procedures into four major groups: selection of measures, use of diagnostics, quality control, and client education.

None of the measure selection approaches or diagnostic procedures were associated with statistically significant above-average savings. The use of heating system performance data to select space-heating system measures and the use of a blower door to measure leakage rates were significant at a 0.10 level of significance, however.

Houses receiving a visual inspection of space-heating systems had a statistically significant, above-average savings of 200 gallons/year. Inspections can improve energy savings by promoting higher quality installations through crew motivation (initially installing measures correctly) and call-backs (correcting improper installations). However, the savings improvement observed from a visual space-heating inspection could be due to the fact that space-heating system work was performed (and thus inspected). Almost all houses (95%) receiving a space-heating system measure also received a visual inspection.

None of the client education measures were associated with statistically significant, above-average savings, perhaps because almost all houses (94%) received in-person education.

11.1.6 High and Low Fuel-Oil Saving Houses

Two groups were formed based on savings in order to examine why differences occurred between those houses which saved the most energy and those which saved the least. The top and bottom 12% (18 houses each) were separated from the sample of 149 weatherized houses with

Table 11.5. Energy savings by service delivery procedure

	Annual pre-weatherization consumption (gallons)	Annual savings (gallons)	Number of dwellings	Significance level
Selection of **Measures**				
Envelope priority list	922	170	120	---
Envelope decision approach	844	191	37	---
Envelope benefit-to-cost	1001	142	44	---
Space heat using test data	934	181	90	—
Combined envelope/space heat	928	182	28	—
Use of Diagnostics				
Blower door for sealing	913	175	99	---
Blower door for leak rates	921	178	104	—
Distribution system seal	870	221	22	—
Distribution system balance	920	169	10	—
Infrared scanning	972	178	11	—
Heating system efficiency	942	166	118	—
Other methods	910	181	8	---
Quality **Control**				
Envelope visual inspection	935	166	142	—
Envelope with blower door	970	187	60	—
Space heat visual check	955	200	59	*
Space heat efficiency test	991	192	55	---
Client **Education**				
In-person education	934	167	140	---
Literature to client	934	160	62	---
Other client education	877	201	5	---

* means that differences in savings are different from zero at the 0.05 level of significance.
— means that differences in savings are not significantly different from zero.

"reliable" data. Table 11.6 contains a listing of the mean values of selected variables of the two groups.

Several observations may be made from this table quite easily. The high savers averaged 498 gallons/year of fuel oil saved (37%) while the low savers saved -44 gallons/year (-6%). The low savers used considerably less fuel in the pre-weatherization period than the high savers (873 vs 1392 gallons/year, respectively), even though both groups were identical in heated area. After weatherization, however, the high savers used about the same amount of fuel as the low savers (894 vs 917 gallons/year, respectively). The high savers were weatherized cost effectively with an average of $1604 being spent on each for labor and materials. The low savers were not weatherized cost effectively, even though an average of $892 was spent on each for labor and materials. The high savers benefitted more from air leakage measures than the low savers, but both ended up at about the same level of tightness. The low savers had more efficient heating systems and higher indoor temperatures than the high savers. These facts suggest that the high savers were houses which really needed weatherization, while the low savers were houses that were relatively more energy efficient. The annual consumption of the low savers averaged 0.67 gal/ft^2/year, which also was the post-weatherization consumption of the high savers.

Figure 11.5 contains plots of measures received by both groups. Similar measures were installed in both groups, but the frequency at which measures were installed were not the same. Measures installed in only the high savers were new space-heating systems and components, high-density wall insulation, low-flow showerheads, and domestic hot-water temperature reduction. Measures installed more frequently (difference of 20 percentage points or more) in the high savers than the low savers were new or additional attic insulation, regular wall insulation, floor insulation, air sealing using a blower door, replacement of broken glass in windows, and heating system clean and tunes. Measures installed more frequently in the low savers than the high savers were replacement windows and new storm doors.

The service delivery procedures differed little between these two groups (Fig, 11.6). About 80% of both groups used a priority list to select envelope measures and 60% used a visual inspection to select space-heating measures. However, 67% of the high savers used heating-system efficiencies to decide upon space-heating measures compared to 50% of the low savers.

Table 11.6. Mean values of measured variables

Variable	Bottom 12% (losers)	Top 12% (winners)
Annual savings (gallons)	-44	498
Percent savings	-5.7	37.5
Weatherization cost for labor & materials ($)	892	1604
Pre-weatherization consumption (gal/ft²/year)	0.67	1.06
Post-weatherization consumption (gal/ft²/year)	0.71	0.66
Pre-weatherization inside temperature (°F)	72.3	70.7
Post-weatherization inside temperature (°F)	72.4	70.1
Indoor temperature difference (°F)	0.1	-0.6
Heated area (ft^2)	1457	1467
Number of stories	1.5	1.7
Pre-weatherization consumption (gallons)	873	1393
Post-weatherization consumption (gallons)	917	895
Pre-weatherization R^2	0.9	0.9
Post-weatherization R^2	0.9	0.9
Days of pre-weatherization data	74.5	68.6
Days of post-weatherization data	92.2	95.4
Pre-weatherization air leakage (cfm50)	3580	3856
Post-weatherization air leakage (cfm50)	3290	3191
Air leakage difference (cfm50)	290	665
Age of space-heating system	25.8	20.6
Pre-weatherization steady-state efficiency	76.5	72.9
Post-weatherization steady-state efficiency	76.2	74.7
Difference in steady-state efficiency	-0.2	1.6
Pre-weatherization smoke number	1.6	2.5
Post-weatherization smoke number	1.9	2.1
Upper fan limit setting (°F)	135	137
Lower fan limit setting (°F)	94	101
Boiler run temperature (°F)	172	188
Boiler cutout switch (°F)	190	201
Annual savings ($)	-44	503
Program benefit-to-cost ratio at 15 years	—	2.96

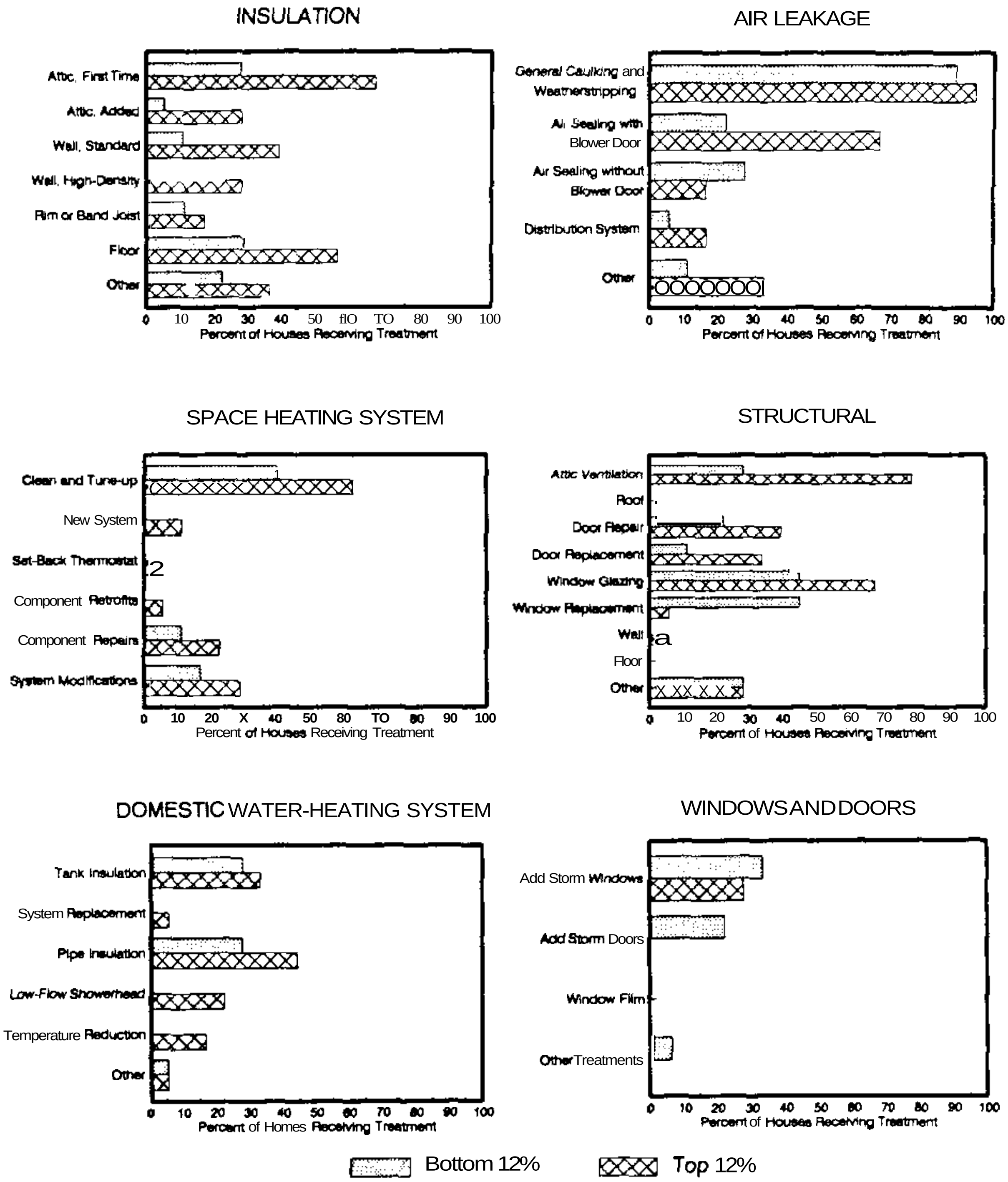


Fig. 11.5. Installation frequency of weatherization measures in high and low saver groups.

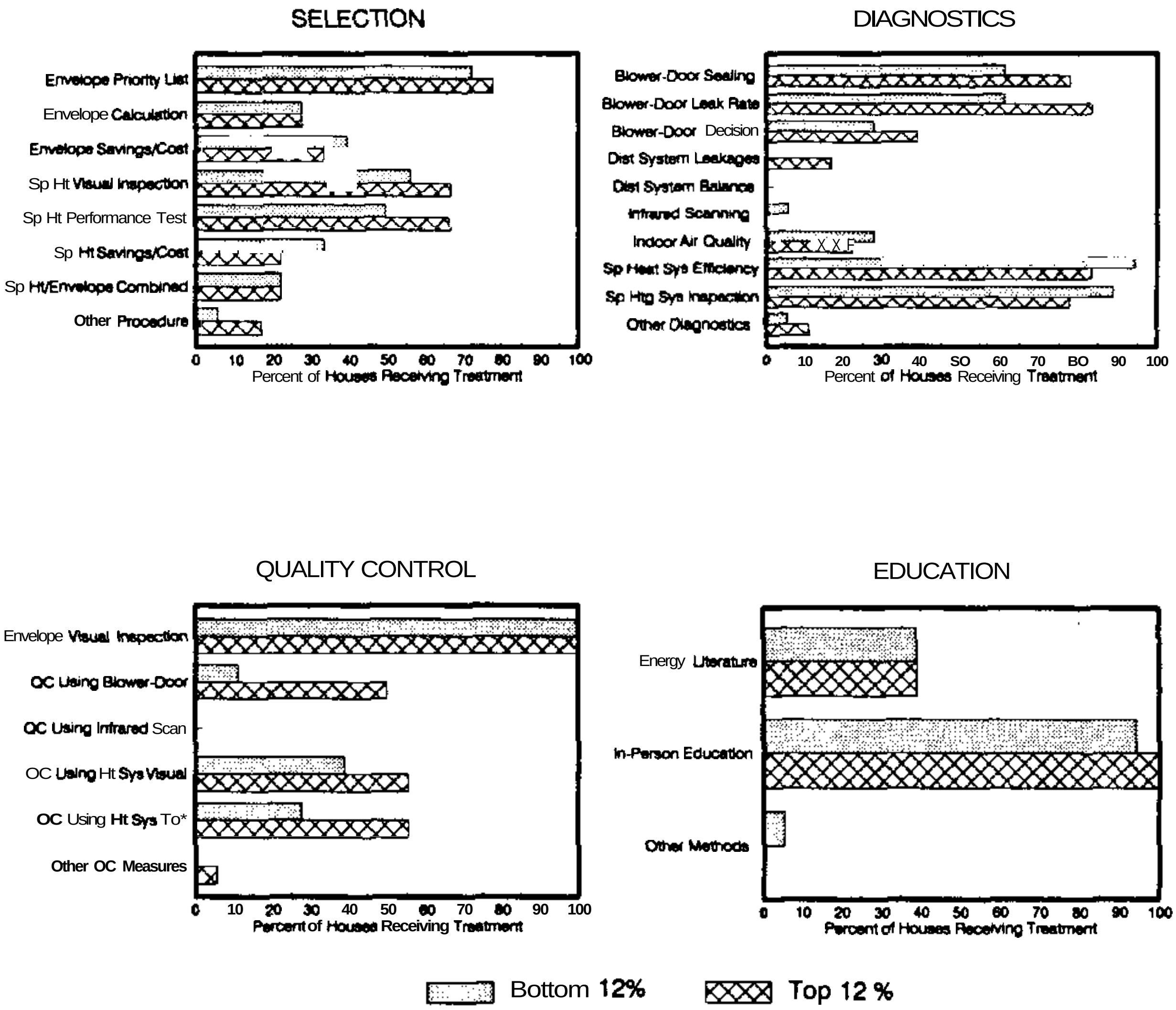


Fig. 11.6. Frequency of use of different measure selection approaches, diagnostic techniques, quality control inspections, and client education.

A blower door was used to find and measure leakage areas in about 80% of the high savers compared to 60% of the low savers. About 90% of both groups measured the furnace steady-state efficiency before weatherization.

A visual inspection of envelope measures was performed in all houses of both groups after weatherization. A blower door was used on 50% of the high savers compared to 11% of the low savers for quality control of envelope measures. About 60% of the high savers conducted visual and testing inspections on heating systems compared to 35% of the low savers.

All houses of both groups had in-person client education, and 40% of each received literature.

11.2 AGENCY AND STATE-LEVEL ANALYSES

Houses were grouped into their source agencies and states in order to get a more macroscopic view of weatherization performance,

Figure 11.7 shows the savings obtained by each individual agency along with the number of houses in the sample from that agency. One agency had no qualifying houses in the subset sample, so only 40 agencies are shown on the plot. Three agencies stand out as their average savings are above 400 gallons/year, but one of these agencies had only one house in its sample while a second had only two. However, one agency had four houses in its sample, so an annual savings of 400 gallons may be an attainable goal. Five agencies had mean annual savings of less than 50 gallons/house. The two lowest agencies had only one or two houses in their sample, but the other three agencies had four, three, and six houses, respectively.

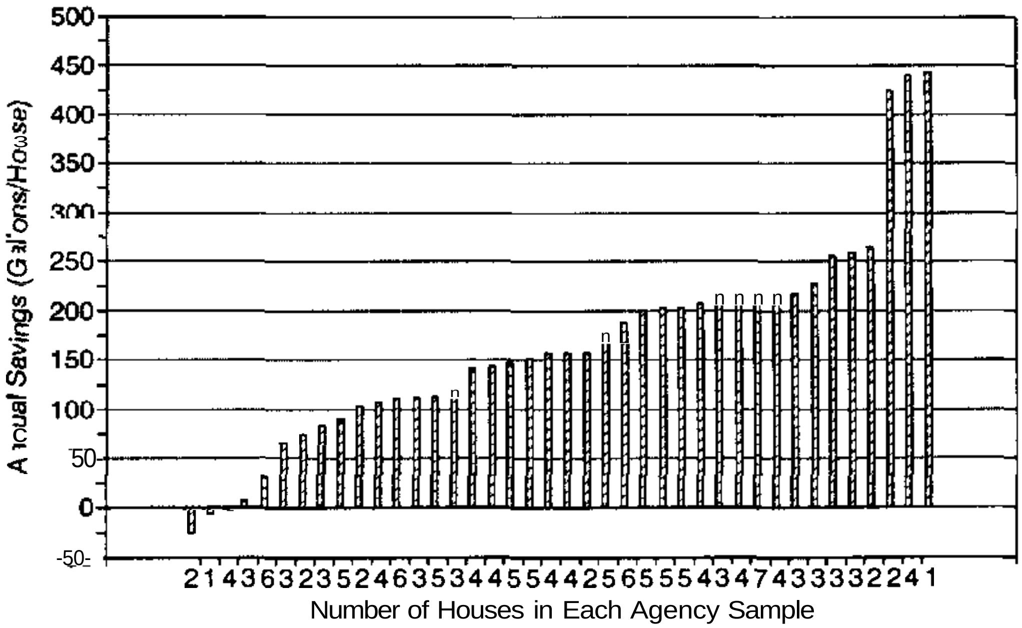


Fig. 11.7. Average annual fuel-oil savings for each local weatherization agency (in increasing order of savings) with the number of houses monitored in each agency identified along the abscissa (x-axis).

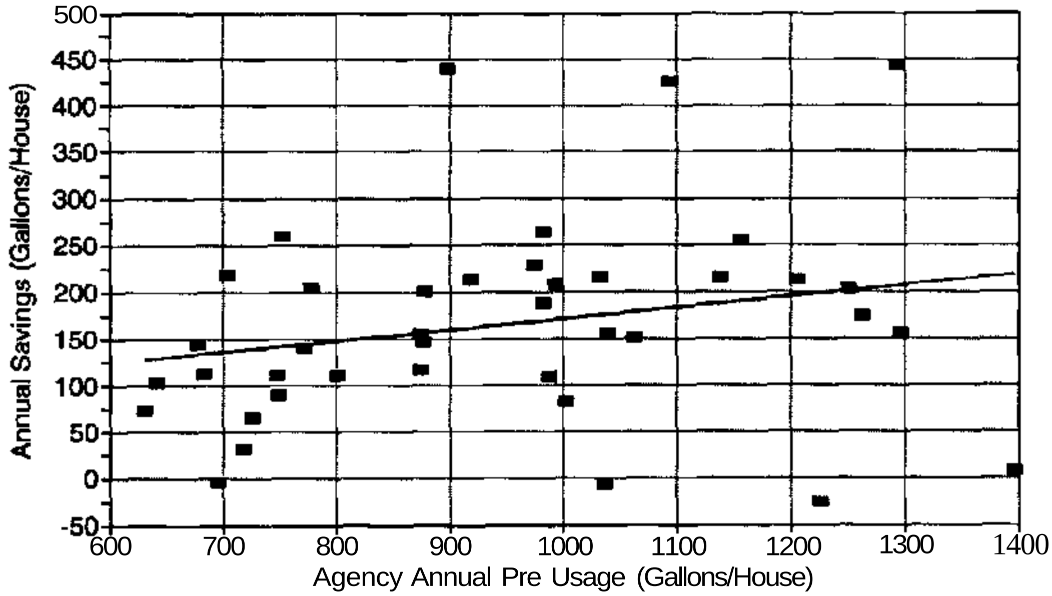


Fig. 11.8. Comparison of average annual **fuel-oil** savings for each local **weatherization** agency to the average pre-weatherization **consumption.**

Figure 11.8 shows a weak relationship between pre-weatherization consumption and savings at the agency level. However, some agencies having high pre-weatherization consumption houses had low savings and visa-versa. The agency having about 10 gallons/year savings at a pre-weatherization consumption of 1400 gallons/year had three houses. This appears to be poor performance, as many opportunities for savings must exist at this level of consumption. The agency having about 440 gallons/year savings at a pre-weatherization consumption of 900 gallons had four houses. This is indeed exemplary performance; the savings is extremely high, approaching 50%, even though the pre-weatherization consumption is below the 930 gallon mean for all houses.

Figure 11.9 shows that about 63% of the agencies obtained an average annual savings between 100-250 gallons/house, while 23% averaged below 100 gallons/house and 15% averaged above 250 gallons/house.

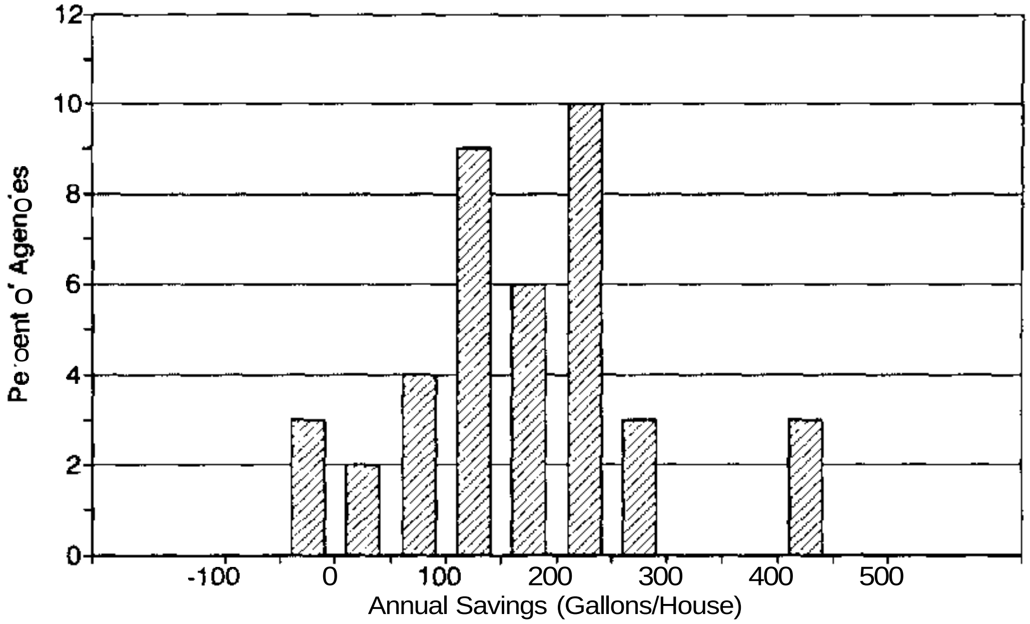


Fig. 11.9. Distribution of the average annual **fuel-oil** savings **achieved** by each local weatherization **agency.**

The preceding analyses show that differences exist in savings among agencies, although differing housing stocks in an agency (row houses vs detached, for instance) may affect the achieved savings.

Since the agencies are monitored by their respective states, Fig. 11.10 plots the annual savings per house attained by each of the nine states in which the Fuel-Oil Study was conducted. The plot shows that two states attained well below-average savings, five states attained average savings, and two states attained well above-average savings. However, an analysis of variance multiple comparison approach using a Tukey-Kramer adjusted test revealed that there was no significant difference in savings among the states at the 95% confidence level. We still believe, however, that differences in state policies toward weatherization have an impact on the achievable savings of the Program.

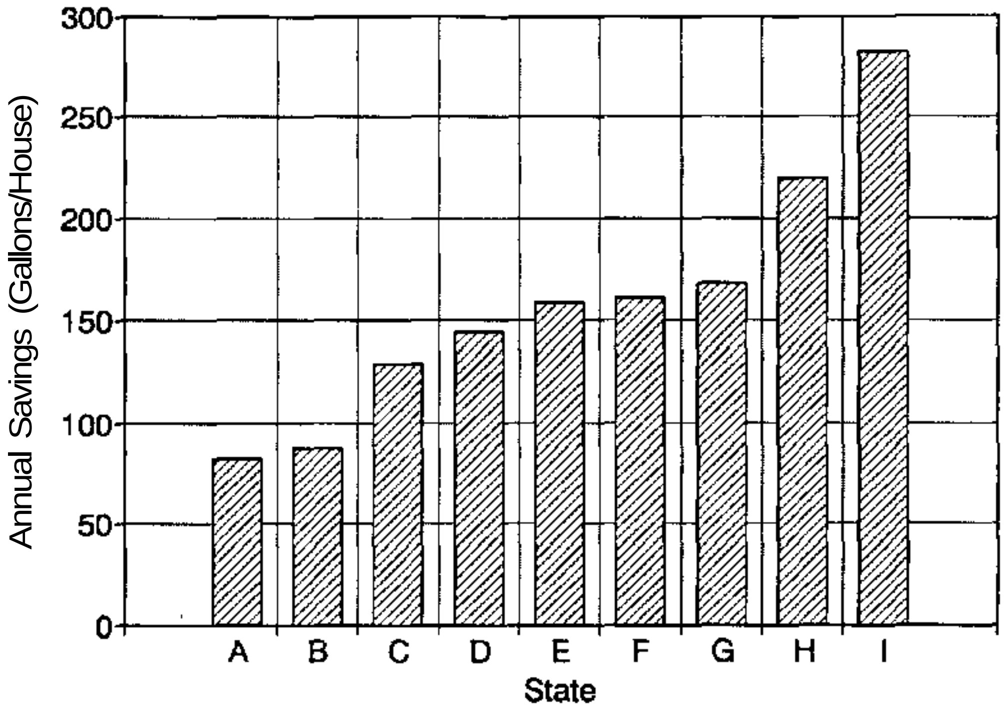


Fig. 11.10. Average annual fuel-oil —ings fo [redacted] sta= (in increasing order of savings).

12. CONCLUSIONS AND RECOMMENDATIONS

The Weatherization Assistance Program cost-effectively weatherized a total of 23,400 single-family fuel-oil heated houses in the nine northeastern states during program years 1991 and 1992. An average annual net fuel-oil savings of 160 gallons (17.7% of pre-weatherization consumption) was achieved at a total average cost of $1819 ($1192 for installation labor and materials and $627 for overhead and management); the resulting program-perspective benefit-to-cost ratio was 1.48 and the societal perspective ratio was 2.01. Although indoor temperatures changed in individual houses following weatherization, there was no average difference when compared to the control houses; thus, there was no overall indoor-temperature take-back effect influencing fuel-oil savings.

A general trend toward higher-than-average fuel-oil savings was observed in houses with high pre-weatherization fuel-oil consumption, although high pre-weatherization consumption explains only a portion of the variance in savings. Program savings could likely be increased by targeting higher energy consumers for weatherization, although equity issues would have to be considered. An analysis of the top and bottom 12% of the sample showed that high savers had consumptions after weatherization about equal to that of the low savers before they were weatherized, indicting that the low savers were, on average, already more energy efficient than the high savers.

Weatherization measures associated with statistically significant, higher-than-average savings were use of a blower door for air-sealing, attic and wall insulation, and replacement space-heating systems. More extensive analysis of the data should be performed to further investigate various interacting factors leading to improved fuel-oil savings and cost-effectiveness. An intangible factor of "state/local weatherization agency leadership and quality" that many practitioners feel is an important cause of improved performance could not be addressed by this study, although large differences in mean savings were observed among agencies and states.

Space-heating system tune-ups were not particularly effective at improving the steady-state efficiency of systems and were not associated with statistically significant, higher-than-average savings, although improved seasonal efficiency and system safety and reliability may have resulted.

Tune-ups were performed on some systems that were already operating efficiently, and they did not achieve maximum savings potential on many inefficient systems. The need to use licensed technicians to audit systems and perform the tune-ups led to the extraneous tune-up problems and the increased costs, although increased use of fully qualified technicians might improve performance. The Weatherization Assistance Program should investigate methods of improving the selection and/or application of space-heating system tune-ups and actively study and promote adoption of improved tune-up procedures as a primary technology transfer activity. A committee composed of experts in the field could be assembled to develop recommended approaches and consult with states to verify benefits. State and local weatherization agency data should be collected to further study and refine tune-up techniques.

Air-leakage measurements showed that weatherized houses were more air-tight following weatherization, but still leakier than what is achievable. Although not statistically verifiable, the use of blower doors and installation of wall insulation were two measures that likely led to greater-than-average air-leakage reductions. Additional technology transfer effort is recommended to increase the use of blower doors considering that only half the weatherized houses used a blower door. A guidebook developed by a committee of experts and covering the following topic areas might be a useful technology transfer and training document: air-leakage theory, use of a blower door, measuring air leakage, finding and sealing leakage sites, and incorporating a blower door into a weatherization program. State and local weatherization agency data should be collected to further study the air-leakage reductions being achieved and the tightness of the houses before and after weatherization.

Weatherization appeared to make occupants feel better about their house and house environment. Most occupants felt that their houses were healthy and safe, and this was supported by field inspections. Occupants felt that weatherization made their houses much more affordable to heat and much less drafty.

The split-winter experimental design with submetering worked well in monitoring fuel-oil consumption and allowing fuel-oil savings to be estimated. An attrition rate of less than 15% is attainable in such a test. A service payment to participants approximating lost savings due to delayed weatherization (in order to collect pre-weatherization data) was beneficial to all and increased overall cooperation from agencies and clients. There is always a fear that the payment may be used to purchase additional fuel for space heating and thus add bias to the experiment, but our measurements of indoor temperatures lead us to conclude that this did not happen.

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APPENDIX A. HOUSE CHARACTERISTICS SURVEY

Information on the physical characteristics of the houses and their mechanical systems (space-heating, space-cooling, and water-heating) was collected at the end of the post-weatherization period using the first survey instrument in this appendix. Information on the floor area, volume, number of rooms, and number of heated rooms was also collected at the beginning of the pre-weatherization period using the second survey form.

Version: April 12, 1991

Auditor: ________________
Date: ________________

FUEL-OIL STUDY HOUSE CHARACTERISTICS SURVEY

IDENTIFICATION

House ID: ____________ Subgrantee name: ____

Occupant name: ______________________________________ Phone number: ________________

Occupant address: ____

GENERAL

Type: _____ SFD — single-family detached **MFS** — small (2-4 units) multifamily MH — manufactured or mobile home
SFA — single-family attached **MFL** — large (>4 units) multifamily

A single-family housing unit is a structure that provides living space for one household or family. The structure may be detached, attached on one side, or attached on two sides. Attached houses are considered single-family houses as long as the house itself is not divided into more than one housing unit and has an independent outside entrance. A single-family house is contained within walls that go from the basement (or ground floor, if there is no basement) to the roof. A mobile home with one or more rooms added is a single— family home. Row houses and side-by-side duplexes (twins) are typically single-family houses.

A small multifamily house or building is a structure that is divided into living quarters for two, three, or four families or households. This category also includes houses originally intended for occupancy by one family (or for some other use) that have since been converted to separate dwellings for two to four families. Typical arrangements in these types of living quarters are separate apartments downstairs and upstairs, or one apartment on each of three or four floors. Over-and-under duplexes are typically in this category.

A mobile or manufactured home is a structure that has all the facilities of a dwelling unit but is built on a movable chassis. It may be placed on a permanent or temporary foundation and may contain one room or more. If rooms are added to the structure, it is considered a single-family home.

Are the following systems shared with other housing units:
space-heating system ______ (Y,N)
space-cooling system ______ (Y,N)
water-heating system ______ (Y,N)

If **SFA**, number of attached housing units: ______ (**NA**, 1, 2, ..,) (typically 2 or less)

EXTERNAL DOORS

Door type	Number without storm door	Number with storm door
Hollow core wood door		
Solid core wood door		
Insulated metal door		

House ID: ______

WINDOWS

Window glazing type	Frame type	Storm window	Area (ft^2)

Window glazing type	
SP	single pane
DP	double pane
TP	triple pane
GB	glass block
TE	temporary (cardboard, plastic, etc.)

Frame type	
W	wood
M	metal
V	vinyl
X	other
N	none

Storm window	
W	wood
M	metal
X	other
N	none

FLOOR AREAS AND VOLUMES

Floor	Total area (ft^2)	Intentionally heated area (ft^2)	Intentionally air-conditioned area (ft^2)	Volume (ft^3)
Basement				
First floor				
Second floor				
All other floors				
Total				

An intentionally heated (air conditioned) space is one with equipment and/or distribution outlets designed to maintain a desired temperature in the space. An unintentionally heated (air conditioned) space is one that is heated (cooled) primarily from equipment jacket and/or distribution losses (there is little control over the resulting temperature). A space is not heated (air conditioned) if there is no source of heating (cooling) to alter the natural temperature of the space. For example, a basement heated primarily from equipment jacket and/or distribution system losses is not considered to be an intentionally heated space. A window air conditioner cools only the room the unit is installed in, not adjacent rooms. If a space was designed to be intentionally heated (cooled) but is maintained by the occupant in an unheated (uncoolcd) condition (by closing registers and doors, for example), the space should still be considered a heated (cooled) space with one exception: an unfinished basement or other unfinished room with a distribution system that is always shut off should be considered unintentionally heated (cooled).

Floor heights used to calculate volume are floor to floor except for the top floor, which is floor to ceiling.

Number of intentionally heated stories: ______ (1, 1.5, 2, 2.5, 3, 3.5, 4 or more)

House ID: ______

ATTICS

FINISHED ATTIC AREAS			
	Area (ft²)	Existing insulation	
		Type	Depth (inches)
Collar beam			
Kneewall			
Roof rafter			

UNFINISHED ATTIC AREAS			
Attic type	Floor area (ft²)	Existing insulation	
		Type	Depth (inches)

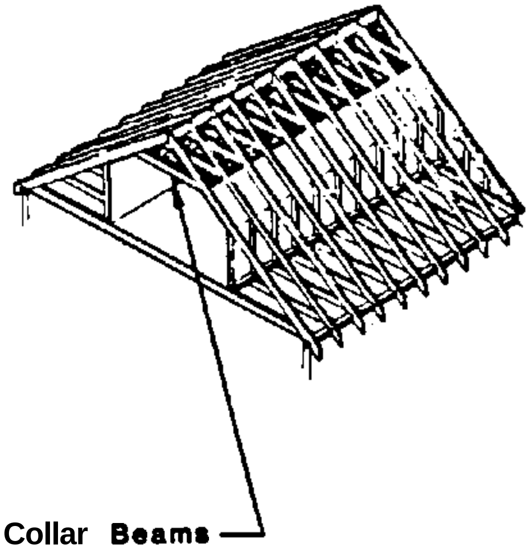
Finished attic areas are defined in the figures on the following page.

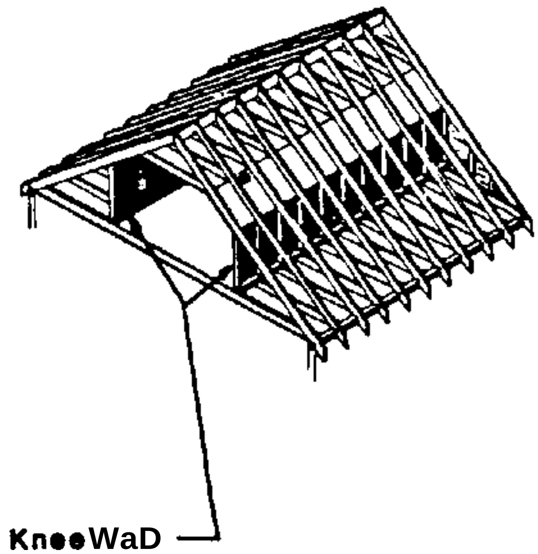
Areas pertain to attic areas adjacent to intentionally heated or air-conditioned spaces. For example, the area above an unconditioned garage should not be included.

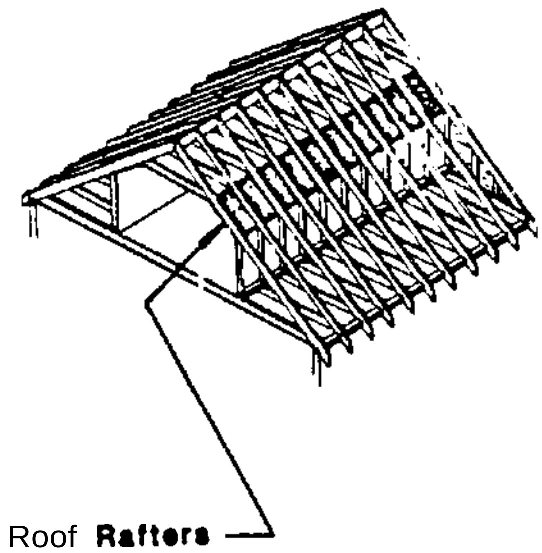
Existing insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglass batt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
V	vermiculite
X	other
N	none

Attic type	
F	floored
U	unfloored
C	cathedral
L	flat roof

Are attic vents present: _____ (Y,N)


Collar Beams


KneeWaD


Roof Rafters

House ID: ______

EXTERIOR WALLS

Wall exposure	Exterior type	Wall type	Gross wall area (ft²)	Insulated sheathing (Y/N)	Existing insulation	
					Type	Depth (inches)

Shared walls found in duplexes and row houses are not exterior walls.

The type of load bearing structure is the wall type. The type of facing on the wall is the exterior type.

Wall exposure	
O	outside
N	non-conditioned attic space
B	buffered space (garage, etc.)

Exterior type	
WO	wood or masonite
AL	aluminum, steel or vinyl
ST	stucco
BR	brick or stone
AS	asphalt shingle
WS	wood shingle
RA	rolled asphalt
N	other
N	none

Wall type	
PF	platform frame
BF	balloon frame
BL	block
ST	stone or masonry
X	other

Insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglass batt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
X	other
N	none

House ID: ______

FOUNDATION SPACES

Type	Space status	Basement or crawl space ceiling area (ft²)	Basement or crawl space ceiling insulation thickness (inches)	Perimeter (band joist)		Wall height		Existing wall insulation	
				Length (ft)	Percent exposed	Total (ft)	Percent above ground	Type	Thickness (inches)

Ceiling area — For slab-on-grade, the area of the intentionally conditioned slab floor.
Perimeter length — Do not include perimeter bordering another foundation space.
Percent exposed — For basements and crawlspaces, the percent of band joist length that is exposed to the outside and not insulated.
Total wall height — Height of basement or crawlspace wall; an estimated average if the height is not uniform.

Foundation type	
B	basement
C	crawlspace
US	uninsulated slab
IS	insulated slab

Foundation space status	
NH	not heated
IH	intentionally heated
UH	unintentionallyheated

Existing wall insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglassbatt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
X	other
N	none

DOMESTIC WATER-HEATING SYSTEM

Fuel:________(NG-natural gas, P-propane, O-oil, K-kerosene, E-electricity, W-wood, S-solar, X-other, N-None)
Type:________(SA-stand alone system, T-tankless [integrated with space-heating system], X-other, N-None)
Is an external blanket insulation used?________(Y,N,NA)
Location: ______ (NH - non-heated space, IH - intentionally heated space, UH - unintentionally heated space)

House ID: ______

APPLIANCES

Appliance	Fuel	Quantity	Location
Cooking range			
Stove top			
Detached oven			
Microwave oven	E		
Refrigerator	E		
Dishwasher	E		
Deep freezer	E		
Clothes washer	E		
Clothes dryer			
Whole house fan	E		
Attic ventilation fan	E		
Well pump	E		
Water bed heater	E		
Other: ________			

Fuel	
NG	natural gas
P	propane
O	oil
K	kerosene
E	electricity
W	wood
C	coal
X	other

Location	
NH	non-heated space
IH	intentionally heated space
UH	unintentionally heated space

AIR CONDITIONERS

Unit type	Nameplate information						Age (years)
	Input (watts)	Voltage (volts)	Current (amps)	Efficiency		Output (Btu/h)	
				EER	SEER		

Unit type	
CAC	central air conditioner
CHP	central heat pump
WAC	window air conditioner
WHP	window heat pump
EC	evaporative cooler
X	other

House ID: ______

SPACE-HEATING SYSTEMS

PRIMARY OIL-FIRED SYSTEM	
System type (see next page)	
System age	years
Original fuel if converted system (see next page or NA)	
Location (see next page)	
Actual installed nozzle size (value and units)	
Vent damper present (Y,N)	
Flame retention head burner present (Y,N)	
Smart thermostat present (Y,N)	
For boilers, outdoor temperature reset present (Y,N,NA)	

AUXILIARY SYSTEMS	
Type (see next page)	Fuel

The primary oil-fired system is the system metered under the study.

DISTRIBUTION SYSTEM

Location	Is any part of the distribution system present in this location? (Y,N,NA)	If present, is the distribution system insulated? (Y,N)	If present, is the structural integrity sound?
Intentionally heated area			
Unintentionally heated area			
Un-heated area			

Does the distribution system include a return system? ____ (Y,N,NA)

Fuel	
NG	natural gas
P	propane
O	oil
K	kerosene
E	electricity
W	wood
C	coal
X	other

Location	
NH	non-heated space
IH	intentionally heated space
UH	unintentionally heated space

SPACE-HEATING SYSTEM TYPES

Central systems		In-space heaters	
1	forced air furnace	Fossil fueled:	
2	gravity furnace	7	room heater
3	steam boiler	8	forced air wall furnace
4	hot water boiler with radiators/convertors	9	gravity wall furnace
5	hot water boiler for slab heating	10	forced air floor furnace
6	heat pump	11	gravity floor furnace
		12	vaporizing pot heater (oil and kerosene)
Other		13	portable kerosene
21	wood or coal stove		
22	fireplace	Electric:	
23	stove top or oven	14	wall
24	other	15	floor
		16	baseboard
		17	ceiling radiant (imbedded cable)
		18	wall or floor radiant (imbedded cable)
		19	portable (cord-connected)
		20	window heat pump

Version: February 6, 1991

Auditor: ____________
Date: ____________

FUEL-OIL STUDY PRE-WEATHERIZATION DATA COLLECTION FORM

IDENTIFICATION

House I.D.:________________ Subgrantee name:________________________________

Occupant name:________________________________ Phone number: ________________

Occupant Address:____

SPACE-HEATING SYSTEM NOZZLE SIZE:______________ (value and units, likely GPH)

HOUSE FLOOR AREA

excluding basement:_______________ square feet

basement only:_______________ square feet

HOUSE VOLUME

excluding basement:_______________ cubic feet

basement only:_______________ cubic feet

ROOMS

How many of each of the following rooms does this house have?

	Number
Bedrooms[1]	________
Full bathrooms[2]	________
Half bathrooms[3]	________
All other rooms[4]	________

How many rooms are currently being heated? ______

---

[1]For one-bedroom efficiency or studio apartment, record "0 bedrooms" and correct number of bathrooms.

[2]Full bathroom is defined as having a sink with running water and flush toilet and bathtub or shower.

[3]Half bathroom is defined as having a toilet or bathtub or shower.

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

APPENDIX B. OCCUPANT QUESTIONNAIRES

Information was collected from the occupants of the houses at the end of the post-weatherization period using the two questionnaires in this appendix. Separate questionnaires were developed for the weathenzed and control houses because of slight wording differences that were required.

version 18W
5/10/91

Interviewer______________

Date of Interview.______________

Time Started______________

FUEL-OIL STUDY OCCUPANT QUESTIONNAIRE
WEATHERIZED HOME

A. Identification

INTERVIEWER INSTRUCTIONS:

Complete Questions A1, A2, and A4 using data from the information sheet before starting the interview.

A1. Household Identifier ______________________________

A2. Name of WAP Applicant ______________________________

SCREENER:

ASK TO SPEAK TO THE APPLICANT NAMED IN QUESTION A2. IF AVAILABLE, READ THE FOLLOWING AND GO TO QUESTION A3.

> 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.

IF THE APPLICANT NAMED DM QUESTION A2 IS NOT AVAILABLE, READ THE FOLLOWING AND THEN ASK QUESTION 1:

> 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.

1. I'd like to speak to a person over eighteen years of age who is knowledgeable about paying the energy bills. Is that person available? (IN ORDER TO QUALIFY, THE RESPONDENT DOES NOT HAVE TO PAY THE CHECK. AS LONG AS THE RESPONDENT IS KNOWLEDGEABLE ABOUT THE ENERGY USE AND/OR BILLS, HE OR SHE QUALIFIES.)

1. YES, THE PERSON YOU ARE SPEAKING TO IS THE RESPONDENT. . . . . CONTINUE WITH QUESTION A3.

2. YES, RESPONDENT IS ANOTHER PERSON. . . ONCE A RESPONDENT IS PRESENT, RETURN TO THE INTRODUCTION AND CONFIRM THAT THE RESPONDENT IS OVER 18 AND IS KNOWLEDGEABLE ABOUT PAYING THE ENERGY BILLS. IF THE RESPONDENT QUALIFIES, CONTINUE WITH QUESTION A3.

3. NO, RESPONDENT IS NOT AVAILABLE. . . . . (NAMES:__________________) IDENTIFY NAMES OF SEVERAL PEOPLE WHO MIGHT BE SUITABLE RESPONDENTS. INFORM THE CURRENT RESPONDENT THAT WE WILL CONDUCT THE INTERVIEW OVER THE TELEPHONE AT A LATER DATE. LEAVE A COPY OF THE EXHIBITS AT THE HOUSE. DO NOT PROCEED WITH THE INTERVIEW.

INTERVIEWER INSTRUCTIONS:

IF RESPONDENT NEEDS INFO: The survey is a part of the Weatherization Assistance Program. The survey is required of every participant in the Fuel Oil Study.

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.

A3. Name of respondent____

Relation to WAP applicant____

[ ] RESPONDENT IS SAME AS WAP APPLICANT

A4. Dates of WAP weatherization work____

A5. I want to confirm that the weatherization work done by the Weatherization Assistance Program took place on (READ DATES FROM QUESTION A4). (RECORD DATES BELOW IF RESPONDENT GIVES DIFFERENT DATES.)

DATES ______________________________

[ ] RESPONDENT CONFIRMS THAT WEATHERIZATION TOOK PLACE ON THE SAME DATES AS QUESTION A4.

[ ] DON'T REMEMBER

INTERVIEWER **INSTRUCTIONS:**

If respondent has trouble remembering the dates in Questions A6, A7, and A8, probe for:

- Season
- Major life event
- Major news story or political event happening at that time

Then, ask for year (and month) again.

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

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

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

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

IF "1989" OR LATER ON QUESTION A7, ASK:

A8. In which month did you move in?*

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

B. Major Heating Fuel

Next, I will ask some questions about the fuels you used to heat your home last winter before and after weatherization on (READ DATES FROM QUESTION A4). *Throughout the survey, when I ask about last winter before weatherization, I mean October, November, and December of 1990. When I ask about last winter after weatherization, I mean February, March, and April of 1991.*

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 hearing system.

(HAND RESPONDENT EXHIBIT BOOKLET)

B1. Please look at Exhibit B1. What was the **one main heating fuel** used for heating your home last 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	[ ]	[ ]

B2. Please look at Exhibit Bl again. You mentioned that your **main heating fuel** used last winter **before** weatherization was (FUEL FROM QUESTION Bl). What **other** fuels were used to heat your home last 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 last winter **before** weatherization-- (FUEL FROM QUESTION Bl) -- 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 last winter after weatherization.

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

	B4 Main Fuel (Mark only one)	B5 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood	f]	[ ]
Bottled gas (LPG or Propane)	[ ]	[ ]
Fuel oil	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity	[ ]	[ ]
Coal or coke	[ ]	[ ]
Wood	[ ]	t]
Solar collectors	[ ]	[ ]
Other (specify)____________________	[ ]	[3
NO FUELS USED	[ ]	[ ]
DON'T KNOW	[ ]	[ ]

B5. Please look at Exhibit Bl again. You mentioned that your main heating fuel used last winter after weatherization, was (FUEL FROM QUESTION B4). What other fuels were used to heat your home last winter 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 mam heating fuel used last winter 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. Last winter **before** the weatherization work was done, did you use any of the following to **help** heat your home? (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. Last winter **after** the weatherization work was done, did you use any of the following to **help** heat your home? (CHECK AS MANY AS WERE USED IN COLUMN B7b.)

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 rum to Exhibit B8. Please tell me how often you used the following to help heat your home last winter **after** the weatherization work was done, as compared to last 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 last 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 last winter before weatherization. How many people were living in your home last winter after weatherization?

____
NUMBER OF RESIDENTS

[ ] SAME NUMBER AFTER WEATHERIZATION AS BEFORE WEATHERIZATION

C3. Were any of the people living in your home last 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. fuel oil	[]	[]	[ ]
2. electricity	[ ]	[ ]	[ ]
3. natural gas	[ ]	[ ]	[ ]
4. property tax	[ ]	[ ]	[ ]
5. insurance (house or renter's)	[ ]	[ ]	[ ]
6. water	[ ]	[ ]	[ ]
7. garbage	[ ]	[ ]	[ ]
8. other (specify):__________________	[ ]	[ ]	[ ]

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 last winter before weatherization, I mean October, November, and December of 1990. When I ask about last winter after weatherization, I mean February, March, and April of 1991. Weatherization work was done to your home on (READ DATES FROM QUESTION A4).

> 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 last winter before weatherization	D2B Number heated last winter 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 last winter before weatherization (RECORD ABOVE ON COLUMN D2A.)

D2b. And how many (READ TYPE OF ROOM) were heated last winter 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. Last 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. Last winter 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 last winter. (REMIND RESPONDENT IF NECESSARY): *Remember that when I ask about last winter before weatherization, I mean October, November, and December of 1990. When I ask about last winter after weatherization, I mean February, March, and April of 1991. Weatherization work was done to your home on* (READ DATES FROM QUESTION A4).

F1a. Last winter **before** your home was weatherized, was there ever a time when you wanted to use your fuel-oil heating system, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken?**	**[ ]**	**[ ]**
You **ran out** of fuel oil?	[ ]	[ ]
The utility company **discontinued** your electric service?	**[ ]**	**[ ]**

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

F1b. Thinking about these times that you went without heat, last 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. Last winter **after** your home was weatherized was there ever a time when you wanted to use your fuel-oil heating system, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was broken?	[ ]	[ ]
You **ran out** of fuel oil?	[ ]	[ ]
The utility company **discontinued** your electric service?	[ ]	[ ]

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

F2b. Thinking about these times that you went without heat, last winter 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 A4), was any home repair or major house renovation that would affect energy use done on your home by yourself or other organization between November 1990 and April 1991?

[ ] Yes
[ ] No (GO TO QUESTION F6)
[ ] DON'T KNOW (GO TO QUESTION F6)

IF YES ON QUESTION F3, ASK:

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

	MONTH
(1) ____________	______
____________	______
(2) ____________	______
____________	______
(3) ____________	______
____________	______
(4) ____________	______
____________	______

F5. In which month was the work done? (RECORD UNDER COLUMN FOR MONTH ABOVE.)

*Now **I'm going** to ask you to describe the number of people in your home **during** the 1990 Thanksgiving holiday period and the **Christmas** holiday period compared to the rest of the winter. By number of people in your home I am referring to **overnight** visiting not visiting for meals or parties.*

F6. Please look at Exhibit F6. First, how did the number of people in your home during the 1990 Thanksgiving holiday and weekend compare to other parts of the winter? (PROBE IF NEEDED: By number of people in your home I am referring to **overnight** visiting not visiting for meals or parties.)

[ ] Fewer people than other parts of the winter
[ ] About the same number of people as other parts of the winter
[ ] More people than other parts of the winter
[ ] DON'T KNOW/DON'T REMEMBER

F7. Please look at Exhibit F6 again. And how did the number of people in your home during the 1990 Christmas holiday through New Year's compare to the other parts of the winter? (PROBE IF NEEDED: By number of people in your home I am referring to overnight visiting not visiting for meals or parties.)

[ ] Fewer people than other parts of the winter
[ ] About the same number of people as other pans of the winter
[ ] More people than other parts of the winter
[ ] DON'T KNOW/DON'T REMEMBER

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. 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 last 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 last 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 last winter 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 last winter 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. 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 last 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 last winter after weatherization?

AFTER

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

G3. Please look at Scale G3. Using a scale of 1 to 7, where 1 is very poor, 4 is acceptable, and 7 is very **healthy,** how would you rate the health of household members last winter **before** weatherization? By health I mean illnesses such as colds, flus, allergies, frequent headaches, frequent nausea, or arthritis.

BEFORE

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

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

AFTER

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

G4. 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 last 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 last winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

G5. 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 last 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 last winter after weatherization?

AFTER

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

G6. Please look at Scale G6. Using a scale of 1 to 7, where 1 is very much lower, 4 is about the same, and 7 is very much higher, how would you rate the property value of your home after weatherization as compared to before weatherization? By property value, I mean the dollar value of the home if sold.

1	2	3	4	5	6	7	8
very much lower			about the same			very much higher	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.________________________

TIME ENDED:____________________

version 18C
5/10/91

Interviewer____________________

Date of Interview.________________

Time Started____________________

FUEL-OIL STUDY OCCUPANT QUESTIONNAIRE
CONTROL HOME

A. Identification

INTERVIEWER INSTRUCTIONS:
Complete Questions A1 and A2 using data from the information sheet before starting the interview.

Al. Household Identifier ____

A2. Name of WAP Applicant ______________________________________

SCREENER:

ASK TO SPEAK TO THE APPLICANT NAMED IN QUESTION A2. IF AVAILABLE, READ THE FOLLOWING AND GO TO QUESTION A3.

> 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.

IF THE APPLICANT NAMED IN QUESTION A2 IS NOT AVAILABLE, READ THE FOLLOWING AND THEN ASK QUESTION 1:

> 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.

1. I'd like to speak to a person over eighteen years of age who is knowledgeable about paying the energy bills. Is that person available? (IN ORDER TO QUALIFY, THE RESPONDENT DOES NOT HAVE TO PAY THE CHECK. AS LONG AS THE RESPONDENT IS KNOWLEDGEABLE ABOUT THE ENERGY USE AND/OR BILLS, HE OR SHE QUALIFIES.)

1. YES, THE PERSON YOU ARE SPEAKING TO IS THE RESPONDENT.	CONTINUE WITH QUESTION A3.
2. YES, RESPONDENT IS ANOTHER PERSON. .	ONCE A RESPONDENT IS PRESENT, RETURN TO THE INTRODUCTION AND CONFIRM THAT THE RESPONDENT IS OVER 18 AND IS KNOWLEDGEABLE ABOUT PAYING THE ENERGY BELLS. IF THE RESPONDENT QUALIFIES, CONTINUE WITH QUESTION A3.
3. NO, RESPONDENT IS NOT AVAILABLE.	(NAMES:____________________) IDENTIFY NAMES OF SEVERAL PEOPLE WHO MIGHT BE SUITABLE RESPONDENTS. INFORM THE CURRENT RESPONDENT THAT WE WILL CONDUCT THE INTERVIEW OVER THE TELEPHONE AT A LATER DATE. LEAVE A COPY OF THE EXHIBITS AT THE HOUSE. DO NOT PROCEED WITH THE INTERVIEW.

INTERVIEWER INSTRUCTIONS:

IF RESPONDENT NEEDS INFO: The survey is a part of the Weatherization Assistance Program. The survey is required of every participant in the Fuel Oil Study.

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.

A3. Name of respondent.____

Relation to WAP contact____

[ ] RESPONDENT IS SAME AS WAP CONTACT

A3a. Has any weatherization work been done to your home by the Weatherization Assistance program before April 1991?

[ ] No **(GO** TO QUESTION **A4)**
[ ] Yes (PROBE AND INSPECT HOME, IF WEATHERIZED BY WAP, SWITCH TO WEATHERIZED HOME QUESTIONNAIRE.)

INTERVIEWER INSTRUCTIONS:

If respondent has trouble remembering the dates in Questions A4, A5, and A6, probe for:

- Season
- Major life event
- Major news story or political event happening at that time

Then, ask for year (and month) again.

A4. In what year was this home built? Just your estimate.*

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

A5. In what year did your family move into this home?*

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

IF "1989" OR LATER ON QUESTION A5, ASK:

A6. In which month did you move in?*

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

B. Major Heating Fuel

Next, I will ask some questions about the fuels you used to heat your home last winter before January 1991 and after January 1991. Throughout the survey, when 1 ask about last winter before January 1991, I mean October, November, and December of 1990. When I ask about last winter after January 1991, I mean February, March, and April of 1991. We are asking about these rime frames because other houses being studied were weather ized in January 1991,

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.

(HAND RESPONDENT EXHIBIT BOOKLET)

B1. Please look at Exhibit B1. What was the one main heating fuel used for heating your home last winter before January 1991?*

	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 Bl again. You mentioned that your main heating fuel used last winter before January 1991 was (FUEL FROM QUESTION Bl). What other fuels were used to heat your home last winter before January 1991 -- 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 mam heating fuel used last winter before January 1991 -- (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 last winter after January 1991.

B4. Please look at Exhibit B1 again. What was the **one main heating fuel** used for heating your home last winter **after** January 1991?*

	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 Bl again. You mentioned that your **main heating** fuel used last winter **after** January 1991, was (FUEL FROM QUESTION B4). What **other** fuels were used to heat your home last winter after January 1991 -- 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 last winter **after** January 1991 -- (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. Last winter before January 1991, did you use any of the following to help heat your home? (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)	f]
[ ]	Other (specify):________________	[ ]
[ ]	NONE	[ ]

B7b. Please look at Exhibit B7 again. Last winter after January 1991, did you use any of the following to help heat your home? (CHECK AS MANY AS WERE USED IN COLUMN B7b.)

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 JANUARY 1991:

B8. Please rum to Exhibit B8. Please tell me how often you used the following to help heat your home last winter after January 1991 as compared to last winter before January 1991. Did you use it less, about the same, or more after January 1991 as compared to before January 1991? (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 last winter **before** January 1991 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 Cl) people living in your home last winter before January 1991. How many people were living in your home last winter after January 1991?

____
NUMBER OF RESIDENTS

[ ] SAME NUMBER AFTER JANUARY 1991 AS BEFORE JANUARY 1991

C3. Were any of the people living in your home last winter before January 1991 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
X. fuel oil	[]	[]	[]
2. electricity	[ ]	[ ]	[ ]
3. natural gas	[ ]	[J	[ ]
4. property tax	[ ]	[ ]	f]
5. insurance (house or renter's)	[ ]	[ ]	[ ]
6. water	[ ]	[J	[ ]
7. garbage	[]	[]	[]
8. other (specify):________________	[ ]	[ ]	[ ]

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 last winter before January 1991, I mean October, November, and December of 1990. When I ask about last winter after January 1991, I mean February, March, and April of 1991.

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.)*

	Dl Total Number	D2A Number heated last winter before January 1991	D2B Number heated last winter after January 1991
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 last winter before January 1991 (RECORD ABOVE ON COLUMN D2A.)

D2b. And how many (READ TYPE OF ROOM) were heated last winter after January 1991? (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. Last winter before January 1991, did you keep your home at the same temperature at all tiroes 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 January 1991, 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 January 1991, at what temperature did you usually keep your home during the day when someone was at home?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E1d. Before January 1991, 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 January 1991, at what temperature did you usually keep your home during sleeping hours?*

Degrees Fahrenheit ________
[ ] HEAT TURNED OFF

(ASK EVERYONE:)

E2a. Last winter **after** January 1991, 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** January 1991, 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** January 1991, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2d. **After** January 1991, 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** January 1991, 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 last winter. (REMIND RESPONDENT IF NECESSARY): *Remember that when I ask about last winter before January 1991, I mean October, November, and December of 1990. When I ask about last winter after January 1991, I mean February, March, and April of 1991.*

F1a. Last winter before January 1991, was there ever a time when you wanted to use your fuel-oil heating system, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was broken?	[ ]	[ ]
You ran out of fuel oil?	[ ]	[ ]
The utility company discontinued your electric service?	[ ]	[ ]

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

F1b. Thinking about these times that your went without heat, last winter before January 1991, 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. Last winter after January 1991, was there ever a time when you wanted to use your fuel-oil heating system, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken?**	[ ]	[ ]
You **ran out** of fuel oil?	[ ]	[ ]
The utility company **discontinued** your electric service?	[ ]	[ ]

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

F2b. Thinking about these times that your went without heat, last winter **after** January 1991, 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 any home repair or major house renovation that would affect energy use done on your home by yourself or other organization between November 1990 and April 1991?

[ ] Yes
[ ] No (GO TO QUESTION F6)
[ ] DON'T KNOW (GO TO QUESTION F6)

IF YES ON QUESTION F3. ASK:

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

		MONTH
(1)	________________	________
	________________	________
(2)	________________	________
	________________	________
(3)	________________	________
	________________	________
(4)	________________	________
	________________	________

F5. In which month was the work done? (RECORD UNDER COLUMN FOR MONTH ABOVE.)

Now I'm going to ask you to describe the number ofpeople in your home during the 1990 Thanksgiving holiday period and the Christmas holiday period compared to the rest of the winter. By number ofpeople in your home I am referring to ***overnight*** *visiting* ***not*** *visiting for meals or parties.*

F6. Please look at Exhibit F6. First, how did the number of people in your home during the 1990 Thanksgiving holiday and weekend compare to other pans of the winter? (PROBE IF NEEDED: By number of people in your home I am referring to **overnight** visiting **not** visiting for meals or parties.)

[ ] Fewer people than other parts of the winter
[ ] About the same number of people as other parts of the winter
[ ] More people than other parts of the winter
[ ] DON'T KNOW/DON'T REMEMBER

F7. Please look at Exhibit F6 again, And how did the number of people in your home during the 1990 Christmas holiday through New Year's compare to the other pans of the winter? (PROBE IF NEEDED: By number of people in your home I am referring to **overnight** visiting **not** visiting for meals or parties.)

[ ] Fewer people than other parts of the winter
[ ] About the same number of people as other parts of the winter
[ ] More people than other parts of the winter
[ ] DON'T KNOW/DON'T REMEMBER

G. Impacts on Health, Safety, Comfort, Affordability

My next questions askfor your opinion about the health, safety, comfort, and value ofyour home,

G1a. 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 last winter before January 1991?

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 last winter before January 1991? (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 last winter after January 1991?

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 last winter after January 1991? (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. 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 last winter **before** January 1991?

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 last winter **after** January 1991?

AFTER

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

G3. Please look at Scale G3. Using a scale of 1 to 7, where 1 is very poor, 4 is acceptable, and 7 is very healthy, how would you rate the health of household members last winter **before** January 1991? By health I mean illnesses such as colds, flus, allergies, frequent headaches, frequent nausea, or arthritis.

BEFORE

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

Using the same scale (REPEAT SCALE IS NECESSARY), how would you rate the health of household members last winter **after** January 1991?

AFTER

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

G4. 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 last winter **before** January 1991? 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 last winter after January 1991?

AFTER

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

G5. 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 last winter before January 1991?

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 last winter **after** January 1991?

AFTER

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

G6. Please look at Scale G6. Using a scale of 1 to 7, where 1 is very much lower, 4 is about the same, and 7 is very much higher, how would you rate the property value of your home after January 1991 as compared to before January 1991? By property value, I mean the dollar value of the home if sold.

1	2	3	4	5	6	7	8
very much lower			about the same			very much higher	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.________________________________

TIME ENDED:____________________

APPENDIX C. WEATHERIZATION INFORMATION SURVEY

Information on the weatherizations performed in each of the weatherized houses (installation dates, energy conservation measures installed, costs, etc.) and program and administration costs for each local weatherization agency was collected using the first survey provided in this appendix following weatherization. The second survey was used to collect a more limited amount of information on the control houses.

Version 3
2/21/91

Form completed by: ______________________
Date: ______________________

FUEL-OIL STUDY WEATHERIZATION INFORMATION SURVEY

A. IDENTIFICATION

A1. House Identifier: (TO be completed by ORNL) ______________________

A2. Subgrantee Name: ______________________

A3. Occupant Name: ______________________

A4. Occupant Phone Number: ______________________

A5. Occupant Address: ______________________

____

B. GENERAL INFORMATION

B1. What was the household's income on the application form at the time when its eligibility was verified for the services it received in the 1990 program year?

$________________

B2. Weatherization work was performed primarily in this house in January 1991. What were the exact start and stop dates for this work (month, day, and year)? (Dates for weatherization work performed at other times will be identified in Section G.)

Weatherization work started on________________________.

Weatherization work was completed on ________________________.

B3. What electric utility company serviced this household and what was the household's utility account number?

Electric utility:____.

Account number: ____.

C. WEATHERIZATION MEASURES INSTALLED

Please check any of the measures listed that were installed in this dwelling during the time period identified in Question B2. (Measures installed at other times will be identified in Section G.) Indicate whether they were installed by in-house crew or contractor. If measures that are not listed were installed, please describe them in the appropriate "Other" category.

	Installed by: In-house crew	Installed by: Contractor
C1. Insulation		
Attic Insulation (installed for the first time)	[ ]	[ ]
Attic Insulation (added to existing insulation)	[ ]	[ ]
*Wall Insulation (normal technique)	[ ]	[ ]
*Wall Insulation (high-density technique)	[ ]	[ ]
Floor Insulation	[ ]	[ ]
Rim or Band Joist Insulation	[ ]	[ ]
Other Envelope Insulation (Specify: ______________________ ______________________)	[ ]	[ ]

The "normal technique" for installing wall insulation is characterized by blowing cellulose or fiberglass insulation into exterior wall cavitites to average densities using a two-hole, gravity-blow installation method. The "high-density technique" is characterized by blowing cellulose insulation into exterior wall cavities to high densities using a one-hole, tube-fill installation method. Under the "high-density technique," special attention is focused on sealing air leakage sites while insulating the walls; air bypasses are identified during the installation process and sealed by plugging the air-leakage pathways with cellulose.

	Installed by: In-house crew	Installed by: Contractor
C2. Air Leakage Control		
General Caulking and Weatherstripping (door and window)	[ ]	[ ]
Air sealing, emphasizing by-passes with blower door testing)	[ ]	[ ]
Air sealing, emphasizing by-passes without blower door testing)	[ ]	[ ]
Distribution System	[ ]	[ ]
Other Infiltration Reduction (Specify: ______________________ ______________________)	[ ]	[ ]

	Installed by: In-house crew	Contractor
C3. Water Heating System		
Water Heater Tank Insulation	[ ]	[ ]
Entire Water Heating System Replacement	[ ]	[ ]
Pipe Insulation	[ ]	[ ]
Low How Shower Heads	[ ]	[ ]
Temperature Reduction	[ ]	[ ]
Other Water Heater Measures	[ ]	[ ]
(Specify:________________________________ ____)		
C4. Structural Repairs (full or partial)		
Attic Ventilation	[ ]	[ ]
Roof	[ ]	[ ]
Doors	[]	[ ]
Replacement of doors	[ ]	[ ]
Windows/Glazing	[ ]	[ ]
Replacement of windows	[ ]	[ ]
Walls	[ ]	[ ]
Floor	[ ]	[ ]
Other Structural Repairs	[ ]	[ ]
(Specify:________________________________ ____)		
C5. Windows and Doors		
Storm Windows (How many?_________)	[ ]	[ ]
Storm Doors	[ ]	[ ]
Window Films or Shades	[ ]	[ ]
Other Window or Door Treatments	[ ]	[ ]
(Specify:________________________________ ____)		

	Installed by: In-house crew	Contractor
C6. Space Heating System		
Clean and Tune-up	[ ]	[ ]
Entire Heating System Replacement	[ ]	[ ]
Set-back Thermostat	[ ]	[ ]
Heating System Component Retrofits	[ ]	[ ]
(Specify:____________________)		
Safety Problem Fixed	[ ]	[ ]
(Specify:__________________________________)		
Repairs	[ ]	[ ]
(Specify:__________________________________)		
Other Heating System Modifications	[ ]	[ ]
(Specify:________________________________ ____)		
C7. Space Cooling System		
Tune-up . . . . (e.g., cleaning, controls adjustment, filter replaced)	[ ]	[ ]
Entire Air-conditioning System Replacement	[ ]	[ ]
Fans Installed or Replaced	[ ]	[ ]
Set-back Thermostat	[ ]	[ ]
Other Cooling System Modifications	[ ]	[ ]
(Specify:________________________________ ____)		
C8. Other Health and Safety Repairs or Improvements		
Smoke Detectors	[ ]	[ ]
Radon Testing	[ ]	[ ]
Carbon Monoxide Testing	[ ]	[ ]
Other	[]	[]
(Specify:________________________________ ____)		

D. SERVICE DELIVERY PROCEDURES

Selection of Measures

D1. Please check the type of procedure that was used to select the measures that were installed in this dwelling during the time period identified in Question B2. (CHECK ALL THAT APPLY)

[ ] Envelope measures were selected using a priority list (i.e., a checklist 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 dollar 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 dollar invested
[ ] Selection of envelope and space-heating system measures was made simultaneously under one approach rather than separately using two distinct procedures.
[ ] Other measure selection procedures. (Specify:____________________________

____)

Use of Diagnostics

D2. Please check the type of diagnostic procedures that were used in this dwelling to perform the work during the time period identified in Question B2. (CHECK ALL THAT APPLY)

[ ] Blower door testing was used to find leakage areas for sealing
[ ] Blower door testing was used to measure air leakage rates
[ ] Blower door testing was used to determine when to stop work using cost-effectiveness guidelines (not minimum ventilation guidelines)
[ ] Distribution system diagnostics were used to find leakage areas for sealing
[ ] Distribution system diagnostics were used to determine system balancing
[ ] Infrared scanning was used
[ ] Indoor air quality testing was used
[ ] Heating system efficiency testing was used
[ ] A heating system safety inspection was conducted
[ ] Other diagnostic procedures. (Specify;________________________________

____)

Quality Control

D3. Please indicate the type of quality control inspection this house received following the work performed during the time period identified in Question B2. (CHECK ALL THAT APPLY)

[ ] A visual quality control inspection after weatherization for envelope measures
[ ] A quality control inspection after weatherization for envelope measures that used blower door testing as a diagnostic tool
[ ] A quality control inspection after weatherization for envelope measures that used infrared scanning as a diagnostic tool
[ ] A visual quality control inspection after weatherization for heating system measures
[ ] A quality control inspection after weatherization for heating system measures that used diagnostic tools such as combustion efficiency testing
[ ] Other quality control procedures. (Specify:_______________________________

____)

Client Education

D4. Please check the types of client education that were provided to this house during the time period identified in Question B2. (CHECK ALL THAT APPLY)

[ ] Literature was mailed or left with client
[ ] In-person client education was provided
[ ] Other (Specify:____

____)

E. COSTS: MATERIALS, LABOR, INSTALLATION OVERHEAD AND PROGRAM MANAGEMENT

<u>Definitions and Instructions</u>

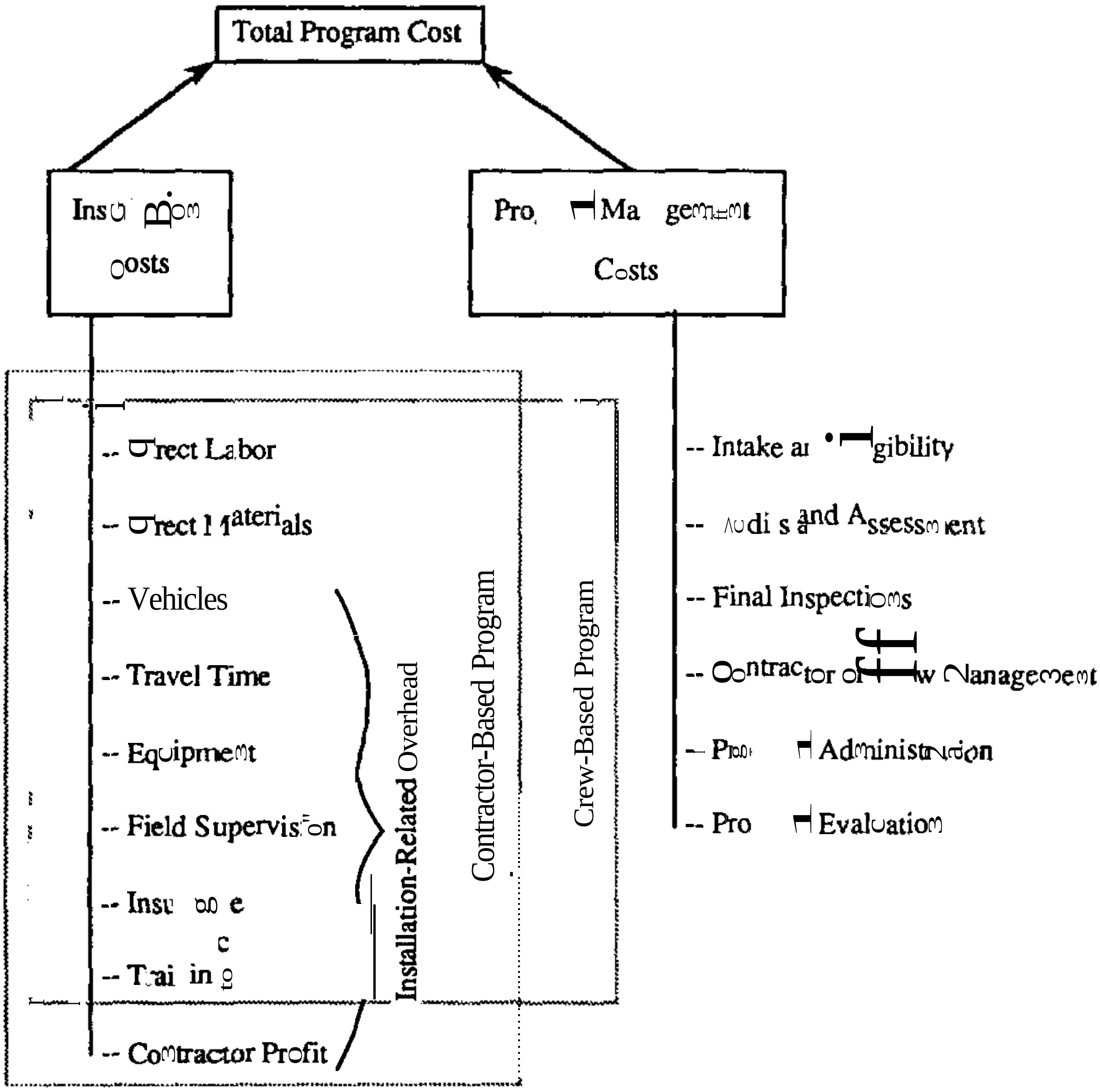
This page and Figure 1 on the following page provide background information for completing questions El to E4 on pages 10 to 12. The total cost of a program can be divided into installation costs and program management costs (Fig.1). Total installation costs include the costs of materials, direct labor and overhead expenses that are directly related to the installation process, such as the costs of vehicles, travel, equipment, insurance, field supervision, and training. When contractors deliver services, these installation overhead expenses are included, along with a profit, in the charges made for a job. When agency crews do the work, some of the installation overhead expenses may not be tracked directly on a per-house basis. As a result, there are separate questions for crew vs. contractor installation costs.

If a job is crew-based, supply the materials costs (Question El), calculate the direct labor costs (Question E2), and estimate the average per-house cost of installation-related overhead expenses (Question E2). To arrive at the overhead expense estimate, for example, your agency's costs for vehicles, equipment, liability insurance, training, travel time, field supervision and any other installation-related expenses in the 1990 program year (PY) should be summed and then divided by the number of homes weatherized in the 1990 program year. If a job is contractor-based, supply the materials costs (Question El) and the total installed costs (Question E3). If both crews and contractors worked on a house, complete all three questions (Questions E1, E2, and E3). In completing Questions E1, E2, and E3, costs should be for measures installed in this dwelling during the time period identified in Question B2. (Costs for weatherization work performed at other times will be identified in Section G.)

In addition, both crew-based and contractor-based programs should estimate an average program management cost per house weatherized. The program management cost should be calculated by subtracting the total installation costs (labor + materials + installation-related overhead) for all houses weatherized in PY 1990 from the total agency budget (in PY 1990). The total program management cost should then be divided by the number of houses weatherized (in PY 1990) to produce an average per-house program management cost (Question E4).

We realize that different agencies track costs in different ways. Please just use your best judgement in estimating the average installation-related overhead and the average program management expenses.

Figure 1. Program Cost Categories



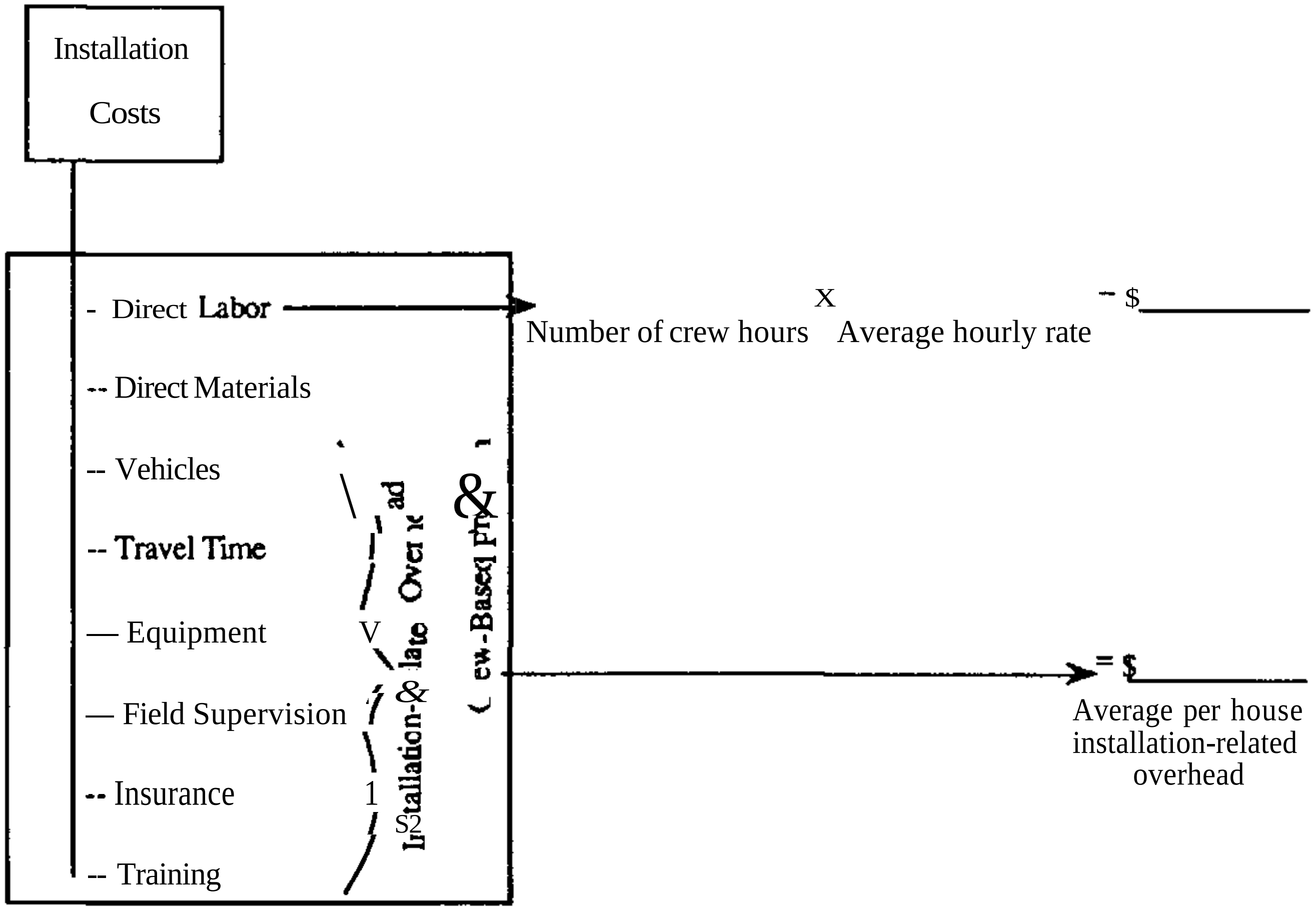
QUESTION El: BREAKDOWN OF MATERIALS COSTS

In the chart below please fill in the crew-based and/or contractor-based materials cost of the measures that were installed in this dwelling during the time period identified in Question B2. Do not include labor, administrative or program support costs here. Do include costs covered by all sources of funding (i.e., PVE, LIHEAP, or utilities). If you cannot provide the costs by measure, just enter the TOTAL materials costs in the box at the bottom.

	Crew-Based Materials Costs	Contractor-Based Materials Costs
Insulation		
attic	$ ______	$ ______
wall	$ ______	$ ______
other	$ ______	$ ______
Air Leakage Control	$ ______	$ ______
Water Heating System Measures	$ ______	$ ______
Structural Repairs	$ ______	$ ______
Windows and Doors	$ ______	$ ______
Space Heating System		
retrofit	$ ______	$ ______
replacement	$ ______	$ ______
Space Cooling System		
retrofit	$ ______	$ ______
replacement	$ ______	$ ______
Other	$ ______	$ ______
	$	$
	Crew-Based Total Materials Costs	Contractor-Based Total Materials Costs

QUESTION E2: CREW-BASED INSTALLATION COSTS

Directions: Please fill in the number of crew hours for this house from information in your files for work performed during the time period identified in Question B2. Please fill in your best estimate of the average hourly rate for your crew and multiply this by the number of hours to produce an estimate of the direct labor costs. Estimate the average installation-related overhead by following the directions in the box at the beginning of Section E (page 8).



QUESTION E3: CONTRACTOR-BASED INSTALLATION COSTS

Directions: Please fill in the total installation costs billed by contractors for this house for work performed during the time period identified in Question B2. This should include all the cost categories listed above (include the materials costs reported on page 10 in this total, as well as labor costs and installation-related overhead) plus the contractor's profit.

Total Installed Cost $________________________________

QUESTION E4: AVERAGE PROGRAM MANAGEMENT COSTS

Total Program Costs for PY 1990 $________

— Total Installation Costs* for All Houses Weatherized in PY 1990 $________

*Add all direct materials costs, labor costs, and installation-related overhead together to obtain this cost figure.

Total Program Management Costs → $________

-- Intake and Eligibility

-- Audits and Assessment

-- Final Inspections

— Contractor or Crew Management

- Program Administration

- Program Evaluation

Average per house** program management cost $________

**Divide the total program management costs for PY 1990 by the number of houses weatherized in PY 1990.

F. FUNDING SOURCES

Fl. What percentage of the funds spent on this house as identified in Section E were funds from DOE's WAP?

_______________%

F2. If funds from non-DOE sources were used, were they all used according to DOE guidelines?

[ ] Yes
[ ] No

F3. Some program management costs (such as client intake and eligibility checks, or office space and expenses) may be absorbed by other programs or agencies (e.g., LIHEAP, Councils on Aging). What percentage of your program management costs would you estimate are absorbed by other programs or agencies?

_______________%

G. OTHER WEATHERIZATION MEASURES INSTALLED AND THEIR COSTS

G1. Space-heating system measures may have been installed in this dwelling at a different time period than that identified in Question B2 (at the time houses were selected for the study, for example). If so, check any of the measures that were installed. Indicate whether they were installed by in-house crew or contractor.

	Installed by: In-house crew	Contractor
Clean and Tune-up	[ ]	[ ]
Entire Heating System Replacement	[ ]	[ ]
Set-back Thermostat	[ ]	[ ]
Repairs	[ ]	[ ]
(Specify:________________________________)		
Heating System Component Retrofits	[ ]	[ ]
(Specify:________________________________)		
Safety Problem Fixed	[ ]	[ ]
(Specify:________________________________)		
Other Heating System Modifications	[ ]	[ ]
(Specify:________________________________)		

G2. What were the costs of the measures identified in Question G1 (refer to Section E for directions)?

Material costs:

	crew-based	contractor-based
retrofit	$____________________	$____________________
replacement	$____________________	$____________________
Total	$____________________	$____________________

Crew-based installation costs;

________________ X ________________ - $________________

Number of crew hours | Average hourly rate | Direct labor costs

Contractor-based installation costs:

Total installation cost: $________________

G3. What percent of the funds identified in Question G2 were funds from DOE's WAP?

____________%

G4. In Question G2 if funds from non-DOE sources were used, were they all used according to DOE guidelines?

[ ] Yes
[ ] No

G5. What were the exact installation dates (month, day, and year) for the measures identified in Question Gl?

Installation started on ______________________________

Installation completed on ______________________________

G6. Were any measures other than those identified in Questions Cl - C8 and Gl installed in this dwelling? If so, please describe the measures installed, their costs, the percentage of funds from DOE's WAP, whether the funds were used according to DOE guidelines, and when the installations were performed.

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Version: March 20, 1991

Form Completed by: ______________________________
Date: ______________________________

FUEL-OIL STUDY CONTROL HOUSE INFORMATION SURVEY

IDENTIFICATION

House identifier: ______________________________

Subgrantee name: ______________________________

Occupant name: ______________________________

Occupant phone number: ______________________________

Occupant address: ______________________________

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GENERAL INFORMATION

What was the household's income on the application form at the time when its eligibility was verified for the weatherization services it will receive in May or June 1991?

$__________________

What electric utility company serviced this household and what was the household's utility account number?

Electric utility: ______________________________

Account number: ______________________________

WEATHERIZATION MEASURES

The control houses will not be weatherized by your agency until May or June 1991. Nevertheless, your agency may have already installed some measures in this dwelling for various reasons (for safety reasons at the time houses were selected for the study, for example). If any measures were installed, please describe them and identify when the installations were performed.

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APPENDIX D. AIR-LEAKAGE MEASUREMENT TEST PROCEDURE

Air-leakage measurements were made in all the houses before and after weatherization following this **procedure.**

Version: April 26, 1991

AIR-LEAKAGE MEASUREMENT TEST PROCEDURE

OBJECTIVE

The objectives of this procedure are to

1. provide the necessary measurements to calculate, for single-family houses, the air flow rate with the house depressurized 50Pa below ambient, the equivalent or effective leakage area[1], and air exchange rate[1] (if the number of conditioned stories is known);

2. examine the air tightness of the house as constructed, including all intentional and non-intentional openings in the envelope; and

3. ensure comparability of measurements performed by different contractors using different brands of blower doors.

Although this procedure does not fully comply with ASTM Standard E779-87[2] especially regarding pressurized measurements, it generally follows the principles contained in the standard.

PRE-TEST PROCEDURE

House Preparation

The house should be prepared for measurement as follows:

1. Close all fireplace and wood stove dampers, glass doors, and other flue openings. Have occupant extinguish all fires. Remove ashes or place wet cloths or newspapers over cold ashes.

2. Turn off exhaust fans, dryers, space-heating systems, water-heating systems, and gas-stoves.

3. Close all windows and exterior doors, including doors to garages and other such buffer spaces that are not heated. A heated space is defined to be a space with permanent space-heating equipment and/or distribution outlets designed to maintain a desired temperature in the space. A space (such as a basement) that is heated primarily from equipment jacket and/or distribution losses (there is little control over the resulting temperature) is not a heated space.

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[1]Handbook of Fundamentals. American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1989.

[2]Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. The American Society for Testing and Materials, 1987.

4. Open all interior doors (except for closets) so that all interior heated space is connected, including heated basements (if only portions of the basement are heated, open all doors necessary to connect these heated basement areas with other heated areas). If a space was designed to be a heated space but is maintained by the occupant in an unheated condition, the space should still be considered a heated space with one exception: an unfinished basement or other unfinished room with a distribution system that is always closed off should not be considered a heated space.

5. Record on the Blower-Door Test Data Sheet the exclusion/inclusion of buffer spaces, zoned rooms, and basements in order that the post-weatherization test can be performed on the same heated space of the house.

Equipment Set-Up

All equipment should be kept at as close to 70°F as possible while in transit and brought into the house immediately upon arrival. Equipment should be set-up as specified below.

1. Deploy a thermometer outside away from the door in a shaded area, and one inside in the same room as the blower door.

2. Zero the gauge to be used to measure air flow through the fan after removing all hoses from the gauge so that both pressure taps are exposed to room air.

3. Install the fan on an exterior door for depressurizing the house. The chosen door must be free of wind interference and obstructions for at least 4 ft upstream of the fan. Install the hose measuring the outside pressure out of line of the blower-door fan. Multiple outside hoses or pressure equalizing boxes must not be used. Set up the gauges inside the house and out of the direct flow of air through the blower-door fan (if a hose is used to measure the inside pressure, ensure that it is out of the direct flow of air as well). Check all hose fittings for tightness and trim or tighten as necessary. Connect all hoses. Check for leaks around the fan and door.

4. The gauge used to measure pressure difference across the house envelope is zeroed to remove the natural pressure difference that may exist between the inside and outside of the house due to thermal or wind effects. Cover the fan opening (using the "shower cap" provided by the manufacturer, plugging or taping all holes with the orifice plate on, or some other equivalent technique). Zero the gauge. Remove the fan opening cover. Re-zero the gauge in this manner each time a new run is started.

5. Briefly walk through the house while maintaining a negative pressure difference across the house of 20-40 Pa to check for previously undetected operable openings in the envelope (i.e. open windows, attic hatches, dampers) and other significant sources of air leakage. Identify on the Blower-Door Test Data Sheet any unusual sources of air leakage. Also, look for indications of weak areas (ceilings, windows) that could be damaged with increased negative pressures.

6. Establish a negative pressure difference across the house of 50 Pa for 15 seconds. Do not pressurize the house after this step.

TEST PROCEDURE

Starting the Test

1. Record the identification number of the blower door so that the same door can be used for future tests.

2. Record the indoor and outdoor temperatures.

3. Record the average wind speed, maximum wind gust, and location of the wind measurement (so that same spot can be used for future tests). The measuring device should be deployed three to five building heights away from buildings and other major obstructions and be faced into the wind. Average wind speed should generally not exceed 10 mph; greater speeds and gusty wind conditions can cause difficulty in obtaining quality air-leakage measurements.

4. Record the local shielding class.

Pressure Station Measurements

A test entails making measurements at all pressure stations identified on the Blower-Door Test Data Sheet unless the maximum pressure generated by the fan is insufficient. In this case, make measurements at as many of the assigned pressure stations as possible. Make measurements starting at the lowest pressure station and proceeding in ascending order.

Orifice Plates

For blower doors with orifice plates, at least one (and possibly two) changes in orifice plates should be expected during any particular test. The number and size of orifice plates used must be recorded with each pressure station.

1. The initial orifice plate should be the smallest allowed by the blower-door manufacturer. Using this plate, attempt to make a measurement at the first pressure station. If this is not possible, move to the next larger orifice until the measurement can be made.

2. As measurements are made at higher pressure stations, change to the next largest orifice plate only when it is no longer possible to reach 5 Pa above the desired pressure station.

Gauge Reading Procedures

1. To make a measurement at each pressure station, first raise the house to about 5 Pa above the desired pressure. Then slowly reduce the pressure until the desired pressure is reached. If the pressure is undershot, raise the pressure again to 5 Pa over the desired pressure and repeat the process.

2. Tap the gauges continuously while adjusting the pressure down to the desired station as the stored spring energy will cause the gauge needles to jump slightly.

3. Set the gauge needle on the indicated pressure stations, within +/- 2 Pa.

4. Wait 30 seconds for the blower-door readings to stabilize. Record the actual house pressure reading, the fan pressure or flow rate reading, and the orifice configuration on the Blower-Door Test Data Sheet. When lining the gauge needle up with the marks on the gauge, read the gauge from directly in front to avoid parallax. Always take readings off of the gauge with the lowest range possible. For example, when measuring a flow pressure of less than 125 Pa, read from a gauge with a range of 0-125 Pa rather than from one with a range of 0-750 Pa. Note the reason for any alternate pressure station readings.

Acceptable Error Level

Input the data collected at eight of the nine pressure stations into the blower-door computer: do not use the 10 Pa data if a 60 Pa reading was made. The test must be repeated if the percent error in the flow data at each pressure station is more than 5%, the correlation coefficient is less than 0.99, or the flow exponent (n) is less than 0.5 or greater than 1.0. These numbers appear on the blower-door tape. Before re-doing a test, examine all hoses and fittings for leakage and carefully re-zero the gauges as these could be the cause of excessive error.

Completing the Test

1. Record the indoor temperature.

2. Return ventilation controls, vents, and thermostats to their original settings. Make sure all space- and water-heating systems are operating correctly. Make sure all pilot lights are lit. Close interior doors to restore the house to it's original state.

3. The printout from each test must be included with the Blower-Door Test Data Sheet.

4. Extreme care must be taken in recording all data points as tests with unacceptable levels of accuracy must be repeated.

Version: April 26, 1991

Technician: ________________

Date: ________________

BLOWER-DOOR TEST DATA SHEET: INFILTEC BLOWER DOOR

House ID: ____________ Subgrantee name: ________________________________

Occupant name: ______________________________ Phone number: ______________

Occupant address: ____

Procedures to prepare house for test: Basement door ______________ (closed or open)

____

Unusual sources of leakage: ____

Test equipment identification number: ______________

Indoor temperature (°F)		Outdoor temperature (°F)	Average wind speed (MPH)	Maximum wind gust (MPH)	Location of wind measurement	Local shielding class
Start	Finish					

Pressure station			Flow rate (cfm)	Orifice
Goal		Actual		
(Pa)	(inches of water)			
10	0.04			
15	0.06			
20	0.08			
25	0.10			
30	0.12			
35	0.14			
40	0.16			
50	0.20			
60	0.24			

Local shielding classes	
1	No obstructions or local shielding
2	Light local shielding; few obstructions, a few trees, or small shed
3	Moderate local shielding; some obstructions within two house heights, thick hedge, solid fence, or one neighboring house
4	Heavy shielding; obstructions around most of perimeter, building or trees within 30 ft in most directions; typical suburban shielding
5	Very heavy shielding; large obstructions surrounding perimeter within two house heights; typical downtown shielding

Notes:

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APPENDIX E. STEADY-STATE EFFICIENCY MEASUREMENT PROCEDURE

The steady-state efficiencies of the space-heating systems were measured in all houses before and after weatherization following this procedure.

Version: April 11, 1991

SPACE-HEATING SYSTEM STEADY-STATE EFFICIENCY MEASUREMENT PROCEDURE

OBJECTIVE

The objectives of this procedure are to

1. provide the necessary measurements to calculate the steady-state efficiency of residential space-heating systems fueled by natural gas or fuel oil; and

2. ensure comparability of measurements performed by different contractors using different brands of combustion efficiency test equipment.

This procedure assumes that the combustion efficiency test equipment has been calibrated following the manufacturer's recommendations. The procedure also assumes the use of electronic test equipment (the procedure should be followed with modifications made as necessary if other types of equipment are used).

SET-UP PROCEDURE

1. When testing units in confined spaces, ensure there is adequate ventilation to exhaust any carbon monoxide or other toxic gases.

2. Set up the test equipment according to the manufacturer's instructions. Be sure all connections are tight. The equipment should be placed indoors for at least fifteen minutes to reach room temperature. If applicable, aspirate room air through the equipment for at least five minutes.

3. If applicable, calibrate the equipment to 20.9% oxygen in a well ventilated area.

4. Identify a location in the system's flue sufficiently large to insert the test probe. The location must be located upstream of any dampers or other sources of air entering the flue. If needed, a 5/16" hole should be drilled into the flue pipe as close to the breech as possible, leaving enough clearance for the probe assembly handle.

5. Install the probe into the flue pipe's test location following the manufacturer's instructions. Make sure all tubing and wiring are free of kinks and away from hot areas of the heating system.

6. Turn on the heating system and allow the system to operate for at least five minutes.

7. Record the type of test to be performed.

8. Record the identification number of the test equipment so that the same equipment can be used for future tests.

MEASUREMENTS

Record the following measurements on the Steady-State Efficiency Data Sheet when the oxygen and temperature measurements do not fluctuate over a one-minute interval (when the temperature measurement does not change more than 5°F):

1. Measure the percent oxygen in the flue gas following the manufacturer's instructions.

2. Measure the room and flue gas temperatures (or net stack temperature) following the manufacturer's instructions.

3. For heating systems using fuel oil, measure the smoke number following the manufacturer's instructions. When using smoke paper to make the measurements, comparisons to charts (scales) must be made in daylight or incandescent light (never fluorescent light). Two pieces of unused smoke paper must be placed behind the test paper to make a comparison because of the transparency of the smoke paper.

COMPLETING THE TEST

1. Turn off the heating system and allow metal parts to cool before removing test equipment.

2. If a hole was drilled into the flue pipe, seal the hole using plugs approved for this purpose.

3. Using charts provided with the test equipment, record the unadjusted steady-stale efficiency of the system (disregarding any adjustments for smoke numbers) and, for fuel-oil systems, the adjusted efficiency.

4. Note the condition of the battery in battery-operated test equipment. If the voltage is low, be sure to charge the battery according to manufacturer's instructions.

Version: April 11, 1991

Technician: ________________
Date: ________________

FUEL-OIL STUDY STEADY-STATE EFFICIENCY DATA SHEET

House I.D.: ____________ Subgrantee name: ______________________________

Occupant name: ______________________________ Phone number: ________________

Occupant Address: ____

Type of test: Pre-weatherization _____ Post-weatherization _____

Test equipment identification number	
Percent oxygen reading	%
Net stack temperature, or	°F
Room temperature	°F
Flue gas temperature	°F
Unadjusted steady-state efficiency	%

For fuel-oil systems:	
Smoke number	
Adjusted steady-state efficiency	%
If the smoke number is: 1, 2, 3, 4, 5, 6, 7, 8, 9 subtract: 0, 0, 0, 1, 2, 3, 4, 6, 7	

Notes:

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APPENDIX F. SAFETY INSPECTION PROCEDURE

The safety and integrity of the space- and water-heating systems of all the houses were evaluated at the end of the post-weatherization period using this procedure.

Version: April 26, 1991

OIL-FIRED SPACE- AND WATER-HEATING SYSTEM INSPECTION PROCEDURE

OBJECTIVE

The objectives of this procedure are to

1. provide the necessary measurements and evaluations to assess the safety and integrity of oil-fired space-heating systems, and

2. provide the necessary measurements and evaluations to assess the safety and integrity of oil-fired domestic water-heating systems.

The procedure is limited to an inspection of the space- and water-heating systems. It does not address other safety or health issues related to the house such as radon levels, structural integrity, code violations, unsanitary conditions, and moisture problems.

The procedure is intended to be a data collection instrument only, with the intent being that an overall assessment of these systems will not be made until sometime after the information has been collected in the field. Some guidelines are provided in the procedure to help make immediate interpretations of the collected data. Guidelines regarding repairs or remedies are beyond the scope of this procedure. Unsafe conditions found while following this procedure should be forwarded immediately to the occupants and proper organization or authority.

The procedure was written assuming two separate oil-fired systems. If the domestic water-heating system uses another fuel or is an integral part of the space-heating system (tankless), then some parts of the procedure will not apply. In developing the procedure, the term furnace strictly refers to space-heating systems that heat and distribute air, and the term boiler refers to hydronic systems. A Fuel-Oil System Inspection Form is included as part of this procedure to record all observations and measured data. This form parallels the procedure with the exception of heat exchanger information which is grouped together on the form.

GENERAL SPACE-HEATING SYSTEM INSPECTION

Any cracks in the heat exchanger of an oil-fired forced-air or gravity furnace presents a dangerous situation as flue gasses can enter the hot-air supply system and be distributed throughout the house. Both visual and metered inspections of the heat exchanger will be performed, even though it is often difficult to spot cracks visually.

1. Identify the system type.
2. Check the on\off operation of the thermostat.
3. Determine if the space-heating system has its own emergency electrical cutoff switch.
4. Determine if all 117 VAC wiring is secure.
5. For a furnace, identify the fan on/off temperature settings. For a boiler, identify the operating setpoint temperature (hot water systems) or operating pressure (steam systems).
6. Determine if a high limit switch is present and identify its setting (their functionality will not be tested under this procedure).

7. Note the presence of any combustible materials, including urethane (flexible foam) pipe insulation, immediately adjacent to the flue pipe or too close to the heating system.
8. Note the presence of any asbestos insulation on the system.
9. For a forced-air or gravity furnace, visually inspect the heat exchanger for cracks with the furnace off. Use a strong light and mirror to see as much of the heat exchanger as possible. Pay special attention to all gaskets and joints between sections, and areas that could be damaged by a leaking humidifier.
10. While performing the draft or carbon monoxide measurements that follow, or in coordination with an efficiency measurement, measure the oxygen levels in the flue with the burner running just before and after the distribution blower turns on, A change of 1% (e.g., from 8% to 9%) may indicate a cracked heat exchanger. (Usually, the oxygen levels will stabilize within 30-60 seconds after the system is turned on and before the distribution blower turns on.)

GENERAL DOMESTIC WATER-HEATING SYSTEM INSPECTION

1. Identify the system and fuel type.
2. If fossil-fuel-fired, note the presence of any combustible materials, including urethane (flexible foam) insulation, immediately adjacent to the flue pipe or too close to the system.
3. Note the presence of a pressure relief valve on the system.
4. Note the hot water setpoint temperature.

LEAKING FUEL SOURCES

Even small leaks in fuel-oil lines are relatively easy to detect. The inspection for fuel-oil leaks will be accomplished visually and by noting any fuel-oil odors in the vicinity of the supply lines. Leaks in outdoor tanks can be difficult to detect, especially if the tank is buried. Therefore, only visual and odor detection methods will be used for above-ground tanks; underground tanks will not be evaluated. Propane or natural gas is often used for domestic water heating in a dwelling heated by fuel oil. Under this procedure, an inspection for combustible gas from such a water-heating system will be performed based on smell; use of a combustible gas analyzer would be an improvement to the procedure if available.

1. Visually inspect the fuel-oil supply line from the space-heating system to the supply tank. Note if there are any leaks as indicated by the presence of fuel on the floor or supply lines, or strong fuel-oil odors in the vicinity of the lines.
2. Visually inspect the fuel-oil supply line (if present) from the water-heating system to the supply tank. Note if there are any leaks as indicated by the presence of fuel on the floor or supply lines, or strong fuel-oil odors in the vicinity of the lines. If the system is heated by gas rather than fuel oil, a leak may be indicated if there are any gas odors in the vicinity of the system or gas lines.
3. Visually inspect the above ground supply tank (if present). Note if there are any leaks as indicated by the presence fuel oil on the ground or lines, abnormal corrosion, or strong fuel odors in the vicinity of the tank.
4. Visually inspect the fuel-oil supply line from the supply tank to determine if a filter and shutoff valve are present.

SPACE-HEATING DISTRIBUTION SYSTEM

1. Check the operation of the circulating fan or pump of non-gravity systems.
2. For a forced-air or gravity furnace, check the condition of air filters and the exiting temperature of the supply air.
3. For a boiler, check the operation of any zone valves and inspect the piping for leaks.
4. Check for the presence of any asbestos insulation on the distribution system.

FLUE AND CHIMNEY INSPECTION (SPACE- AND WATER-HEATING SYSTEMS)

1. Visually check the chimney from the ground outside the structure to ascertain overall soundness. If there is an indication of a serious problem, take a closer view from the roof if practical.
2. Determine if the chimney extends above the roof at least 2 ft and that there is 10 ft of horizontal clearance around the top of the chimney.
3. Inspect the chimney and flue pipes from inside the house. Note any obvious holes, leaks, and untight connections in either system.
4. Remove the flue pipe if practical and inspect the chimney using a flashlight and mirror. Note any debris or deposits of more than 1/4 inch thick on the inside of the chimney. Note the presence or absence of a flue liner.
5. For space-heating systems only, check for the existence and correct function (damper swings, has a counterweight, and opens when the system is firing) of the barometric damper.

SPACE- AND WATER-HEATING SYSTEM DRAFTS

Both the time necessary to establish a proper draft and the steady-state draft are important quantities. There usually is no problem if a draft is established within 30 seconds; the system should be examined if a draft takes between 30 and 180 seconds to be established; a problem likely exists if a draft takes longer than 180 seconds to become established. An acceptable steady-state draft depends upon the outside air temperature. In all cases, however, any spillage (backdrafting) from the flue to the room containing the system is unacceptable once the draft has been established. The following table may be used as a guide:

Outdoor temperature	Acceptable Draft	Unacceptable Draft
> 80°F	-0.005 to -0.20 inches water	0 inches water or greater
between 30 °F and 80°F	-0.01 to -0.20 inches water	-0.01 inches water or greater
< 30°F	-0.02 to -0.20 inches water	-0.02 inches water or greater

In addition, if the room where the systems are located is maintained at a pressure 5 Pa less than ambient, backdrafting is a potential problem.

1. Turn off the space- and water-heating systems for at least 20 minutes.

2. Turn on all exhaust fans in the house (except whole house ventilation fans), including the clothes dryer if one is present. Close all interior doors and the door to the room containing the systems.
3. Measure the outdoor temperature.
4. Measure the draft of the systems between the breech and barometric damper with the distribution fan and systems off.
5. Turn on the space-heating system. Measure the time required for backdrafting to stop (for a draft to become established). Measure the draft of the system at the following intervals from the time the system was turned on: 30 seconds, 1 minute, 2 minutes, and 3 minutes. Use a smoke pencil to detect airflow.
6. With the space-heating system operating, measure the pressure difference between the room containing the systems and the outside. If the basement is depressurized more than 0.02 inches water (5 Pa) relative to the outside, than make a second measurement with the space-heating system off.
7. Turn the space-heating system off and the water-heating system on. Repeat steps 4 and 5 for the water-heating system.

CARBON MONOXIDE

Carbon monoxide (CO) is extremely dangerous since it is both odorless and colorless as well as being toxic. However, if emanating from an oil burner, CO will often be accompanied by other combustion gases and fuels which do emit odors. CO readings should be made with an appropriate meter following the manufacturer's instructions. Readings will be recorded in parts per million (ppm) and only after they have become reasonably stable.

Any levels of CO in the household proper above 40 ppm warrants a closer inspection of the space-heating system. A level of CO greater than 100 ppm in the flue gas signals that the oil burner should be inspected (higher CO levels may occur in gas-fired systems). High smoke numbers measured during an efficiency test will likely accompany high CO readings in oil-burning systems.

1. Turn the carbon monoxide monitoring instrument on and allow it to warm up for one minute. Carefully obtain a "zero" instrument reading outside the house away from any combustion sources (running automobile engines, lawn mowers, etc.) The meter will usually not read zero, so note the reading.
2. After turning on the space- and water-heating systems, measure the CO in both flue gases before the barometric damper (this step can be coordinated with an efficiency test if one is to be performed).
3. Measure the CO in the room containing the space-heating system within 5 feet of the system.
4. Measure the CO in the kitchen and living room (the living room is defined to be the main living area of the house, usually characterized by the room with a television in it). Note if a gas stove top, gas oven, or fossil-fueled space heater were operating during the tests. Note any flue-gas odors in the house (also determine if the occupants have noticed any odors in the house when the system is operating).
5. For a forced-air or gravity furnace, measure the CO in the register with the shortest ducting from the space-heating system.

Version: April 26, 1991

Inspector: ____________________
Date: ____________________

FUEL-OIL STUDY SYSTEM SAFETY INSPECTION FORM

IDENTIFICATION

House ID: ______________ Subgrantee name: ________________________________

Occupant name: ______________________________ Phone number: ________________

Occupant address: ____

GENERAL SPACE-HEATING SYSTEM INSPECTION

Type (**FAF-central** forced-air furnace, **GF-central** gravity furnace, SB-steam boiler, **HWBR-hot** water boiler with radiators or **convertors,** HWBS-hot water boiier for slab heating)	
Thermostat **on/off** operating (Y,N)	
Electrical cutoff switch present (Y,N)	
Wiring secure (Y,N)	
Furnace fan **on/off** temperature switches present **(Y,N,NA)**	
If **yes:** Upper setting _____°F Lower **setting** _____°F	
Boiler operating temperature (°F or NA)	
High limit switch settings (none, °F, psi)	
Combustible materials near flue **(Y,N)**	
Asbestos insulation present on system (Y,N)	

GENERAL DOMESTIC WATER-HEATING SYSTEM INSPECTION

Type (SA-stand alone, **T-tankless)**	
Fuel **(NG-natural** gas, **P-propane, O-oil, E-electricity)**	
Combustible materials near flue (Y,N,NA)	
Pressure relief valve present **(Y,N)**	
Temperature setting (°F or NA) (record highest setting for electrically heated systems)	°F

House ID: ______

FUEL LEAKS

	Leak
Space-heating system supply line (Y,N)	
Water-heating system supply line (Y,N,NA)	
Above ground storage tank (Y,N,NA)	

Is a filter and shutoff valve present in the supply line leading from the storage tank? _____ (Y,N)

SPACE-HEATING DISTRIBUTION SYSTEM

Forced-air or gravity furnaces	
Circulating fan operating (Y,N,NA)	
Condition of air filters (N-none, C-clean, D-dirty, P-plugged)	
Exit temperature of supply air	°F

Boilers	
Circulating pump operating (Y,N,NA)	
Zone valves operating (Y,N,NA)	
Leaks exist (Y,N)	

Is asbestos insulation present on the distribution system? _____ (Y,N)

House ID: _______

FLUE AND CHIMNEY INSPECTION

	Space-heating system	Water-heating system
Structurally sound **(Y,N,NA)**		
Chimney extends > 2 **ft** above roof **(Y,N,NA)**		
Clearance at chimney top > 10 ft (Y,N,NA)		
Leaks exist **(Y,N,NA)**		
Thick debris present **(Y,N,NA)**		
Flue liner present **(Y,N,NA)**		
Barometric damper (space-heating systems only):		
Exists **(Y,N)**		
Functions correctly (Y,N,NA)		

SPACE- AND WATER-HEATING SYSTEM DRAFTS

Outdoor temperature: _______°F	Space-heating system	Water-heating system
Draft with system off	in. water	in. water
Time to stop backdrafting	seconds	seconds
Draft with system on		
30 seconds	in. water	in. water
1 minute	in. water	in. water
2 minutes	in. water	in. water
3 minutes	in. water	in. water
Pressure difference between space-heating system room and outside (positive number indicates that the basement is **depressurized** relative to the outside):		
space-heating system on	in. water	
space-heating system off	in. water	

House ID: ______

CARBON MONOXIDE TESTING

Ambient	ppm
Space-heating system flue gas	ppm
Water-heating system flue gas	ppm
Five feet from space-heating system	ppm
Kitchen	ppm
Living room	ppm
Register (ppm or NA)	ppm
Were the following operating during the test:	
Gas stove top (Y,N)	
Gas oven (Y,N)	
Fossil-fuel space-heater (Y,N)	

HEAT EXCHANGER

Cracks observed visually (Y,N,NA)	
Percent oxygen reading before blower turns on	%
Percent oxygen reading after blower turns on	%
Flue gas odor noticed in house (Y,N,NA)	

COMMENTS

____

____

____

APPENDIX G. TABLES OF OCCUPANT AND HOUSE CHARACTERISTICS

Table G.1. Summary **statistics** concerning **occupants**

CONTROL HOUSES (TOTAL OBSERVATIONS: 99)

Statistics	Year built	Year moved in	Age < 5	Age 5-17	Age 18-64
Number	92	95	30	37	71
Minimum	1890.000	1935.000	1.000	1.000	1.000
Maximum	1990.000	1991.000	4.000	5.000	5.000
Mean	1930.511	1972.242	1.767	2.108	1.901
Standard deviation	30.545	16.214	0.817	1.173	0.897
Statistics	Age 65+	Total occupants	Income **($/year)**	Mortgage **($/month)**	Rent **($/month)**
Number	39	97	89	86	9
Minimum	1.000	1.000	2840.000	0.000	100.000
Maximum	3.000	9.000	22588.000	950.000	650.000
Mean	1.333	3.247	11101.910	199.430	355.556
Standard deviation	0.530	1.877	4718.910	261.978	170.375

WEATHERIZED HOUSES (TOTAL OBSERVATIONS: 207)

Statistics	Year built	Year moved in	Age < 5	Age 5-17	Age 18-64
Number	191	195	43	78	137
Minimum	1890.000	1915.000	1.000	1.000	1.000
Maximum	1986.000	1991.000	3.000	6.000	5.000
Mean	1927.209	1972.364	1.395	2.090	1.752
Standard deviation	30.356	17.360	0.583	1.164	0.784
Statistics	Age 65+	Total occupants	Income **($/year)**	Mortgage **($/month)**	Rent **($/month)**
Number	86	198	196	161	28
Minimum	1.000	1.000	1096.960	0.000	100.000
Maximum	2.000	10.000	25049.000	950.000	650.000
Mean	1.186	2.843	10763.451	192.547	326.786
Standard deviation	0.391	1.842	5029.347	262.988	157.810

ALL HOUSES (TOTAL OBSERVATIONS: 306)

Statistics	Year built	Year moved in	Age < 5	Age 5-17	Age 18-64
Number	283	290	73	115	208
Minimum	1890.000	1915.000	1.000	1.000	1.000
Maximum	1990.000	1991.000	4.000	6.000	5.000
Mean	1928.283	1972.324	1.548	2.096	1.803
Standard deviation	30.403	16.965	0.708	1.162	0.825
Statistics	Age 65+	Total occupants	Income **($/year)**	Mortgage **($/month)**	Rent **($/month)**
Number	125	295	285	247	37
Minimum	1.000	1.000	1096.960	0.000	100.000
Maximum	3.000	10.000	25049.000	950.000	650.000
Mean	1.232	2.976	10869.017	194.943	333.784
Standard deviation	0.442	1.860	4928.711	262.125	159.013

Table **G.2.** Distribution of various house parameters for the control and weatherized houses

CONTROL HOUSES, N = 106

FOUNDATION AREA (Ft²)

Value	Count	Percent
0	1	.94
200	2	1.89
400	13	12.26
600	36	33.96
800	29	27.36
1000	14	13.21
1200	7	6.60
1400	3	2.83
1600	1	.94

BASEMENT AREA (Ft²)

Value	Count	Percent
0	3	2.83
200	7	6.60
400	22	20.75
600	34	32.08
800	18	16.98
1000	15	14.15
1200	5	4.72
1400	2	1.89

LIVING AREA (Ft²)

Value	Count	Percent
400	0	.00
600	7	6.60
800	12	11.32
1000	20	18.87
1200	21	19.81
1400	21	19.81
1600	11	10.38
1800	6	5.66
2000	3	2.83
2200	0	.00
2400	4	3.77
2600	1	.94

HEATED LIVING AREA (Ft²)

Value	Count	Percent
400.000	0	.00
600.000	8	7.62
800.000	13	12.38
1000.000	19	18.10
1200.000	20	19.05
1400.000	21	20.00
1600.000	12	11.43
1800.000	4	3.81
2000.000	3	2.86
2200.000	1	.95
2400.000	3	2.86
2600.000	1	.95

Note: 1 Case with missing data.

WEATHERIZED HOUSES, N = 214

FOUNDATION AREA (Ft²)

Value	Count	Percent
0	1	.47
200	10	4.72
400	48	22.64
600	72	33.96
800	44	20.75
1000	23	10.85
1200	8	3.77
1400	5	2.36
1600	1	.47

Note: 2 Cases with missing data.

BASEMENT AREA (Ft²)

Value	Count	Percent
0	14	6.54
200	20	9.35
400	55	25.70
600	59	27.57
800	38	17.76
1000	17	7.94
1200	7	3.27
1400	3	1.40
1600	1	.47

LIVING AREA (Ft²)

Value	Count	Percent
400	4	1.87
600	17	7.94
800	29	13.55
1000	52	24.30
1200	39	18.22
1400	31	14.49
1600	20	9.35
1800	7	3.27
2000	6	2.80
2200	1	.47
2400	1	.47
2600	1	.47
2800	3	2.80

HEATED LIVING AREA (Ft²)

Value	Count	Percent
400	7	3.27
600	22	10.28
800	37	17.29
1000	50	23.36
1200	32	14.95
1400	27	12.62
1600	22	10.28
1800	6	2.80
2000	5	2.34
2200	1	.47
2400	1	.47
2600	0	.00
2800+	4	1.86

Table G.2. Distribution of various house parameters for the control and **weatherized** houses (continued)

CONTROL HOUSES, N = 106

EXTERNAL WALL AREA (Ft²)

Value	Count	Percent
400	1	.96
600	1	.96
800	11	10.58
1000	14	13.46
1200	15	14.42
1400	9	8.65
1600	13	12.50
1800	16	15.38
2000	9	8.65
2200	5	4.81
2400	1	.96
2600	2	1.92
2800	3	2.88
3000+	4	3.84

Note: 2 Cases with missing data.

WINDOW AREA (Ft²)

Value	Count	Percent
25	0	.00
50	3	2.83
75	5	4.72
100	15	14.15
125	18	16.98
150	17	16.04
175	16	15.09
200	11	10.38
225	4	3.77
250	6	5.66
275	3	2.83
300	5	4.72
325	0	.00
350	0	.00
375+	3	2.83

FINISHED ATTIC AREA (Ft²)

Value	Count	Percent
0	2	7.69
200	1	3.85
400	4	15.38
600	6	23.08
800	6	23.08
1000	3	11.54
1200	3	11.54
1400	0	.00
1600	1	3.85

Note: 2 Cases with missing data.

UNFINISHED ATTIC AREA (Ft²)

Value	Count	Percent
0	2	2.13
200	10	10.64
400	10	10.64
600	27	28.72
800	18	19.15
1000	12	12.77
1200	5	5.32
1400	8	8.51
1600	1	1.06
1800	1	1.06

Note: 12 Cases with missing data.

WEATHERIZED HOUSES, N = 214

EXTERNAL WALL AREA (Ft²)

Value	Count	Percent
400	0	.00
600	1	.48
800	20	9.66
1000	33	15.94
1200	28	13.53
1400	39	18.84
1600	30	14.49
1800	13	6.28
2000	18	8.70
2200	7	3.38
2400	6	2.90
2600	5	2.42
2800	5	2.42
3000+	2	.96

Note: 7 Cases with missing data.

WINDOW AREA (Ft²)

Value	Count	Percent
25	0	.00
50	8	3.76
75	20	9.39
100	28	13.15
125	48	22.54
150	30	14.08
175	30	14.08
200	15	7.04
225	15	7.04
250	6	2.82
275	7	3.29
300	2	.94
325	2	.94
350	0	.00
375+	2	.94

Note: 1 Case with missing data.

FINISHED ATTIC AREA (Ft²)

Value	Count	Percent
0	1	1.59
200	10	15.87
400	12	19.05
600	14	22.22
800	15	23.81
1000	9	14.29
1200	1	1.59
1400	0	.00
1600	1	1.59

Note: 151 Cases with missing data.

UNFINISHED ATTIC AREA (Ft²)

Value	Count	Percent
0	8	4.37
200	24	13.11
400	27	14.75
600	46	25.14
800	35	19.13
1000	28	15.30
1200	8	4.37
1400	5	2.73
1600	1	.55
1800+	1	.55

Note: 31 Cases with missing data.

Table G.2. Distribution of various house parameters for the control and weathenzed houses (continued)

CONTROL HOUSES, N = 106

FOUNDATION CEILING INSULATION (In)

Value	Count	Percent
0	97	92.38
1	0	.00
2	1	.95
3	0	.00
4	0	.00
5	0	.00
6	6	5.71
7	0	.00
8	1	.95

Note: 1 Case with missing data.

FOUNDATION WALL INSULATION (In)

Value	Count	Percent
0	99	93.40
1	0	.00
2	2	1.89
3	3	2.83
4	0	.00
5	0	.00
6	2	1.89

EXTERIOR WALL INSULATION (In)

Value	Count	Percent
0	52	50.00
1	1	.96
2	11	10.58
3	31	29.81
4	8	7.69
5	0	.00
6	1	.96

Note: 2 Cases with missing data.

UNFINISHED ATTIC INSULATION (In)

Value	Count	Percent
0	17	18.48
1	4	4.35
2	7	7.61
3	13	14.13
4	3	3.26
5	2	2.17
6	22	23.91
7	2	2.17
8	14	15.22
9	2	2.17
10	5	5.43
11	0	.00
12	1	1.09

Note: 14 Cases with missing data.

WEATHERIZED HOUSES, N = 214

FOUNDATION CEILING INSULATION (In)

Value	Count	Percent
0	167	79.15
1	1	.47
2	3	1.42
3	14	6.64
4	3	1.42
5	3	1.42
6	19	9.00
7	0	.00
8+	1	.47

Note: 3 Cases with missing data.

FOUNDATION WALL INSULATION (In)

Value	Count	Percent
0	194	92.82
1	3	1.44
2	4	1.91
3	8	3.83

Note: 34 Cases with missing data.

EXTERIOR WALL INSULATION (In)

Value	Count	Percent
0	84	40.38
1	6	2.88
2	24	11.54
3	74	35.58
4	18	8.65
5	0	.00
6	2	.96

Note: 6 Cases with missing data.

UNFINISHED ATTIC INSULATION (In)

Value	Count	Percent
0	16	8.89
1	1	.56
2	4	2.22
3	6	3.33
4	6	3.33
5	8	4.44
6	50	27.78
7	11	6.11
8	41	22.78
9	6	3.33
10	21	11.67
11	0	.00
12	10	5.56

Note: 34 Cases with missing data.

Table G.2. Distribution of Various House **Parameters** for the control and **weatherized** houses (continued)

CONTROL HOUSES, N = 106

FINISHED ATTIC INSULATION (In)

Value	Count	Percent
0	5	20.00
1	3	12.00
2	3	12.00
3	7	28.00
4	1	4.00
5	3	12.00
6	2	8.00
7	0	.00
8	1	4.00

Note: 81 Cases with missing data.

BASEMENT VOLUME (Cu Ft)

Value	Count	Percent
0	3	2.83
1000	4	3.77
2000	7	6.60
3000	12	11.32
4000	17	16.04
5000	25	23.58
6000	15	14.15
7000	8	7.55
8000	6	5.66
9000	4	3.77
10000	1	.94
11000	1	.94
12000	2	1.89
13000	0	.00
14000	1	.94

LIVING SPACE VOLUME (Cu Ft)

Value	Count	Percent
0	0	.00
1000	0	.00
2000	0	.00
3000	0	.00
4000	3	2.83
5000	2	1.89
6000	9	8.49
7000	7	6.60
8000	11	10.38
9000	19	17.92
10000	13	12.26
11000	9	8.49
12000	12	11.32
13000	7	6.60
14000	3	2.83
15000	4	3.77
16000	0	.00
17000	2	1.89
18000	1	.94
19000	1	.94
20000+	3	2.83

UEATHERIZED HOUSES, N = 214

FINISHED ATTIC INSULATION (In)

Value	Count	Percent
0	7	11.86
1	0	.00
2	3	5.08
3	4	6.78
4	12	20.34
5	6	10.17
6	18	30.51
7	4	6.78
8	4	6.78
9	0	.00
10	1	1.69

Note: 155 Cases with missing data.

BASEMENT VOLUME (Cu Ft)

Value	Count	Percent
0	12	5.63
1000	8	3.76
2000	21	9.86
3000	39	18.31
4000	41	19.25
5000	28	13.15
6000	27	12.68
7000	12	5.63
8000	12	5.63
9000	6	2.82
10000	5	2.35
11000	0	.00
12000	1	.47
13000	1	.47
14000	0	.00

Note: 1 Case with missing data.

LIVING SPACE VOLUME (Cu Ft)

Value	Count	Percent
0	2	.93
1000	1	.47
2000	0	.00
3000	1	.47
4000	9	4.21
5000	10	4.67
6000	21	9.81
7000	23	10.75
8000	27	12.62
9000	26	12.15
10000	20	9.35
11000	20	9.35
12000	18	8.41
13000	11	5.14
14000	7	3.27
15000	3	1.40
16000	4	1.87
17000	2	.93
18000	2	.93
19000	2	.93
20000+	5	2.33

Table G.2. Distribution of various house parameters for the control and weathenzed houses (continued)

ESTIMATED YEAR IN WHICH HOUSE WAS BUILT

CONTROL HOUSES, N = 92

Value	Count	Percent
1890	24	26.09
1900	6	6.52
1910	6	6.52
1920	5	5.43
1930	9	9.78
1940	9	9.78
1950	15	16.30
1960	11	11.96
1970	5	5.43
1980	1	1.09
1990	1	1.09

Note: 4 Cases with missing data

WEATHERIZED HOUSES, N = 191

Value	Count	Percent
1890	53	27.75
1900	13	6.81
1910	24	12.57
1920	10	5.24
1930	17	8.90
1940	16	8.38
1950	22	11.52
1960	20	10.47
1970	12	6.28
1980	4	2.09
1990	0	.00

Note: 16 Cases with missing data

YEAR THAT OCCUPANT MOVED INTO HOUSE

CONTROL HOUSES, N = 95

Value	Count	Percent
1910	0	.00
1920	0	.00
1930	1	1.05
1940	11	11.58
1950	13	13.68
1960	16	16.84
1970	10	10.53
1980	35	36.84
1990	9	9.47

Note: 4 Cases with missing data

UEATHERIZED HOUSES, N = 195

Value	Count	Percent
1910	2	1.03
1920	1	.51
1930	9	4.62
1940	9	4.62
1950	29	14.87
1960	21	10.77
1970	37	18.97
1980	67	34.36
1990	20	10.26

Note: 12 Cases with missing data

NUMBER OF OCCUPANTS IN EACH HOUSE

CONTROL HOUSES, N = 97

Value	Count	Percent
1	20	20.62
2	21	21.65
3	15	15.46
4	18	18.56
5	12	12.37
6	4	4.12
7	5	5.15
8	1	1.03
9	1	1.03

Note: 2 Cases with missing data

UEATHERIZED HOUSES, N = 198

Value	Count	Percent
1	66	33.33
2	36	18.18
3	30	15.15
4	25	12.63
5	22	11.11
6	11	5.56
7	7	3.54
8	0	.00
9	0	.00
10	1	.51

Note: 9 Cases with missing data

Table G.2. Distribution of various house parameters for the control and weatherized houses (continued)

MONTHLY RENTAL/MORTGAGE PAYMENTS BY OCCUPANTS

OCCUPANT RENTERS, N = 37

Value	Count	Percent
0	0	.00
100	8	21.62
200	4	10.81
300	14	37.84
400	7	18.92
500	1	2.70
600	3	8.11

OCCUPANT **OWNERS,** N = 249

Value	Count	Percent
0	131	52.61
100	18	7.23
200	28	11.24
300	18	7.23
400	19	7.63
500	9	3.61
600	8	3.21
700	8	3.21
800	5	2.01
900	5	2.01

ANNUAL INCOME

CONTROL **HOUSES,** N = 104

Value	Count	Percent
0	0	.00
2000	4	3.85
4000	11	10.58
6000	13	12.50
8000	24	23.08
10000	18	17.31
12000	12	11.54
14000	2	1.92
16000	8	7.69
16000	5	4.81
20000	3	2.88
22000	4	3.85

Note: 7 Cases **with** missing date

WEATHERIZED **HOUSES,** N = 206

Value	Count	Percent
0	1	.49
2000	9	4.37
4000	27	13.11
6000	35	16.99
8000	35	16.99
10000	30	14.56
12000	20	9.71
14000	15	7.28
16000	10	4.85
18000	12	5.83
20000	7	3.40
22000	3	1.46
24000	2	.97

Note: 12 Cases **with** missing data

Table **G.3.** Survey statistics concerning bouse physical characteristics

Statistics	Foundation ceiling area	Basement area	Basement volume
Number	318	320	319
Minimum	150.000	0.000	0.000
Maximum	1752.000	1752.000	14688.000
Mean	786.506	693.672	5094.364
Standard deviation	268.926	307.457	2490.794

Statistics	Living space total area	Living space heated area	Living space volume
Number	320	320	320
Minimum	480.000	0.000	89.000
Maximum	3520.000	3452.000	26926.000
Mean	1332.300	1274.188	10239.353
Standard deviation	464.954	451.237	3832.519

Statistics	Exterior wall area	Window area
Number	311	319
Minimum	448.000	50.000
Maximum	5240.000	563.000
Mean	1608.942	169.107
Standard deviation	582.297	68.835

Statistics	Finished attic area	Unfinished attic area
Number	89	277
Minimum	52.000	78.000
Maximum	1700.000	2329.000
Mean	736.472	782.068
Standard deviation	328.717	362.325

Table G.4. Summary statistics concerning windows and exterior doors

Type of window	Control		Weatherized		All houses	
	Number	Percent	Number	Percent	Number	Percent
Single pane total	95	90	179	85	274	87
Wood	92	96	175	97	267	97
Metal	3	4	3	2	6	2
Vinyl	0	0	1	1	1	1
Double pane total	10	10	32	15	42	13
Wood	3	30	12	38	15	36
Metal	2	20	5	15	7	17
Vinyl	5	50	15	47	20	47
Storm window total	83	79	150	71	233	74
Uood	5	6	8	5	13	6
Metal	77	93	141	94	218	93
Vinyl	1	1	1	1	2	1

Note: Number means number of houses, rather than number of windows.
Total means number of houses with window type.

	Number of exterior doors							
	0	1	2	3	4	5	6	7
Control houses:								
All doors		4	70	30	1	1	0	0
Doors with storm doors	14	12	62	17	1	0	0	0
Ueatherized houses:								
All doors		10	145	50	6	1	0	1
Doors with storm doors	26	38	120	27	1	0	0	0
All houses:								
All doors		14	215	80	7	2	0	1
Doors with storm doors	40	50	182	44	2	0	0	0

Type of exterior door	Control		Ueatherized		All houses	
	Number	Percent	Number	Percent	Number	Percent
Uood, raised panel	81	77	160	75	241	76
Uood, solid core	12	11	32	15	44	13
Wood, hollow core	11	10	17	8	28	9
Metal, insulated	2	2	3	2	5	2

Table G.5. Summary of insulation types

CONTROL HOUSES

Insulation type	External wall	Unfinished attic	Finished attic	Foundation wall
None	50	17	5	99
Blown cellulose	17	35	4	0
Blown fiberglass	0	0	1	0
Fiberglass batt	30	33	10	7
Blown rock wool	2	4	2	0
Rock wool batt	1	2	2	0
Rigid board, foam	2	0	0	0
Other	2	2	1	0
Total	104	93	25	106

WEATHERIZED HOUSES

Insulation type	External wall	Unfinished attic	Finished attic	Foundation wall
None	83	16	7	195
Blown cellulose	66	110	37	2
Blown fiberglass	6	5	2	0
Fiberglass batt	45	37	12	10
Blown rock wool	1	9	0	0
Rock wool batt	4	2	0	0
Rigid board, foam	2	0	1	2
Other	1	0	0	0
Total	208	179	59	209

AVERAGE INSULATION DEPTH IN INCHES

	External wall	Unfinished attic	Finished attic	Foundation wall	Foundation ceiling
Control house	1.62	4.59	2.84	0.25	0.44
Weatherized house	1.90	6.57	4.68	0.19	0.97
Difference (Weatherized minus Control)	0.28	1.98	1.84	-0.06	0.53

Table G.6. Occupant responses to *type* and amount of auxiliary fuel usage

Auxiliary fuel type	Control house usage				Weatherized house usage			
	Pre-weatherization period		Post-weatherization period		Pre-weatherization period		Post-weatherization period	
No response	33	33%	34	34%	64	31%	64	31%
Did not use any	47	71%	49	74%	92	64%	110	77%
Electricity	9	14%	6	9%	17	12%	12	8%
Wood	5	8%	5	8%	13	9%	11	8%
Kerosene	2	3%	2	3%	7	5%	3	2%
Natural gas	0	0%	0	0%	3	2%	1	1%
Coal	0	0%	0	0%	2	1%	1	1%
More than one type	3	4%	3	4%	9	7%	5	3%
Totals of responses	66	100%	65	100%	143	100%	143	100%

Percentage of time auxiliary fuel used	Control house usage				Weatherized house usage			
	Pre-weatherization period		Post-weatherization period		Pre-weatherization period		Post-weatherization period	
No response	33	33%	34	34%	64	31%	64	31%
Never used	47	48%	49	51%	92	64%	110	77%
50% of time	0	0%	0	0%	9	6%	4	3%
75% of time	4	4%	4	4%	13	9%	8	5%
All the time	15	15%	12	12%	29	20%	22	15%
Totals	66	100%	65	100%	143	100%	143	100%

Table G.7. Weatherized homes using auxiliary heat in both pre and post periods

Number of houses	Pre-weatherization		Post-weatherization		Change in usage
	Type of auxiliary heat	Use (% of time)	Type of auxiliary heat	Use (% of time)	
1	Coal	50%	Coal	50%	None
7	Electric	100%	Electric	100%	None
1	Elec/Wood	100%	Elec/Wood	100%	None
1	Elec/Wood	50%	Elec/Wood	75%	Increase
1	Elec/Wood	75%	Electric	100%	Increase
2	Kerosene	100%	Kerosene	100%	None
1	Kerosene	75%	Kerosene	75%	None
1	Kero/Elec	?	Kero/Elec	7	None
1	Nat Gas	75%	Nat Gas	100%	Increase
1	Other	100%	Other	100%	None
1	Other	75%	Other	75%	None
5	Wood	100%	Wood	100%	None
2	Wood	50%	Wood	100%	Increase
1	Wood	50%	Wood	50%	None
1	Wood	50%	Wood	75%	Increase
2	Wood	75%	Wood	75%	None

APPENDIX H. TABLES OF FUEL-OIL CONSUMPTIONS AND SAVINGS

Table H.1. TMY weather file used for each local Weatherization agency

Agency	Location	TMY City	Heating degree days
Community Action of Greater Middletown	Middletown, CT	Hartford, CT	5900
The Community Renewal Team of Greater Hartford	Hartford, CT	Hartford, CT	5900
Thames Valley Council Weatherization	Jewett City, CT	Hartford, CT	5900
Franklin Community Action Corporation	Greenfield, MA	Albany, NY	6205
North Shore Community Action Program	Peabody, MA	Boston, MA	5336
South Shore Community Action Council	Plymouth, MA	Boston, MA	5336
Springfield Action Commission	Springfield, MA	Hartford, CT	5900
Community Action Program Inner City	Chelsea, MA	Boston, MA	5366
Berkshire County Action Council Weatherization	Pittsfield, MA	Albany, NY	6205
Lynn Economic Opportunity	Lynn, MA	Boston, MA	5336
Kennebeck Valley Community Action Program	Waterville, ME	Bangor, ME	7220
Southern Maine Technical College	So. Portland, ME	Portland, ME	6523
Community Concepts, Inc.	So. Paris, ME	Bangor, ME	7220
Southern New Hampshire	Manchester, NH	Concord, NH	6728
Tri-County Community Action	Berlin, NH	Burlington, VT	7123
Rockingham County Community Action	Portsmouth, NH	Portland, ME	6523
Camden County Council of Economic Opportunity	Camden, NJ	Philadelphia, PA	4780
Puerto Rican Action Board	New Brunswick, NJ	Newark, NJ	4775
Test City Child Care Center	Bridgeton, NJ	Wilmington, DE	4807
Cayuga County Action Program	Auburn, NY	Binghamton, NY	6821
Stonleigh Housing, Inc.	Canastota, NY	Syracuse, NY	6328
Greene County Community Action Agency	Catskill, NY	Albany, NY	6205
People's Equal Action and Community Effort	Syracuse, NY	Syracuse, NY	6328
Tompkins County Equal Opportunity Council	Ithaca, NY	Binghamton, NY	6821
Albany County Opportunity, Inc.	Albany, NY	Albany, NY	6205
Wyoming County Office for the Aging	Warsaw, NY	Buffalo, NY	6116
Seneca County Weatherization	Seneca Falls, NY	Syracuse, NY	6328
Livingston County Weatherization	Mt. Morris, NY	Buffalo, NY	6116
Bedford County Weatherization	Everett, PA	Harrisburg, PA	5016
Berks Community Action Program	Reading, PA	Allentown, PA	5489
Council on Economic Opportunity	Wilkes-Barre, PA	Wilkes-Barre, PA	5848
Weatherization Incorporated	Huntingdon, PA	Harrisburg, PA	5016
Equal Opportunity Cabinet	Pottsville, PA	Allentown, PA	5489
SEDA — Council of Governments	Lewisburg, PA	Wilkes-Barre, PA	5848
South Central Community Action Program	Gettysburg, PA	Harrisburg, PA	5016
Tri-Town Equal Opportunity Program	Johnson, RI	Providence, RI	5617
Warwick Community Action	Warwick, RI	Providence, RI	5617
Self Help, Inc.	E. Providence, RI	Providence, RI	5617
Champlain Valley Office of Economic Opportunity	Burlington, VT	Burlington, VT	7123
Northeast Employment and Training Organization	St. Johnsbury, VT	Burlington, VT	7123
Central Vermont Community Action Council	Barre, VT	Burlington, VT	7123

Table H.2. Summary of sample (unweighted) results for 1990-1992

ID	Test Year	Type	Heated Area (Ft²)	Temperature (°F) Pre	Post	Change	Fuel-Oil Usage Data (Gal/Year) Pre	Post	Savings	%Savings	Measured Statistics Pre R^2	Days	Post R^2	Days	HVAC Type	DHU System Fuel	Tank
1	1	W	480	60.7	62.4	1.70	217	196	20.8	9.6	0.252	48	0.793	105	FA	Elec	SA
2	1	W	504	70.9	70.5	-0.40	727	340	387.4	53.3	0.626	69	0.881	88	Gr	Elec	SA
3	1	U	529	68.4	69.1	0.65	422	348	73.7	17.5	0.912	61	0.878	85	FA	Prop	SA
4	1	U	607	62.8	63.1	0.37	325	316	9.4	2.9	0.763	68	0.879	102	FA	Elec	SA
5	1	C	622	69.1	69.0	-0.11	773	784	-10.1	-1.3	0.934	21	0.932	102	Gr	ELec	SA
6	2	C	624	62.2	61.4	-0.78	1343	1272	71.0	5.3	0.318	69	0.460	127	HUB	ELec	SA
7	1	U	625	70.6	70.9	0.29	537	393	144.8	26.9	0.637	98	0.584	115	HUB	Oil	None
8	1	U	630	72.5	71.6	-0.90	628	411	217.0	34.6	0.977	90	0.940	100	FA	NGas	SA
9	1	V	642	71.5	71.6	0.08	943	605	337.6	35.8	0.888	67	0.858	77	FA	Elec	SA
10	1	U	648	70.5	70.0	-0.53	995	708	286.2	28.8	0.709	63	0.563	92	FA	Oil	None
11	2	U	655	75.2	76.7	1.50	1041	1088	-46.9	-4.5	0.980	97	0.966	81	FA	NGas	SA
12	1	U	657	63.9	67.3	3.37	623	581	42.5	6.8	0.824	61	0.836	108	FA	Elec	SA
13	1	W	662	70.0	70.4	0.34	716	608	107.7	15.0	0.946	115	0.956	71	HUB	Elec	SA
14	1	U	672	67.8	68.4	0.59	490	471	19.9	4.1	0.958	98	0.946	109	FA	ELec	SA
15	1	U	672	70.5	70.5	-0.03	915	900	15.6	1.7	0.928	75	0.940	105	FA	ELec	SA
16	2	U	672	55.7	56.4	0.66	429	361	67.6	15.8	0.916	79	0.908	115	StB	Oil	None
17	1	U	714	70.3	70.5	0.23	567	494	72.6	12.8	0.922	73	0.940	100	StB	Oil	None
18	1	U	714	69.2	66.5	-2.66	419	248	170.6	40.7	0.912	74	0.926	100	FA	NGas	SA
19	2	U	718	70.6	68.5	-2.13	1240	602	637.5	51.4	0.876	76	0.872	103	StB	OH	None
20	1	U	742	71.0	68.8	-2.17	680	424	255.7	37.6	0.803	57	0.862	100	FA	Elec	SA
21	2	U	750	71.5	72.4	0.91	524	477	47.1	9.0	0.966	100	0.915	113	FA	Elec	SA
22	2	U	757	71.9	71.4	-0.46	891	674	216.7	24.3	0.763	64	0.868	80	??	??	??
23	1	W	764	70.0	71.5	1.46	606	512	94.0	15.5	0.823	64	0.851	57	FA	Prop	SA
24	1	U	765	71.2	71.6	0.38	570	402	167.9	29.5	0.968	87	0.940	102	HUB	Prop	SA
25	1	W	768	68.8	69.3	0.49	816	782	34.5	4.2	0.935	95	0.916	106	HUB	OH	None
26	2	C	768	66.9	68.2	1.26	395	431	-35.5	-9.0	0.912	98	0.909	121	FA	Oil	SA
27	2	C	768	72.9	72.9	0.01	1196	1158	37.8	3.2	0.958	104	0.934	121	HUB	Oil	None
28	1	U	768	68.3	68.8	0.45	562	416	146.3	26.0	0.872	67	0.874	100	FA	Elec	SA
29	1	U	781	73.3	73.7	0.42	653	592	61.1	9.4	0.930	96	0.917	105	HUB	Elec	SA
30	2	U	783	73.9	72.2	-1.74	271	194	77.2	28.5	0.401	112	0.383	97	FA	Elec	SA
31	1	U	792	77.6	71.6	-5.97	1084	599	485.5	44.8	0.935	62	0.950	70	FA	Elec	SA
32	2	C	792	72.2	72.7	0.51	563	672	-109.2	-19.4	0.772	141	0.504	119	HUB	Oil	None
33	1	U	792	74.4	75.1	0.64	827	709	118.1	14.3	0.946	53	0.955	108	StB	Oil	None
34	1	U	795	71.4	71.8	0.40	577	494	82.3	14.3	0.083	96	0.534	97	FA	ELec	SA
35	2	U	800	66.2	70.4	4.22	596	508	87.5	14.7	0.738	47	0.710	90	FA	Elec	SA
36	2	C	803	70.6	70.5	-0.13	736	743	-7.3	-1.0	0.965	131	0.949	111	HUB	OH	None
37	2	C	810	73.5	72.7	-0.87	502	469	33.2	6.6	0.850	72	0.900	119	FA	Prop	SA
38	1	U	816	70.2	69.7	-0.53	1055	898	156.4	14.8	0.934	73	0.927	88	HUB	OH	None
39	2	W	828	73.4	72.3	-1.05	655	523	132.1	20.2	0.954	101	0.937	98	FA	Elec	SA
40	1	C	850	73.7	74.3	0.59	852	884	-32.2	-3.8	0.975	88	0.970	102	HUB	Oil	None
41	1	U	851	72.9	74.0	1.03	574	504	69.4	12.1	0.409	65	0.703	95	FA	Elec	SA
42	1	C	855	64.1	62.6	-1.51	438	405	33.2	7.6	0.774	90	0.793	53	HUB	Elec	SA
43	1	W	858	67.1	66.5	-0.54	730	489	241.5	33.1	0.849	56	0.794	99	HUB	Oil	None
44	2	W	864	68.8	68.6	-0.12	407	414	-7.1	-1.7	0.933	93	0.939	81	FA	ELec	SA
45	1	C	868	68.9	69.6	0.72	914	929	-15.0	-1.6	0.842	76	0.889	102	FA	Elec	SA
46	1	C	875	72.2	71.6	-0.58	653	705	-52.1	-8.0	0.943	90	0.930	102	HUB	Oil	None
47	2	W	876	65.8	66.1	0.34	820	795	24.8	3.0	0.904	89	0.920	111	FA	Oil	SA
48	1	U	879	66.5	64.5	-2.02	1135	574	560.9	49.4	0.699	55	0.625	99	FA	Elec	SA
49	1	W	882	69.4	69.4	0.01	780	563	216.2	27.7	0.957	58	0.866	97	FA	ELec	SA
50	1	U	884	72.5	72.9	0.46	1493	1426	67.2	4.5	0.945	66	0.937	97	StB	Oil	None
51	1	U	888	67.9	68.5	0.63	648	488	159.4	24.6	0.802	62	0.880	100	HWB	OH	None
52	2	C	900	66.3	64.8	-1.47	712	683	29.3	4.1	0.855	85	0.852	122	HUB	Oil	None
53	2	U	908	71.0	71.0	-0.05	536	533	3.4	0.6	0.957	108	0.955	105	HUB	Oil	None
54	1	C	911	68.0	68.7	0.67	722	668	54.3	7.5	0.801	77	0.935	102	HWB	Oil	None
55	2	U	916	70.6	69.6	-1.04	827	541	285.8	34.6	0.955	46	0.935	113	HUB	Oil	None
56	2	C	918	73.1	72.2	-0.89	841	795	45.7	5.4	0.859	108	0.833	120	HUB	Oil	None
57	2	U	921	73.8	74.8	0.99	970	854	115.6	11.9	0.501	70	0.706	69	HUB	Elec	SA
58	2	U	924	70.8	68.4	-2.37	738	685	52.4	7.1	0.785	76	0.868	100	FA	Prop	SA
59	1	C	927	67.7	67.9	0.26	571	610	-38.6	-6.8	0.916	76	0.920	102	HUB	NGas	SA
60	2	U	932	74.4	75.3	0.96	1294	850	443.9	34.3	0.878	53	0.899	108	HUB	ELec	SA
61	1	U	936	63.3	66.3	2.98	632	511	120.9	19.1	0.669	77	0.780	91	HUB	Oil	None
62	2	W	937	70.5	70.2	-0.33	858	756	102.3	11.9	0.954	111	0.952	84	FA	Elec	SA
63	1	C	960	68.3	68.2	-0.08	640	667	-27.1	-4.2	0.891	99	0.801	102	HUB	Oil	None
64	1	U	960	71.4	72.2	0.73	497	462	34.5	6.9	0.820	76	0.682	100	HUB	Oil	None
65	2	C	966	72.7	73.1	0.39	929	917	12.2	1.3	0.966	138	0.932	118	HUB	Oil	None
66	2	U	966	67.7	67.6	-0.17	445	692	-247.1	-55.5	0.216	67	0.757	93	FA	Elec	SA
67	2	U	976	65.8	64.9	-0.92	901	695	206.1	22.9	0.958	65	0.913	110	FA	Elec	SA
68	1	U	989	76.7	76.0	-0.73	866	862	4.7	0.5	0.447	83	0.869	88	HUB	??	??

Table H.2. Summary of sample (unweighted) results for 1990-1992 (continued)

ID	Test Year	Type	Heated Area (Ft^2)	Temperature (°F) Pre	Post	Change	Fuel-Oil Usage Data (Gal/Year) Pre	Post	Savings	% Savings	Measured Statistics Pre R^2	Days	Post R^2	Days	HVAC Type	DHU System Fuel	Tank
69	2	W	995	67.4	66.7	-0.70	683	814	-130.9	-19.2	0.918	49	0.906	90	??	??	??
70	2	W	996	66.0	66.9	0.88	403	359	44.5	11.0	0.939	41	0.935	104	FA	Elec	SA
71	1	U	1000	69.3	70.9	1.57	618	598	20.4	3.3	0.854	51	0.881	72	HWB	Oil	None
72	2	C	1000	61.3	61.9	0.62	796	813	-17.2	-2.2	0.879	95	0.876	127	HUB	Oil	None
73	1	U	1008	74.8	75.0	0.21	1455	1016	438.1	30.1	0.950	69	0.947	99	StB	NGas	SA
74	1	C	1012	68.6	66.8	-1.85	1038	1041	-3.5	-0.3	0.931	58	0.905	98	FA	Prop	SA
75	1	W	1016	71.8	72.2	0.47	1572	1250	321.4	20.5	0.722	71	0.847	99	StB	Oil	None
76	2	U	1021	64.6	64.1	-0.53	601	388	213.4	35.5	0.901	61	0.831	87	HUB	Oil	None
77	1	U	1023	72.1	72.8	0.63	917	870	47.0	5.1	0.841	67	0.834	98	??	??	??
78	2	W	1028	70.2	66.8	-3.45	475	515	-40.0	-8.4	0.339	42	0.888	92	FA	Elec	SA
79	2	C	1035	67.9	67.7	-0.20	713	679	33.8	4.7	0.831	100	0.893	123	FA	Elec	SA
80	2	W	1038	71.9	73.1	1.28	348	741	-393.0	113.0	0.032	66	0.922	116	HUB	Elec	SA
81	1	C	1044	74.9	73.6	-1.31	671	804	-133.2	-19.8	0.843	76	0.894	102	FA	Elec	SA
82	2	U	1044	68.8	68.6	-0.27	265	283	-17.9	-6.8	0.898	88	0.802	81	FA	NGas	SA
83	1	C	1050	70.2	70.3	0.11	650	624	26.9	4.1	0.950	91	0.942	102	FA	Oil	None
84	2	U	1056	71.9	71.1	-0.80	1052	796	255.3	24.3	0.931	77	0.868	77	FA	NGas	SA
85	2	U	1058	69.1	69.3	0.17	1005	1009	-3.9	-0.4	0.848	67	0.941	104	HUB	Oil	SA
86	1	C	1064	67.5	68.0	0.46	837	909	-72.2	-8.6	0.937	69	0.950	102	StB	Oil	None
87	1	U	1072	70.6	72.6	2.06	927	789	137.5	14.8	0.957	84	0.954	92	HUB	Elec	SA
88	1	U	1080	74.9	75.4	0.46	560	643	-82.5	-14.7	0.943	90	0.899	93	FA	NGas	SA
89	2	C	1083	75.3	75.6	0.35	757	764	-6.8	-0.9	0.950	142	0.884	117	HUB	Oil	None
90	2	U	1087	71.0	70.1	-0.86	881	818	63.2	7.2	0.794	54	0.753	92	HUB	Oil	None
91	1	U	1088	72.7	74.3	1.52	622	518	103.9	16.7	0.942	55	0.923	71	HUB	Oil	None
92	1	U	1092	70.7	71.6	0.90	840	526	314.4	37.4	0.854	70	0.872	99	FA	NGas	SA
93	1	U	1100	63.4	62.6	-0.80	494	457	37.5	7.6	0.848	70	0.921	87	FA	Prop	SA
94	2	U	1100	65.9	69.3	3.44	687	568	119.0	17.3	0.759	50	0.927	89	FA	Elec	SA
95	1	U	1104	63.8	63.9	0.06	297	253	43.9	14.8	0.777	78	0.595	85	FA	OH	SA
96	1	C	1104	72.9	72.9	-0.03	613	586	27.0	4.4	0.900	70	0.950	101	FA	Elec	SA
97	2	W	1112	66.2	65.6	-0.63	711	693	17.8	2.5	0.681	105	0.846	107	FA	Oil	SA
98	1	W	1120	73.4	74.2	0.76	672	595	77.2	11.5	0.966	70	0.950	93	FA	Elec	SA
99	1	U	1120	69.7	68.4	-1.33	921	550	370.7	40.3	0.895	80	0.914	51	HUB	Oil	None
100	2	U	1120	68.4	67.2	-1.20	920	1055	-135.7	-14.8	0.553	63	0.660	28	FA	Elec	SA
101	1	U	1127	69.2	69.9	0.73	1520	875	644.8	42.4	0.937	30	0.872	70	FA	Elec	SA
102	2	W	1132	75.0	75.6	0.61	493	354	139.1	28.2	0.229	72	0.395	74	FA	Elec	SA
103	2	U	1134	69.1	69.4	0.24	813	672	140.8	17.3	0.946	105	0.948	94	HUB	Elec	SA
104	1	U	1140	70.5	69.5	-1.03	499	534	-35.6	-7.1	0.000	61	0.299	105	StB	Oil	None
105	1	U	1144	62.2	64.1	1.95	1170	466	703.9	60.2	0.861	76	0.905	93	FA	Elec	SA
106	1	U	1145	70.7	70.7	0.00	567	400	167.0	29.5	0.703	71	0.776	101	FA	Prop	SA
107	2	U	1148	71.7	72.4	0.65	947	693	254.2	26.8	0.897	59	0.869	109	HUB	Elec	SA
108	1	U	1150	69.4	69.5	0.10	588	557	31.0	5.3	0.938	91	0.960	100	FA	Elec	SA
109	1	U	1152	72.9	72.6	-0.22	623	589	34.1	5.5	0.921	75	0.963	88	HUB	Oil	None
110	1	C	1152	66.5	66.4	-0.16	646	625	21.7	3.4	0.907	14	0.966	101	FA	Elec	SA
111	1	U	1155	68.0	69.4	1.49	1094	605	468.9	44.7	0.962	78	0.913	57	FA	Prop	SA
112	2	C	1160	73.2	72.9	-0.30	663	686	-23.5	-3.5	0.862	94	0.880	127	FA	Elec	SA
113	2	U	1164	66.6	64.3	-2.36	670	634	36.0	5.4	0.921	6	0.906	99	FA	Prop	SA
114	1	U	1168	69.7	67.6	-2.10	674	484	189.1	28.1	0.850	57	0.932	99	FA	Elec	SA
115	1	C	1176	70.6	71.0	0.33	809	821	-11.1	-1.4	0.777	67	0.909	93	HUB	Oil	None
116	2	U	1182	69.3	65.0	-4.27	1139	737	401.8	35.3	0.853	46	0.852	104	StB	Oil	None
117	1	U	1184	68.8	69.6	0.78	661	563	97.9	14.8	0.745	77	0.911	105	FA	Elec	SA
118	1	U	1186	73.1	72.4	-0.78	848	865	-16.3	-1.9	0.866	74	0.911	99	FA	Elec	SA
119	1	C	1188	79.9	79.0	-0.85	1174	1149	25.5	2.2	0.892	78	0.940	102	HUB	Oil	None
120	1	U	1196	68.3	68.8	0.49	850	655	194.7	22.9	0.893	60	0.801	87	HUB	Oil	None
121	1	U	1196	73.1	72.4	-0.65	786	768	17.8	2.3	0.875	76	0.382	99	??	Oil	None
122	1	U	1196	72.3	73.1	0.84	800	780	19.6	2.5	0.160	55	0.671	99	FA	Elec	SA
123	2	C	1196	68.5	69.0	0.54	1257	1150	106.5	8.5	0.504	143	0.964	119	HUB	Oil	None
124	1	C	1200	71.7	70.9	-0.85	491	505	-13.5	-2.7	0.853	85	0.902	103	HUB	Oil	None
125	2	U	1200	71.2	70.4	-0.80	1093	692	401.0	36.7	0.891	60	0.876	107	??	??	??
126	1	C	1200	68.6	69.7	1.12	906	1008	-102.2	-11.3	0.911	82	0.873	102	StB	Oil	None
127	2	U	1202	71.8	72.0	0.23	1135	1103	32.4	2.9	0.943	97	0.936	106	FA	Oil	SA
128	2	U	1212	68.4	68.9	0.53	1095	877	218.1	19.9	0.899	72	0.941	98	StB	Elec	SA
129	2	U	1215	71.7	71.2	-0.55	913	785	128.3	14.0	0.905	92	0.925	112	StB	NGas	SA
130	1	U	1215	67.9	66.8	-1.12	820	815	5.4	0.7	0.884	53	0.899	101	HUB	Oil	None
131	2	U	1216	69.7	69.3	-0.39	146	527	-381.0	261.7	0.215	97	0.617	95	FA	Prop	SA
132	1	U	1231	58.8	61.9	3.04	517	438	79.1	15.3	0.801	56	0.803	99	StB	NGas	SA
133	1	U	1232	69.1	68.8	-0.31	664	636	27.6	4.2	0.958	80	0.949	106	FA	Elec	SA
134	1	C	1236	73.0	76.8	3.82	574	794	-219.6	-38.3	0.412	71	0.834	105	FA	??	??
135	2	U	1240	71.1	71.0	-0.12	573	579	-5.3	-0.9	0.885	101	0.742	92	FA	Elec	SA
136	1	C	1242	73.9	73.9	-0.03	710	768	-58.3	-8.2	0.920	102	0.951	102	HUB	Elec	SA

Table H.2. Summary of sample (unweighted) results for 1990-1992 (continued)

ID	Test Year	Type	Heated Area (Ft²)	Temperature (°F)			Fuel-Oil Usage Data (Gal/Year)				Measured Statistics				HVAC Type	DHU System	
				Pre	Post	Change	Pre	Post	Savings	% Savings	Pre R^2	Days	Post R^2	Days		Fuel	Tank
137	2	C	1244	72.0	72.3	0.32	579	618	-39.3	-6.8	0.923	119	0.914	123	FA	Elec	SA
138	1	W	1248	74.0	73.9	-0.06	1126	1179	-52.5	-4.7	0.834	54	0.903	100	FA	Elec	SA
139	1	W	1248	71.3	72.1	0.82	1738	1327	411.0	23.6	0.962	55	0.947	105	StB	NGas	SA
140	2	C	1253	71.5	71.4	-0.12	906	919	-12.7	-1.4	0.961	132	0.945	127	HUB	Oil	None
141	1	C	1254	68.4	71.1	2.72	762	867	-104.9	-13.8	0.909	99	0.926	102	HUB	Oil	None
142	1	C	1262	69.3	67.3	-2.00	1132	1144	-11.7	-1.0	0.935	65	0.944	101	StB	NGas	SA
143	2	C	1264	67.7	67.1	-0.55	502	531	-28.2	-5.6	0.888	109	0.913	121	FA	ELec	SA
144	1	W	1268	74.2	74.6	0.34	1192	1170	21.8	1.8	0.908	88	0.909	88	??	Oil	None
145	1	U	1276	80.3	81.0	0.75	1374	1379	-5.3	-0.4	0.901	60	0.940	100	StB	Oil	None
146	2	U	1276	67.7	65.9	-1.74	787	685	102.7	13.0	0.916	69	0.886	108	HUB	Oil	None
147	2	W	1280	68.0	66.2	-1.81	593	799	-206.5	-34.8	0.143	87	0.361	113	StB	Oil	None
148	1	U	1280	69.2	69.8	0.59	1037	1043	-6.5	-0.6	0.937	59	0.919	97	Gr	Oil	SA
149	1	C	1288	68.6	69.4	0.78	1558	1612	-53.5	-3.4	0.968	77	0.958	102	FA	NGas	SA
150	1	C	1288	68.5	69.2	0.76	523	520	3.5	0.7	0.848	48	0.862	97	FA	Prop	SA
151	2	U	1290	73.8	73.9	0.17	968	719	248.9	25.7	0.897	109	0.889	103	HUB	Oil	Hone
152	2	U	1292	69.5	68.6	-0.86	1434	1008	425.2	29.7	0.193	66	0.802	113	HUB	Oil	SA
153	2	C	1292	62.1	63.1	1.02	921	957	-36.6	-4.0	0.881	108	0.903	120	HUB	Oil	None
154	2	U	1296	66.3	66.2	-0.16	827	727	99.5	12.0	0.886	68	0.890	103	FA	Elec	SA
155	2	C	1296	70.6	68.6	-2.00	383	373	10.0	2.6	0.949	130	0.958	132	FA	Elec	SA
156	1	U	1300	67.5	68.2	0.71	1344	1098	245.9	18.3	0.840	97	0.848	114	FA	Elec	SA
157	2	C	1300	77.4	77.4	-0.03	1070	1226	-155.7	-14.5	0.949	137	0.754	127	FA	Prop	SA
158	1	C	1312	72.0	71.4	-0.60	1116	1098	18.1	1.6	0.898	72	0.926	102	HWB	Oil	None
159	2	U	1312	73.3	71.8	-1.47	539	417	122.4	22.7	0.928	42	0.834	117	FA	NGas	SA
160	1	U	1314	67.7	68.2	0.47	785	620	164.7	21.0	0.911	61	0.921	80	FA	Elec	SA
161	1	C	1314	66.8	68.1	1.26	1011	1052	-41.8	-4.1	0.863	71	0.905	101	HUB	Oil	None
162	1	C	1314	74.8	74.1	-0.63	893	929	-36.5	-4.1	0.932	83	0.942	102	FA	NGas	SA
163	1	U	1320	73.0	73.9	0.92	909	687	221.6	24.4	0.971	58	0.909	102	FA	NGas	SA
164	2	C	1320	72.0	71.4	-0.59	771	765	5.8	0.8	0.936	127	0.918	118	StB	Oil	SA
165	1	U	1323	70.7	71.2	0.45	726	744	-18.7	-2.6	0.689	62	0.832	106	Gr	ELec	SA
166	2	W	1323	70.9	71.0	0.11	766	840	-73.8	-9.6	0.669	73	0.766	33	FA	Elec	SA
167	1	W	1325	70.2	71.2	0.99	817	816	0.6	0.1	0.472	72	0.903	86	HUB	Oil	None
166	1	C	1330	70.5	70.4	-0.12	937	1028	-90.4	-9.6	0.810	75	0.852	102	??	??	??
169	2	W	1331	74.2	72.2	-1.96	1449	1034	415.0	28.6	0.906	108	0.932	94	FA	ELec	SA
170	2	W	1344	69.5	65.3	-4.28	905	595	309.5	34.2	0.883	69	0.756	104	HUB	Oil	None
171	2	U	1344	74.2	73.1	-1.16	383	522	-139.5	-36.4	0.299	84	0.635	57	HUB	Elec	SA
172	1	C	1344	69.3	69.9	0.67	1793	2070	-276.9	-15.4	0.918	64	0.961	101	??	oil	None
173	2	C	1344	67.0	67.3	0.25	1295	1359	-63.9	-4.9	0.937	97	0.938	121	HUB	Oil	None
174	1	C	1353	66.7	67.8	1.15	1308	1620	-312.2	-23.9	0.899	89	0.790	102	HWB	??	??
175	2	C	1358	75.5	75.6	0.13	1360	1405	-44.7	-3.3	0.922	104	0.900	74	HUB	Oil	None
176	1	U	1364	72.3	71.7	-0.59	1084	840	243.6	22.5	0.932	51	0.953	99	HUB	Oil	None
177	1	U	1368	72.3	70.3	-2.01	842	535	307.5	36.5	0.893	47	0.894	87	FA	ELec	SA
178	2	U	1380	72.6	70.8	-1.76	1321	1196	125.1	9.5	0.966	94	0.943	80	??	??	??
179	1	U	1390	66.9	67.7	0.79	849	614	234.9	27.7	0.769	58	0.927	99	HUB	Elec	SA
180	2	C	1410	71.0	71.5	0.52	1356	1442	-86.0	-6.3	0.939	117	0.948	120	Gr	Oil	None
181	1	U	1412	68.1	69.4	1.31	704	517	187.4	26.6	0.928	83	0.884	87	FA	Elec	SA
182	2	U	1416	69.3	68.8	-0.58	731	727	3.8	0.5	0.725	54	0.901	110	HUB	Oil	None
183	1	C	1427	78.0	77.7	-0.29	1776	2042	-265.9	-15.0	0.600	73	0.794	101	??	??	??
184	1	C	1428	68.7	69.1	0.34	1347	1405	-58.3	-4.3	0.939	90	0.925	102	HUB	Oil	None
185	1	C	1428	67.5	66.5	-1.07	685	641	44.2	6.5	0.756	49	0.874	101	Gr	Prop	SA
186	1	U	1430	69.9	70.4	0.52	638	444	194.9	30.5	0.957	80	0.934	105	FA	Prop	SA
187	1	C	1430	67.6	67.7	0.09	698	719	-20.4	-2.9	0.859	85	0.906	102	HUB	Oil	None
188	2	U	1440	68.5	67.3	-1.21	953	497	456.1	47.9	0.903	49	0.913	111	FA	NGas	SA
189	1	C	1440	75.9	77.3	1.37	812	1004	-191.4	-23.6	0.719	67	0.869	102	??	ELec	SA
190	2	W	1440	74.1	71.8	-2.30	900	608	291.9	32.4	0.779	32	0.490	51	FA	NGas	SA
191	2	U	1440	69.8	70.9	1.15	784	745	39.2	5.0	0.950	77	0.878	98	HUB	Oil	None
192	2	C	1440	67.5	67.6	0.06	847	876	-29.4	-3.5	0.896	87	0.748	120	StB	Oil	None
193	2	U	1443	71.7	69.2	-2.44	1599	1439	160.1	10.0	0.828	66	0.852	112	FA	ELec	SA
194	1	U	1444	69.1	69.8	0.69	767	661	106.5	13.9	0.930	74	0.964	87	FA	Oil	SA
195	1	C	1447	70.1	70.5	0.48	1936	1972	-36.5	-1.9	0.758	71	0.844	101	StB	NGas	SA
196	2	U	1448	72.0	71.7	-0.28	503	604	-101.2	-20.1	0.021	56	0.112	122	HWB	Oil	None
197	2	U	1458	64.2	65.9	1.65	807	581	226.3	28.0	0.893	49	0.898	111	HUB	NGas	SA
198	1	C	1464	69.6	70.3	0.69	803	972	-169.1	-21.1	0.636	80	0.872	102	StB	oil	None
199	1	U	1467	70.6	71.9	1.24	1000	942	58.5	5.9	0.889	77	0.901	87	HUB	NGas	SA
200	2	U	1468	67.3	66.9	-0.36	471	396	75.5	16.0	0.772	68	0.740	103	HUB	Oil	None
201	1	U	1474	67.2	67.9	0.67	729	728	1.4	0.2	0.850	91	0.826	93	FA	Elec	SA
202	2	U	1475	67.3	68.8	1.56	1335	1001	333.8	25.0	0.815	69	0.751	111	StB	Oil	None
203	2	C	1480	71.7	71.1	-0.55	969	938	30.8	3.2	0.963	109	0.951	112	HUB	Oil	None
204	1	C	1482	69.9	69.9	-0.05	568	576	-7.4	-1.3	0.949	21	0.933	81	??	??	??

Table H.2. Summary of sample (unweighted) results for 1990-1992 (continued)

ID	Test Year	Type	Heated Area (Ft²)	Temperature (°F) Pre	Temperature (°F) Post	Temperature (°F) Change	Fuel-Oil Usage Data (Gal/Year) Pre	Fuel-Oil Usage Data (Gal/Year) Post	Savings	% Savings	Measured Statistics Pre R^2	Days	Post R^2	Days	HVAC Type	DHU System Fuel	DHU System Tank
205	1	W	1484	70.3	69.7	-0.58	682	576	105.8	15.5	0.791	51	0.912	106	HUB	Oil	Hone
206	2	C	1485	69.2	68.8	-0.32	268	4	264.4	98.6	0.185	105	0.154	121	HWB	Oil	None
207	1	U	1492	66.5	67.4	0.89	1073	930	143.0	13.3	0.902	69	0.877	70	HWB	Oil	None
208	2	U	1492	74.8	73.4	-1.44	278	680	-401.8	144.5	0.000	103	0.000	110	FA	Oil	SA
209	1	C	1498	71.3	71.5	0.15	842	932	-90.0	-10.7	0.859	95	0.944	102	HUB	Oil	None
210	2	U	1509	74.1	72.7	-1.48	718	565	153.3	21.3	0.951	90	0.916	81	FA	Elec	SA
211	1	C	1509	67.1	67.9	0.79	802	865	-62.9	-7.8	0.907	91	0.930	102	HUB	Elec	SA
212	2	U	1512	70.2	71.2	1.08	621	505	115.9	18.7	0.631	65	0.870	107	FA	Elec	SA
213	2	U	1512	74.9	74.7	-0.27	943	795	147.5	15.6	0.947	111	0.911	100	HWB	Oil	None
214	2	C	1520	67.3	67.8	0.49	891	917	-26.6	-3.0	0.945	105	0.892	122	HUB	Oil	None
215	1	U	1529	71.3	71.0	-0.30	1058	740	317.7	30.0	0.937	69	0.873	83	??	Oil	None
216	1	C	1530	71.1	71.1	0.07	643	648	-4.8	-0.7	0.906	84	0.878	102	HUB	Oil	None
217	1	W	1540	70.0	69.7	-0.36	1196	987	209.5	17.5	0.285	87	0.910	74	HUB	Oil	None
218	1	C	1554	72.4	72.6	0.19	1144	1174	-29.7	-2.6	0.934	88	0.906	102	HUB	NGas	SA
219	1	U	1560	65.5	67.0	1.46	1161	981	180.0	15.5	0.723	74	0.841	92	StB	Elec	SA
220	2	C	1564	75.1	75.4	0.36	987	1009	-22.3	-2.3	0.976	143	0.974	122	FA	Elec	SA
221	2	C	1584	65.6	65.6	-0.04	955	974	-18.8	-2.0	0.875	101	0.878	117	StB	Oil	None
222	1	U	1587	74.9	74.6	-0.29	1261	1335	-73.6	-5.8	0.927	87	0.890	88	Gr	NGas	SA
223	2	U	1589	78.3	70.4	-7.89	951	60	891.1	93.7	0.630	54	0.096	104	HUB	NGas	SA
224	1	U	1596	72.8	73.7	0.96	1625	1500	124.5	7.7	0.873	44	0.941	74	StB	Oil	None
225	1	C	1598	73.1	71.8	-1.30	1820	1412	408.3	22.4	0.943	95	0.777	102	FA	Prop	SA
226	1	U	1598	68.6	69.2	0.55	756	768	-11.3	-1.5	0.931	87	0.882	69	FA	Oil	SA
227	2	U	1600	68.6	70.3	1.65	1087	1028	59.1	5.4	0.894	61	0.936	106	FA	Elec	SA
228	2	U	1606	74.5	73.4	-1.12	1168	890	277.9	23.8	0.945	70	0.937	90	FA	Elec	SA
229	1	C	1618	68.8	68.1	-0.67	1456	1444	12.2	0.8	0.787	99	0.849	102	FA	Elec	SA
230	2	C	1625	61.6	59.2	-2.41	645	705	-60.0	-9.3	0.755	132	0.570	129	HUB	Oil	SA
231	1	C	1637	70.0	69.7	-0.28	1381	1475	-93.6	-6.8	0.950	89	0.971	102	??	Prop	SA
232	2	U	1638	70.7	71.4	0.77	553	611	-57.8	-10.5	0.809	46	0.653	36	FA	Prop	SA
233	2	C	1655	69.9	68.5	-1.37	596	573	23.2	3.9	0.891	99	0.842	120	??	Elec	SA
234	1	C	1657	70.0	70.6	0.63	594	623	-29.1	-4.9	0.932	76	0.928	102	HUB	Oil	SA
235	1	U	1664	65.9	65.8	-0.18	1453	993	460.6	31.7	0.878	68	0.942	94	FA	Elec	SA
236	2	C	1674	64.5	64.6	0.09	893	967	-73.8	-8.3	0.739	84	0.829	122	HUB	Elec	SA
237	1	W	1676	65.9	66.3	0.42	1436	718	718.9	50.0	0.901	83	0.844	91	FA	Prop	SA
238	1	C	1680	70.9	70.9	-0.02	1034	1064	-30.0	-2.9	0.924	80	0.944	101	HUB	Oil	None
239	1	U	1684	74.3	73.8	-0.45	1801	1391	409.9	22.8	0.854	70	0.900	88	StB	Oil	None
240	2	U	1688	77.1	76.3	-0.76	1536	1461	74.7	4.9	0.920	98	0.741	111	HUB	Oil	None
241	2	U	1691	71.8	72.3	0.49	1734	1796	-61.3	-3.5	0.907	31	0.938	94	HUB	Oil	None
242	2	U	1700	65.9	65.9	0.00	1079	695	384.0	35.6	0.948	98	0.726	97	HUB	Oil	None
243	2	U	1709	66.4	68.4	1.99	919	264	654.7	71.2	0.684	47	0.150	86	FA	Prop	SA
244	1	C	1719	71.1	70.8	-0.27	971	1046	-75.0	-7.7	0.941	67	0.896	101	HWB	Oil	None
245	1	U	1750	72.5	71.5	-0.99	1876	1670	206.5	11.0	0.945	51	0.934	74	FA	Elec	SA
246	1	C	1752	67.9	68.0	0.16	1488	1565	-76.8	-5.2	0.894	74	0.886	102	HUB	Oil	None
247	1	U	1752	71.6	71.8	0.25	945	1036	-91.1	-9.6	0.891	68	0.872	100	StB	NGas	SA
248	2	U	1760	72.6	72.7	0.17	1072	760	312.6	29.2	0.834	58	0.767	82	FA	Elec	SA
249	1	C	1764	73.2	72.7	-0.55	1351	1395	-43.2	-3.2	0.532	79	0.955	102	HUB	Oil	None
250	1	C	1766	74.2	73.5	-0.75	1390	1282	108.1	7.8	0.917	66	0.940	101	StB	Oil	None
251	2	C	1771	64.7	63.7	-1.03	1117	1254	-137.2	-12.3	0.875	122	0.938	120	StB	Oil	None
252	2	U	1791	67.5	66.8	-0.66	866	613	252.8	29.2	0.782	13	0.927	112	HUB	Oil	None
253	1	C	1800	68.1	65.4	-2.66	1697	1456	240.9	14.2	0.884	70	0.899	101	??	??	??
254	2	C	1826	64.8	65.6	0.77	715	805	-89.6	-12.5	0.528	93	0.758	120	HWB	Oil	None
255	2	U	1843	72.1	69.2	-2.94	633	419	214.0	33.8	0.084	60	0.283	106	HUB	Elec	SA
256	1	U	1843	68.2	69.3	1.16	1307	1218	89.2	6.8	0.907	74	0.928	88	HUB	Oil	None
257	1	C	1844	65.8	66.6	0.74	723	692	31.1	4.3	0.890	63	0.936	93	FA	Prop	SA
258	1	C	1844	62.2	61.4	-0.87	935	959	-23.7	-2.5	0.871	90	0.828	102	HUB	Elec	SA
259	2	U	1860	73.0	73.6	0.59	1304	1089	215.3	16.5	0.954	69	0.962	104	HWB	Elec	SA
260	1	W	1872	66.7	67.1	0.38	934	906	28.2	3.0	0.859	55	0.897	105	HUB	Oil	None
261	2	C	1892	71.4	70.8	-0.55	30	13	17.6	58.1	0.000	93	0.191	122	HWB	Oil	
262	2	U	1892	72.7	71.3	-1.37	1219	977	241.8	19.8	0.951	100	0.952	110	HUB	Oil	None
263	1	U	1906	65.9	67.9	2.06	941	674	266.5	28.3	0.131	64	0.024	98	HWB	Oil	None
264	2	U	1973	75.2	74.5	-0.66	1014	850	164.0	16.2	0.941	52	0.952	105	HUB	Oil	None
265	2	C	1984	68.5	66.9	-1.67	923	901	21.5	2.3	0.960	136	0.926	122	FA	Oil	SA
266	2	C	2014	70.1	69.1	-0.99	1135	1204	-69.1	-6.1	0.840	108	0.921	123	FA	Elec	SA
267	1	C	2016	70.0	70.5	0.43	364	396	-31.8	-8.7	0.911	70	0.915	101	HUB	Oil	None
268	2	U	2040	73.5	73.2	-0.27	1519	1164	355.6	23.4	0.941	29	0.629	123	FA	Prop	SA
269	1	U	2059	70.3	69.8	-0.52	1388	1325	63.4	4.6	0.825	74	0.744	83	FA	Elec	SA
270	2	U	2064	72.2	71.2	-0.97	370	361	8.9	2.4	0.703	82	0.850	a	StB	Oil	None
271	2	U	2069	65.8	66.0	0.19	534	404	129.9	24.3	0.925	38	0.897	114	FA	NGas	SA
272	2	C	2100	74.3	74.3	-0.01	1257	1293	-36.0	-2.9	0.902	74	0.894	117	HUB	Oil	None

Table H.2. Summary of sample (unweighted) results for 1990-1992 (continued)

ID	Test Year	Type	Heated Area (Ft^2)	Temperature (°F)			Fuel-Oil Usage Data (Gal/Year)				Measured Statistics				HVAC Type	DHU System	
				Pre	Post	Change	Pre	Post	Savings	% Savings	Pre R^2	Days	Post R^2	Days		Fuel	Tank
273	1	C	2140	74.2	73.2	-1.00	1772	1739	33.9	1.9	0.792	64	0.871	100	FA	Elec	SA
274	1	C	2154	68.7	69.0	0.26	1214	1076	137.9	11.4	0.797	67	0.744	100	HUB	Elec	SA
275	2	C	2160	72.6	71.6	-0.97	2419	2349	69.9	2.9	0.960	115	0.966	122	HUB	Elec	SA
276	2	W	2172	78.8	77.8	-0.94	546	562	-15.6	-2.9	0.784	90	0.768	81	FA	Oil	SA
277	2	C	2242	70.1	70.3	0.18	227	225	2.3	1.0	0.244	143	0.201	117	FA	Elec	SA
278	2	W	2250	67.4	67.4	0.04	781	728	53.3	6.8	0.898	98	0.847	104	HUB	Oil	None
279	1	C	2266	70.8	69.9	-0.95	825	835	-10.3	-1.2	0.913	88	0.944	102	FA	Oil	SA
280	2	U	2294	71.5	71.1	-0.31	644	320	324.1	50.3	0.829	46	0.686	93	FA	Elec	SA
281	1	U	2380	66.7	67.3	0.65	593	567	26.4	4.5	0.630	69	0.393	88	HUB	Oil	None
282	2	W	2414	71.6	72.1	0.49	1129	904	224.3	19.9	0.929	72	0.834	104	HUB	Oil	None
283	2	C	2448	70.1	71.5	1.42	1041	814	227.3	21.8	0.841	119	0.078	121	HUB	NGas	SA
284	2	W	2472	71.6	70.9	-0.68	2002	1556	445.6	22.3	0.876	112	0.938	121	HUB	Oil	None
285	2	C	2476	65.5	64.9	-0.64	597	620	-23.2	-3.9	0.776	121	0.727	123	HUB	Elec	SA
286	2	C	2488	64.8	62.5	-2.25	716	1116	-400.4	-56.0	0.346	85	0.769	120	FA	Elec	SA
287	1	U	2524	71.5	71.8	0.36	667	461	205.9	30.9	0.878	87	0.904	98	FA	Prop	SA
288	2	W	2576	72.1	72.7	0.59	995	1066	-70.4	-7.1	0.934	75	0.906	98	HUB	Oil	None
289	2	U	2578	67.1	66.2	-0.89	1192	1045	147.4	12.4	0.757	68	0.859	107	HUB	Oil	None
290	2	W	2632	69.2	69.8	0.59	565	549	16.4	2.9	0.942	69	0.119	81	FA	Elec	SA
291	1	C	2640	70.5	68.5	-1.98	1979	1585	394.8	19.9	0.912	96	0.636	102	StB	Oil	None
292	1	C	2736	71.4	71.9	0.50	998	1310	-312.1	-31.3	0.949	99	0.000	101	StB	Elec	None
293	2	C	2763	70.4	69.8	-0.65	929	700	228.4	24.6	0.923	128	0.649	120	HUB	Oil	None
294	1	W	2800	74.8	74.9	0.13	2077	1494	583.2	28.1	0.880	74	0.928	105	StB	Oil	None
295	1	W	2824	69.2	69.4	0.24	1070	650	420.6	39.3	0.894	66	0.839	98	HUB	NGas	SA
296	2	W	2922	71.9	70.9	-0.95	552	646	-94.1	-17.1	0.839	71	0.874	111	HWB	Oil	None
297	1	U	3230	72.3	71.5	-0.80	2131	2084	46.2	2.2	0.921	61	0.926	94	StB	Oil	None
298	1	U	3312	66.4	66.9	0.54	2136	2407	-271.2	-12.7	0.784	83	0.688	85	StB	NGas	SA

Notes:

- Test Year – 1 means 1990-1991 heating season, 2 means 1991-1992 heating season.
- Type – C means control house, U means weatherized house.
- Temperature – Average indoor temperature for pre- or post-weatherization period, and
  – average indoor temperature change from pre- to post-weatherization period.
- Days – Days of data used for regression analysis.
- HVAC System – FA means a forced-air furnace.
  HUB means a hot water boiler with convectors or radiators.
  StB means a steam boiler with convectors or radiators.
  Gr means a boiler with no circulating pump, or a gravity hot-air furnace.
- Tank – SA means stand-alone tank, None means tankless (coil in boiler) system.

Table H.3. Distributions of energy related parameters for the control houses

PRE-INSIDE TEMPERATURE, N = 105

Value	Count	Percent
58	0	.00
60	2	1.90
62	3	2.86 B
64	8	7.62
66	16	15.24
68	23	21.90
70	23	21.90
72	18	17.14
74	9	8.57
76	2	1.90 B
78	1	.95

POST-INSIDE **TEMPERATURE, N** = 105

Value	Count	Percent
58.	1	.95
60.	3	2.86
62.	4	3.81
64.	6	5.71
66.	16	15.24
68.	24	22.86
70.	26	24.76
72.	14	13.33
74.	6	5.71
76.	4	3.81
78.	1	.95

PRE-GALLONS/YEAR FUEL USE, N = 105

Value	Count	Percent
0	1	.95
200	5	4.76
400	13	12.38
600	24	22.86
800	27	25.71
1000	12	11.43
1200	12	11.43
1400	3	2.86
1600	4	3.81
1800	3	2.86
2000+	0	.95

POST-GALLONS/YEAR FUEL USE, N = 105

Value	Count	Percent
0	2	1.90 B
200	3	2.86 B
400	9	8.57
600	26	24.76
800	24	22.86
1000	16	15.24
1200	9	8.57
1400	9	8.57
1600	3	2.86 B
1800	1	.95
2000+	3	2.86 B

(PRE-POST) GALLONS/YEAR FUEL DIFFERENCE, **N =** 105

Value	Count	Percent
-500	1	.95
-400	2	1.90
-300	3	2.86
-200	8	7.62
-100	55	52.38
0	27	25.71
100	3	2.86 B
200	4	3.81
300	1	.95
400	1	.95

PERCENT SAVINGS IN FUEL USAGE, N = 105

Value	Count	Percent
-60	1	.95
-50	0	.00
-40	2	1.90 B
-30	3	2.86 B
-20	10	9.52
-10	53	50.48
0	28	26.67
10	3	2.86 B
20	3	2.86 B
30	0	.00
40	0	.00
50+	2	1.90 B

Table HA Distribution of energy related parameters for the weathenzed houses

PRE-INDOOR TEMPERATURE, N = 193

Value	Count	Percent
54	1	.52
56	0	.00
58	1	.52
60	1	.52
62	6	3.11
64	11	5.70
66	29	15.03
68	35	18.13
70	54	27.98
72	31	16.06
74	18	9.33
76	3	1.55
78	2	1.04
80	1	.52

POST-INDOOR TEMPERATURE, N = 193

Value	Count	Percent
54	0	.00
56	1	.52
58	0	.00
60	1	.52
62	4	2.07
64	13	6.74
66	28	14.51
68	45	23.32
70	49	25.39
72	34	17.62
74	14	7.25
76	3	1.55
78	0	.00
80	1	.52

PRE-GALLONS/YEAR FUEL USE, N = 193

Value	Count	Percent
0	1	.52
200	9	4.66
400	36	18.65
600	45	23.32
800	42	21.76
1000	29	15.03
1200	11	5.70
1400	11	5.70
1600	3	1.55
1800	2	1.04
2000	4	2.07

POST-GALLONS/YEAR FUEL USE, N = 193

Value	Count	Percent
0	3	1.55
200	15	7.77
400	59	30.57
600	55	28.50
800	25	12.95
1000	19	9.84
1200	7	3.63
1400	6	3.11
1600	2	1.04
1800	0	.00
2000+	2	1.03

(PRE-POST) GALLONS/YEAR FUEL DIFFERENCE, N = 193

Value	Count	Percent
-500	1	.52
-400	2	1.04
-300	3	1.55
-200	4	2.07
-100	22	11.40
0	58	30.05
100	39	20.21
200	29	15.03
300	13	6.74
400	14	7.25
500	2	1.04
600	3	1.55
700	2	1.04
800	1	.52

PERCENT SAVINGS IN FUEL USE, N = 193

Value	Count	Percent
-50-	1	.53
-40	2	1.05
-30	1	.53
-20	6	3.16
-10	19	10.00
0	45	23.68
10	42	22.11
20	39	20.53
30	21	11.05
40	7	3.68
50	4	2.11
60	1	.53
70	1	.53
80+	1	.53

Table H.5. **Summary** statistics for **different** control house data sets

(a) CONTROL HOUSES - ALL DATA

Statistics	Heated Area (Ft²)	Inside Temperature (°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	105	105	105	105	105	105	105
Minimum	622.000	61.260	59.210	30.300	3.700	-400.400	-55.953
Maximum	2763.000	79.850	79.000	2418.900	2349.000	408.300	98.620
Mean	1447.219	69.888	69.762	937.759	958.133	-20.374	-2.172*
Standard Dev	465.503	3.529	3.689	406.221	409.496	116.526	15.902

(b) CONTROL HOUSES - R2 > .5

Statistics	Heated Area (Ft²)	Inside Temperature (°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	97	97	97	97	97	97	97
Minimum	622.000	61.260	59.210	364.000	372.600	-312.200	-23.872
Maximum	2763.000	79.850	79.000	2418.900	2349.000	408.300	24.596
Mean	1410.381	69.960	69.803	961.523	979.974	-18.452	-1.919*
Standard Dev	422.116	3.527	3.585	394.883	392.051	101.542	8.437

(c) CONTROL HOUSES - R2 > .7

Statistics	Heated Area (Ft²)	Inside Temperature (°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	88	88	88	88	88	88	88
Minimum	622.000	61.260	61.370	364.000	372.600	-312.200	-23.872
Maximum	2476.000	79.850	79.000	2418.900	2349.000	408.300	22.429
Mean	1378.523	69.971	69.836	946.030	966.285	-20.256	-2.141*
Standard Dev	385.055	3.418	3.429	381.531	383.064	85.947	7.224

(d) CONTROL HOUSES - R2 > .85

Statistics	Heated Area (Ft²)	Inside Temperature (°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	62	62	62	62	62	62	62
Minimum	622.000	61.260	61.880	364.000	372.600	-276.900	-15.443
Maximum	2266.000	79.850	79.000	2418.900	2349.000	240.900	14.197
Mean	1363.452	70.114	70.036	942.942	966.395	-23.453	-2.487*
Standard Dev	358.573	3.303	3.269	371.999	377.059	63.747	5.294

* Mean of % savings calculated from means of pre- and post-weatherization usage values.

Table H.6. Summary statistics for different weatherized house data sets

(a) WEATHERIZED HOUSES - ALL DATA

Statistics	Healed Area	Inside Temperature(°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	193	193	193	193	193	193	193
Minimum	480.000	55.690	56.350	145.600	60.100	-401.800	-261.676
Maximum	3312.000	80.270	81.020	2135.900	2407.100	891.100	93.682
Mean	1313.192	70.169	70.079	881.707	738.856	142.851	16.202*
Standard Dev	521.809	3.485	3.267	378.726	340.092	195.220	30,812

(b) WEATHERIZED HOUSES - R2 > .5

Statistics	Heated Area	Inside Temperature(°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	166	166	166	166	166	166	166
Minimum	504.000	55.690	56.350	265.100	248.300	-271.200	-19.160
Maximum	3312.000	80.270	81.020	2135.900	2407.100	718.900	60.168
Mean	1309.735	70.032	70.019	921.508	764.348	157.161	17.054*
Standard Dev	530.718	3.439	3.302	375.560	348.158	171.797	15.646

(c) WEATHERIZED HOUSES - R2 > .7

Statistics	Heated Area	Inside Temperature(°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	149	149	149	149	149	149	149
Minimum	529.000	55.690	56.350	265.100	248.300	-130.900	-19.160
Maximum	3230.000	80.270	81.020	2130.600	2084.400	718.900	60.168
Mean	1309.832	70.109	70.077	930.101	768.099	162.002	17.418*
Standard Dev	510.313	3.478	3.322	368.775	328.527	166.735	14.836

(d) WEATHERIZED HOUSES - R2 > .85

Statistics	Heated Area	Inside Temperature(°F)		Fuel-Oil Usage (Gallons Year)			
		Pre	Post	Pre	Post	Pre-Post	% Saving
No. of Cases	101	101	101	101	101	101	101
Minimum	529.000	55.690	56.350	403.300	248.300	-130.900	-19.160
Maximum	3230.000	80.270	81.020	2130.600	2084.400	703.900	60.168
Mean	1264.782	70.630	70.583	970.300	799.951	170.349	17.556*
Standard Dev	485.143	3.330	3.300	377.495	341.049	175.399	15.229

* Mean of % savings calculated from means of pre- and post-weatherization usage values.

Table **H.7.** Distribution of energy related parameters for control houses with $R^2 > 0.7$

PRE-INSIDE TEMPERATURE, N = 88

Value	Count	Percent
58	0	.00
60	1	1.14
62	2	2.27
64	6	6.82
66	16	18.18
68	20	22.73
70	17	19.32
72	15	17.05
74	9	10.23
76	1	1.14
78	1	1.14

POST-INSIDE **TEMPERATURE,** N = 88

Value	Count	Percent
58	0	.00
60	2	2.27
62	3	3.41
64	5	5.68
66	16	18.18
68	20	22.73
70	21	23.86
72	12	13.64
74	6	6.82
76	2	2.27
78	1	1.14

PRE-GALLONS/YEAR FUEL USE, N = 88

Value	Count	Percent
0	0	.00
200	3	3.41
400	11	12.50
600	21	23.86
800	24	27.27
1000	11	12.50
1200	9	10.23
1400	3	3.41
1600	3	3.41
1800	2	2.27
2000+	1	1.14

POST-GALLONS/YEAR FUEL USE, N = 88

Value	Count	Percent
0	0	.00
200	2	2.27
400	9	10.23
600	22	25.00
800	21	23.86
1000	14	15.91
1200	6	6.82
1400	8	9.09
1600	3	3.41
1800	1	1.14
2000+	1	2.27

(PRE-POST) GALLONS/YEAR FUEL **DIFFERENCE,** N = 88

Value	Count	Percent
-500	0	.00
-400	1	1.14
-300	1	1.14
-200	6	6.82
-100	52	59.09
0	24	27.27
100	2	2.27
200	1	1.14
300	0	.00
400	1	1.14

PERCENT SAVINGS IN FUEL USAGE, N = 88

Value	Count	Percent
-50	0	.00
-40	0	.00
-30	2	2.27
-20	7	7.95
-10	51	57.95
0	25	28.41
10	2	2.27
20	1	1.14

Table H.8. Distribution of energy related **parameters** for weathenzed houses with $R^2 > 0.7$

PRE-INDOOR TEMPERATURE, N = 149

Value	Count	Percent
54	1	.67
56	0	.00
58	1	.67
60	0	.00
62	4	2.68
64	10	6.71
66	22	14.77
68	31	20.81
70	38	25.50
72	24	16.11
74	14	9.40
76	2	1.34
78	1	.67
80	1	.67

POST-INDOOR TEMPERATURE, N = 149

Value	Count	Percent
54	0	.00
56	1	.67
58	0	.00
60	1	.67
62	2	1.34
64	11	7.38
66	20	13.42
68	37	24.83
70	37	24.83
72	25	16.78
74	11	7.38
76	3	2.01
78	0	.00
80	1	.67

PRE-GALLONS/YEAR FUEL USE, N = 149

Value	Count	Percent
0	0	.00
200	3	2.01
400	23	15.44
600	35	23.49
800	33	22.15
1000	27	18.12
1200	11	7.38
1400	9	6.04
1600	3	2.01
1800	2	1.34
2000	3	2.01

POST-GALLONS/YEAR FUEL USE, N = 149

Value	Count	Percent
0	0	.00
200	9	6.04
400	46	30.87
600	42	28.19
800	20	13.42
1000	16	10.74
1200	7	4.70
1400	6	4.03
1600	2	1.34
1800	0	.00
2000	1	.67

(PRE-POST) GALLONS/YEAR FUEL DIFFERENCE, N = 149

Value	Count	Percent
-500	0	.00
-400	0	.00
-300	0	.00
-200	1	.67
-100	17	11.41
0	45	30.20
100	34	22.82
200	24	16.11
300	10	6.71
400	13	8.72
500	1	.67
600	2	1.34
700	2	1.34

PERCENT SAVINGS IN FUEL USE, N = 149

Value	Count	Percent
-50	0	.00
-40	0	.00
-30	0	.00
-20	3	2.01
-10	15	10.07
0	36	24.16
10	35	23.49
20	32	21.48
30	19	12.75
40	6	4.03
50	2	1.34
60	1	.67

APPENDIX I. SAMPLE WEIGHTING METHODOLOGY

The equations used to calculate the average regional values under the weighted ratio-estimator averaging procedure are provided at the end of this Appendix.

A weight was defined in this study as the number of houses in the overall population of single-family fuel-oil heated houses that were weatherized in the nine northeast states during program years 1991 and 1992 that a monitored house represented. Table I.1 contains the weights used for calculations in this study. The first entry in Table I.1, Community Action of Greater Middletown (CAGM) of Connecticut, will be used as an example of estimating a weight.

Four houses in CAGM were assigned to the weatherized group. CAGM weatherized 98 single-family fuel-oil heated houses during the program year. Therefore, each monitored house represented

$$(98 / 4) = 24.50 \text{ single-family fuel-oil heated houses}$$

in CAGM. On a statewide basis, Connecticut had 15 agencies administering the Weatherization Assistance Program. We monitored two agencies during the first heating season, so each agency represented

$$(15 / 2) = 7.50 \text{ agencies}$$

in the state of Connecticut. Again on a state-wide basis, each house monitored in CAGM represented

$$(24.5 * 7.5) = 183.75 \text{ single-family fuel-oil heated houses}$$

in Connecticut. Therefore, the combined four houses monitored at CAGM represented

$$(4) * (183.75) = 735.00 \text{ single-family fuel-oil heated houses}$$

in Connecticut.

Control houses in the sample were treated in the same manner as weatherized houses. Since only three control houses were monitored from CAGM, each control house in CAGM represented

$$(98 / 3) * (15 / 2) = 245.00 \text{ single-family fuel-oil heated houses}$$

in Connecticut, with the combined three houses representing

$$(3) * (245.00) = 735.00 \text{ single-family fuel-oil heated houses}$$

in the state of Connecticut. Note that the representations of combined weatherized and combined controls were equal.

Weighted results for any individual variable were estimated by adding the products of weight times variable for each house and dividing by the sum of the weights of those houses (which equals 735 for CAGM). For example, if three control houses in CAGM had inside temperatures of 70, 71, and 72°F, respectively, the weighted average is

$$(70*245 + 71*245 + 72*245) / (245 + 245 + 245) = 71°F,$$

which is also the same as the arithmetic average. If the next agency in Connecticut, the Community Resource Team of Greater Hartford (CRT) has three control houses with inside temperatures of 67, 68, and 69°F, the weighted average of the CAGM and CRT houses is

$$[(70*245 + 71*245 + 72*245) + (67*325 + 68*325 + 69*325)] / [(245 + 245 + 245) + (325 + 325 + 325)] = 69.29°F,$$

which is different from the arithmetic average of 69.50°F.

The above examples are included to demonstrate that weighted results and arithmetic averages can differ, with differences increasing as respective weights and sums of respective weights differ. This same summing method is used to estimate weighted results for the entire sample by simply summing the weight times variable terms for the entire sample and dividing by the sum of the weights for the sample. Simply stated,

$$2\,(\text{Weight} * \text{Variable}) \,/\, \Sigma(\text{Weights}) = \text{Weighted Average of Variable.}$$

Table I.1. Summary of weights used for energy-use calculations

St	No. State CAPS	CAP	Test_Houses WX	Cont	Tot	Total CAP S-Family FO WX	WX'd CAP Factor	Control CAP Factor	State Factor	WX'd House Weight	Control House Weight	Fuel-Oil S-Family WX Homes
CT	15	CAGH	4	3	7	98	24.50	32.67	7.50	183.75	245.00	735.0
CT	15	CRT	4	3	7	130	32.50	43.33	7.50	243.75	325.00	975.0
CT	15	TVCCA	7	4	11	100	14.29	25.00	15.00	214.29	375.00	1500.0
MA	24	FCAC	5	3	8	54	10.80	18.00	6.00	64.80	108.00	324.0
HA	24	NSCAP	5	3	8	53	10.60	17.67	6.00	63.60	106.00	318.0
HA	24	SSCAC	5	2	7	132	26.40	66.00	6.00	158.40	396.00	792.0
HA	24	SAC	4	3	7	90	22.50	30.00	6.00	135.00	180.00	540.0
HA	24	CAP IC	5	0	5	36	7.20	0.00	8.00	57.60	0.00	288.0
HA	24	BCAC	7	4	11	25	3.57	6.25	8.00	28.57	50.00	200.0
HA	24	LEO	6	2	8	75	12.50	37.50	8.00	100.00	300.00	600.0
HE	12	KVCAP	5	2	7	51	10.20	25.50	6.00	61.20	153.00	306.0
ME	12	SHT	4	3	7	60	15.00	20.00	6.00	90.00	120.00	360.0
HE	12	CCI	7	4	11	184	26.29	46.00	12.00	315.43	552.00	2208.0
NH	6	SNH	4	3	7	98	24.50	32.67	3.00	73.50	98.00	294.0
NH	6	TCCA	5	3	8	109	21.80	36.33	3.00	65.40	109.00	327.0
NH	6	RCCA	5	2	7	98	19.60	49.00	6.00	117.60	294.00	588.0
NJ	22	CCCEO	4	3	7	63	15.75	21.00	11.00	173.25	231.00	693.0
NJ	22	PRAB	4	2	6	37	9.25	18.50	11.00	101.75	203.50	407.0
NJ	22	TCCCC	7	4	11	45	6.43	11.25	22.00	141.43	247.50	990.0
NY	74	CCAP	3	3	6	23	7.67	7.67	14.80	113.47	113.47	340.4
NY	74	SHI	4	2	6	19	4.75	9.50	14.80	70.30	140.60	281.2
NY	74	GCCAA	3	2	5	28	9.33	14.00	14.80	138.13	207.20	414.4
NY	74	PEACE	2	2	4	4	2.00	2.00	14.80	29.60	29.60	59.2
NY	74	TCEOC	3	1	4	13	4.33	13.00	14.80	64.13	192.40	192.4
NY	74	ACOI	3	1	4	4	1.33	4.00	18.50	24.67	74.00	74.0
NY	74	WCOA	6	3	9	11	1.83	3.67	18.50	33.92	67.83	203.5
NY	74	SCW	3	0	3	6	2.00	0.00	18.50	37.00	0.00	111.0
NY	74	LCCAP	6	4	10	15	2.50	3.75	18.50	46.25	69.38	277.5
PA	44	BCW	3	1	4	66	22.00	66.00	11.00	242.00	726.00	726.0
PA	44	BCAP	3	2	5	93	31.00	46.50	11.00	341.00	511.50	1023.0
PA	44	CEO	5	3	8	123	24.60	41.00	11.00	270.60	451.00	1353.0
PA	44	WI	3	3	6	68	22.67	22.67	11.00	249.33	249.33	748.0
PA	44	SEDA	5	4	9	148	29.60	37.00	14.67	434.13	542.67	2170.7
PA	44	EOC	6	4	10	41	6.83	10.25	14.67	100.22	150.33	601.3
PA	44	SCCAP	7	2	9	42	6.00	21.00	14.67	88.00	308.00	616.0
R!	6	TTCAP	5	3	8	49	9.80	16.33	3.00	29.40	49.00	147.0
RI	6	WCA	5	2	7	50	10.00	25.00	3.00	30.00	75.00	150.0
RI	6	SHINC	7	4	11	72	10.29	18.00	6.00	61.71	108.00	432.0
VT	5	CVOEO	5	3	8	45	9.00	15.00	2.50	22.50	37.50	112.5
VT	5	NETO	5	0	5	53	10.60	0.00	2.50	26.50	0.00	132.5
VT	5	CVCAC	4	3	7	162	40.50	54.00	5.00	202.50	270.00	810.0
Tot	208		193	105	298	2673			416.00			23420.6

Notes:
WX = Weatherized
S-Family = Single-Family home.
Total CAP S-Family FO WX = Estimated number of single-family homes weatherized by CAP in test year.
WX'd House Weight = Weight applied to each weatherized home.
Fuel-Oil S-Family WX Homes = Estimated number of single-family homes weatherized in two test years.

DIFFERENT ESTIMATES OF $\bar{\bar{Y}}_{ts}$ and $\bar{\bar{Y}}_{t}$, and $\bar{\bar{Y}}$

WHICH DO NOT REQUIRE PRIOR KNOWLEDGE OF $M_{...}$,

$M_{t..}$, $M_{ts.}$, and M_{tsc}.

(Alternative IIa)

I. SETTING FOR STATE s DURING WINTER t

Let $M_{ts\cdot}$ = the number of home units in the s^{th} state (where $s = 1, 2.....9$) of the t^{th} winter (where $t = 1, 2$),

N_{ts} = the number of CAPS in the s^{th} state of the t^{th} winter,

and n_{ts} = the number of CAPS in the sample selected from the s^{th} state during the t^{th} winter.

II. SAMPLE STATISTICS FOR STATE s DURING THE t^{th} WINTER

Using the same notation as before, we have a sample of n_{ts} CAPS:

$$CAP_{ts1}, CAP_{ts2}, \ldots, CAP_{tsc}, \ldots, CAP_{tsn_{ts}}$$

t^{th} Winter

All Known! $\left\{ \begin{array}{l} M_{tsc} \\ m_{tsc} \\ \bar{y}_{tsc} \\ s^2_{tsc} \\ \hat{Y}_{tsc\cdot} = M_{tsc}\,\bar{y}_{tsc} \end{array} \right.$

III. ESTIMATES FOR STATE s IN WINTER t

A "ratio" estimator of $\bar{\bar{Y}}_{ts}$ is

$$\hat{\bar{\bar{Y}}}_{ts(R)} = \frac{\sum_{c=1}^{n_{ts}} \hat{Y}_{tsc\cdot}}{\sum_{c=1}^{n_{ts}} M_{tsc}} = \frac{\sum_{c=1}^{n_{ts}} M_{tsc}\,\bar{y}_{tsc}}{\sum_{c=1}^{n_{ts}} M_{tsc}}$$

(The above is equation (11.25) in Cochran (1977).)

The approximate sampling variance of $\hat{\bar{\bar{Y}}}_{ts(R)}$ is

$$Var(\hat{\bar{\bar{Y}}}_{ts(R)}) \simeq \frac{1}{M_{ts\cdot}^2}\left[\frac{N_{ts}^2}{n_{ts}}\left(\frac{N_{ts}-n_{ts}}{N_{ts}}\right)\frac{\sum_{c=1}^{N_{ts}} M_{tsc}^2(\bar{\bar{Y}}_{tsc}-\bar{\bar{Y}}_{ts})^2}{N_{ts}-1}\right.$$

$$\left. + \frac{N_{ts}}{n_{ts}}\sum_{c=1}^{N_{ts}} M_{tsc}^2\left(\frac{M_{tsc}-m_{tsc}}{M_{tsc}}\right)\frac{S_{tsc}^2}{m_{tsc}}\right]$$

(The above *is* equation (11.27) in Cochran (1977).)

An approximate estimate of $Var(\hat{\bar{\bar{Y}}}_{ts(R)})$ is

$$\hat{Var}(\hat{\bar{\bar{Y}}}_{ts(R)}) \simeq \frac{1}{M_{ts\cdot}^2}\left[\frac{N_{ts}^2}{n_{ts}}\left(\frac{N_{ts}-n_{ts}}{N_{ts}}\right)\frac{\sum_{c=1}^{n_{ts}} M_{tsc}^2(\bar{y}_{tsc}-\hat{\bar{\bar{Y}}}_{ts(R)})^2}{n_{ts}-1}\right.$$

$$\left. + \frac{N_{ts}}{n_{ts}}\sum_{c=1}^{n_{ts}} M_{tsc}^2\left(\frac{M_{tsc}-m_{tsc}}{M_{tsc}}\right)\frac{s_{tsc}^2}{m_{tsc}}\right]$$

One need only be concerned about computing $\hat{\bar{\bar{Y}}}_{ts(R)}$ and $\hat{Var}(\hat{\bar{\bar{Y}}}_{ts(R)})$ for $s = 1, 2, \ldots, 9$ and t — 1, 2. Because $M_{ts\cdot}$ is unknown, estimate it by

$$\hat{M}_{ts\cdot} = N_{ts}\left(\sum_{c=t}^{n_{ts}} M_{tsc}/n_{ts}\right) \text{ for } t = 1, 2 \text{ and } s = 1, 2, \ldots, 9.$$

IV. ESTIMATES FOR THE ENTIRE NORTHEAST DURING WINTER *t*

Let $\hat{M}_{t\cdot\cdot} = \sum_{s=1}^{9}\hat{M}_{ts\cdot}$ and $P_{ts} = \hat{M}_{ts\cdot}/\hat{M}_{t\cdot\cdot}$ for s = 1,2.....9.

An estimate of $\bar{\bar{Y}}_t$ is given by

$$\hat{\bar{\bar{Y}}}_{t(R)} = \sum_{s=1}^{9} P_{ts}\hat{\bar{\bar{Y}}}_{ts(R)} .$$

The approximate sampling variance of $\hat{\bar{\bar{Y}}}_{t(R)}$ is

$$Var(\hat{\bar{\bar{Y}}}_{t(R)}) = \sum_{s=1}^{9} P_{ts}^2 Var(\hat{\bar{\bar{Y}}}_{ts(R)}) ,$$

and an approximate **estimate** of $Var(\hat{\bar{\bar{Y}}}_{t(R)})$ is

$$\hat{Var}(\hat{\bar{\bar{Y}}}_{t(R)}) = \sum_{s=1}^{9} P_{ts}^2 \hat{Var}(\hat{\bar{\bar{Y}}}_{ts(R)}) \ .$$

Our **concern** is in computing $\hat{\bar{\bar{Y}}}_{t(R)}$ and $\hat{Var}(\hat{\bar{\bar{Y}}}_{t(R)})$.

V. ESTIMATES FOR THE ENTIRE NORTHEAST OVER BOTH WINTERS

Let $\hat{M}_{\cdot\cdot\cdot} = \hat{M}_{1\cdot\cdot} + \hat{M}_{2\cdot\cdot}$,

$\hat{P}_1 = \hat{M}_{1\cdot\cdot}/\hat{M}_{\cdot\cdot\cdot}$,

and $\hat{P}_2 = \hat{M}_{2\cdot\cdot}/\hat{M}_{\cdot\cdot\cdot}$.

An **estimate** of $\bar{\bar{Y}}$ is

$$\hat{\bar{\bar{Y}}} = \hat{P}_1 \hat{\bar{\bar{Y}}}_{1(R)} + \hat{P}_2 \hat{\bar{\bar{Y}}}_{2(R)} \ .$$

The approximate sampling variance of $\hat{\bar{\bar{Y}}}$ is

$$Var(\hat{\bar{\bar{Y}}}) = (\hat{P}_1)^2 Var(\hat{\bar{\bar{Y}}}_{1(R)}) + (\hat{P}_2)^2 Var(\hat{\bar{\bar{Y}}}_{2(R)}) \ ,$$

and an approximate estimate of $Var(\hat{\bar{\bar{Y}}})$ is

$$\hat{Var}(\hat{\bar{\bar{Y}}}) = (\hat{P}_1)^2 \hat{Var}(\hat{\bar{\bar{Y}}}_{1(R)}) + (\hat{P}_2)^2 \hat{Var}(\hat{\bar{\bar{Y}}}_{2(R)}) \ .$$

Our concern is in computing $\hat{\bar{\bar{Y}}}$ and $\hat{Var}(\hat{\bar{\bar{Y}}})$.

APPENDIX J. TABLES FOR STEADY-STATE EFFICIENCY

Table **J.1.** Combustion steady-state efBciency chart for No. 2 fuel oil

X O_2	NET STACK TEMPERATURE (T_{stack} - T_{room}) F°												
	300	350	400	450	500	550	600	650	700	750	800	850	900
15	75.50	72.25	69.50	66.25	63.00	60.00	56.75	53.50	50.25	47.00	43.50	40.25	36.75
14	77.25	74.50	72.75	70.00	68.00	64.25	61.50	58.75	55.75	52.75	49.25	47.25	44.50
13	79.75	77.25	75.00	72.50	70.00	67.75	65.25	62.75	60.25	57.50	55.00	52.50	50.00
12	80.75	78.50	76.75	74.75	72.50	70.25	68.25	66.00	63.75	61.50	59.00	56.25	54.25
11	82.25	80.25	78.50	76.50	74.50	72.50	70.50	68.50	65.75	64.25	62.25	60.00	58.00
10	83.00	81.00	79.75	77.75	76.00	74.25	72.50	70.75	68.75	67.00	64.75	63.00	61.00
9	84.00	82.25	80.75	79.00	77.25	75.75	74.00	72.25	70.75	68.75	67.00	65.25	63.50
8	84.75	83.00	81.75	80.25	78.50	77.00	75.50	73.75	72.25	70.75	69.00	67.50	65.75
7	85.50	83.75	82.25	80.75	79.25	77.75	76.25	74.75	73.25	71.50	70.00	68.50	67.00
6	85.75	84.50	83.00	81.50	80.25	78.75	77.25	75.75	74.50	73.00	71.50	70.00	68.50
5	86.00	85.00	83.75	82.25	81.00	79.50	78.25	77.00	75.50	74.00	72.50	71.25	70.00
4	86.50	85.25	84.00	83.00	81.50	80.25	79.00	77.75	76.50	75.25	73.50	72.75	71.00
3	87.00	85.75	84.50	83.50	82.25	81.00	79.75	78.50	77.25	76.00	74.75	73.75	72.00
2	87.25	86.00	84.75	83.75	82.50	81.50	80.25	79.00	78.00	76.75	75.50	74.50	73.00
1	87.50	86.50	85.00	84.25	83.25	82.00	81.00	79.50	78.75	77.50	76.25	75.25	74.00

The following adjustments to the steady-state efficiency must be made based on the measured smoke number:

If smoke number is ->	0	1	2	3	4	5	6	7	a	9
Subtract from %SSE ->	0	0	0	0	1	2	3	4	6	7

Table J.2. Mean values and standard errors of steady-state efficiencies for different heating system types

Type of heating system/house	Number in sample	Adjusted steady-state efficiency[1]					
		Pre-weatherization		Post-weatherization		Difference	
		Mean value	Std. error	Mean value	Std. error	Mean value	Std. error
All Systems - **Weatherized**	136						
No clean & tune-up	65	77.2	0.8	77.7	0.6	0.51	0.54
Clean & tune-up	71	75.0	0.7	75.8	0.7	0.80	0.60
All Systems - Control	72						
No clean & tune-up	72	75.0	0.6	76.6	0.6	1.54	0.43
Forced- Air - Weatherized	65						
No clean & tune-up	32	77.7	0.9	77.6	0.9	-0.09	0.74
Clean & tune-up	33	75.9	0.9	76.3	0.9	0.38	0.77
Forced-Air - **Control**	16						
No clean & tune-up	16	76.5	1.2	77.7	1.1	1.16	1.32
Hydronic - Weatherized	45						
No clean & tune-up	18	79.1	0.9	78.9	1.1	-0.17	0.63
Clean & tune-up	27	76.0	1.0	76.9	1.0	0.96	0.89
Hydronic - Control	44						
No clean & tune-up	44	74.9	0.8	76.6	0.7	1.72	0.48

[1] Steady-state efficiencies were adjusted for smoke numbers.

Table J.3. Mean values and standard errors of steady-state efficiencies for systems with and without flame-retention burners

Type of oil burner/house	Number in sample	Adjusted steady-state efficiency[1]					
		Pre-weatherization		Post-weatherization		Difference	
		Mean value	Std. error	Mean value	Std. error	Mean value	Std. error
FR Burners - **Weatherized**	66						
No clean & tune-up	40	79.0	0.7	79.5	0.6	0.58	0.49
Clean & tune-up	26	77.2	1.0	78.4	1.1	1.18	1.01
FR Burners - Control	34						
No clean & tune-up	34	76.7	0.8	78.8	0.7	2.05	0.67
No FR Burners - **Weatherized**	65						
No clean & tune-up	22	73.9	1.6	74.5	1.0	0.59	1.32
Clean & tune-up	43	74.1	0.9	74.4	0.8	0.27	0.74
No FR Burners - Control	36						
No clean & tune-up	36	73.2	0.9	74.6	0.8	1.37	0.54

[1] Steady-state efficiencies were adjusted for smoke numbers.

APPENDIX K. OCCUPANT RESPONSES TO QUESTIONNAIRES

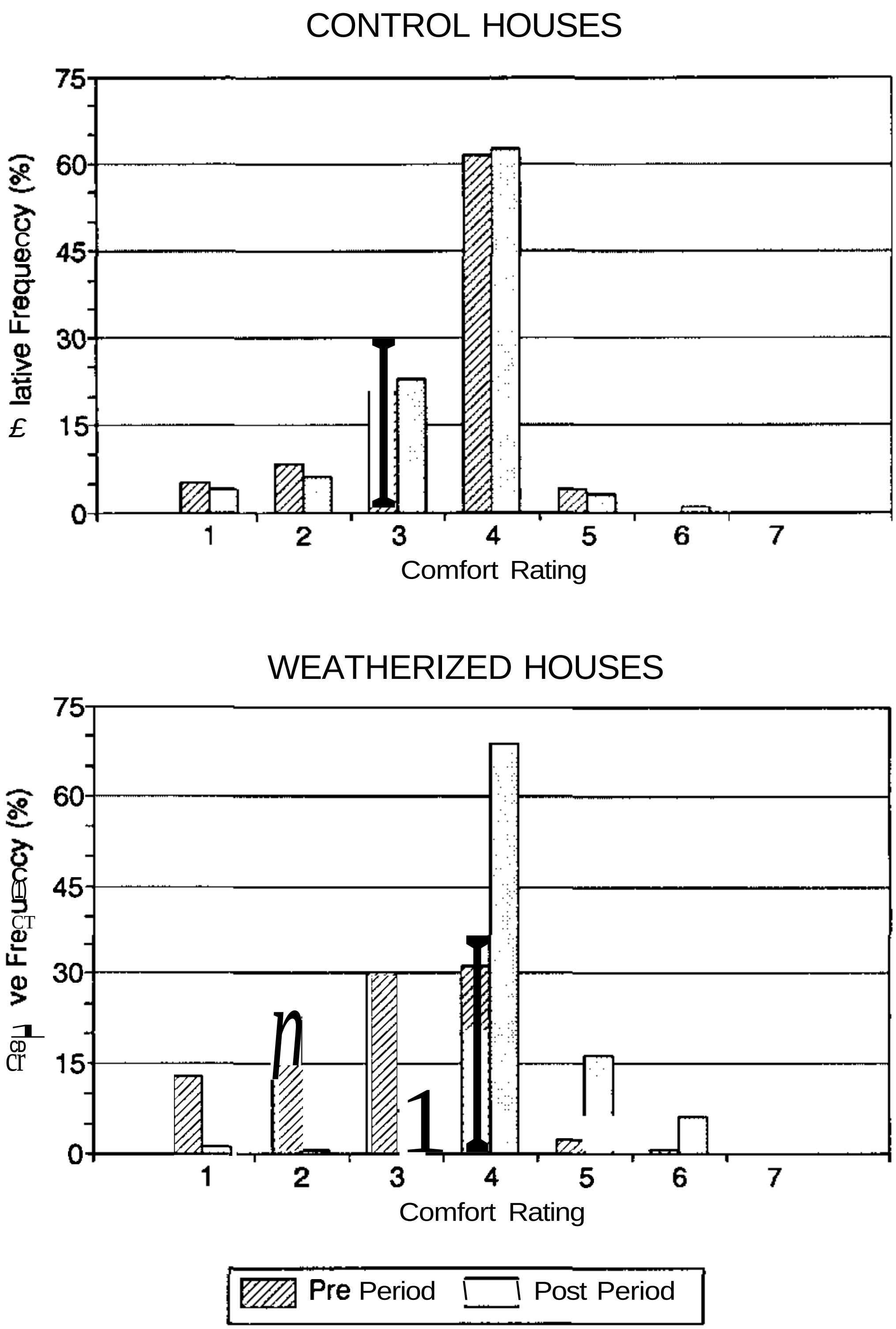


Fig. K.1. Distribution of occupant ratings for indoor comfort for control and weatherized houses. A scale of 1 to 7 was used, where 1 was poor and 7 was excellent

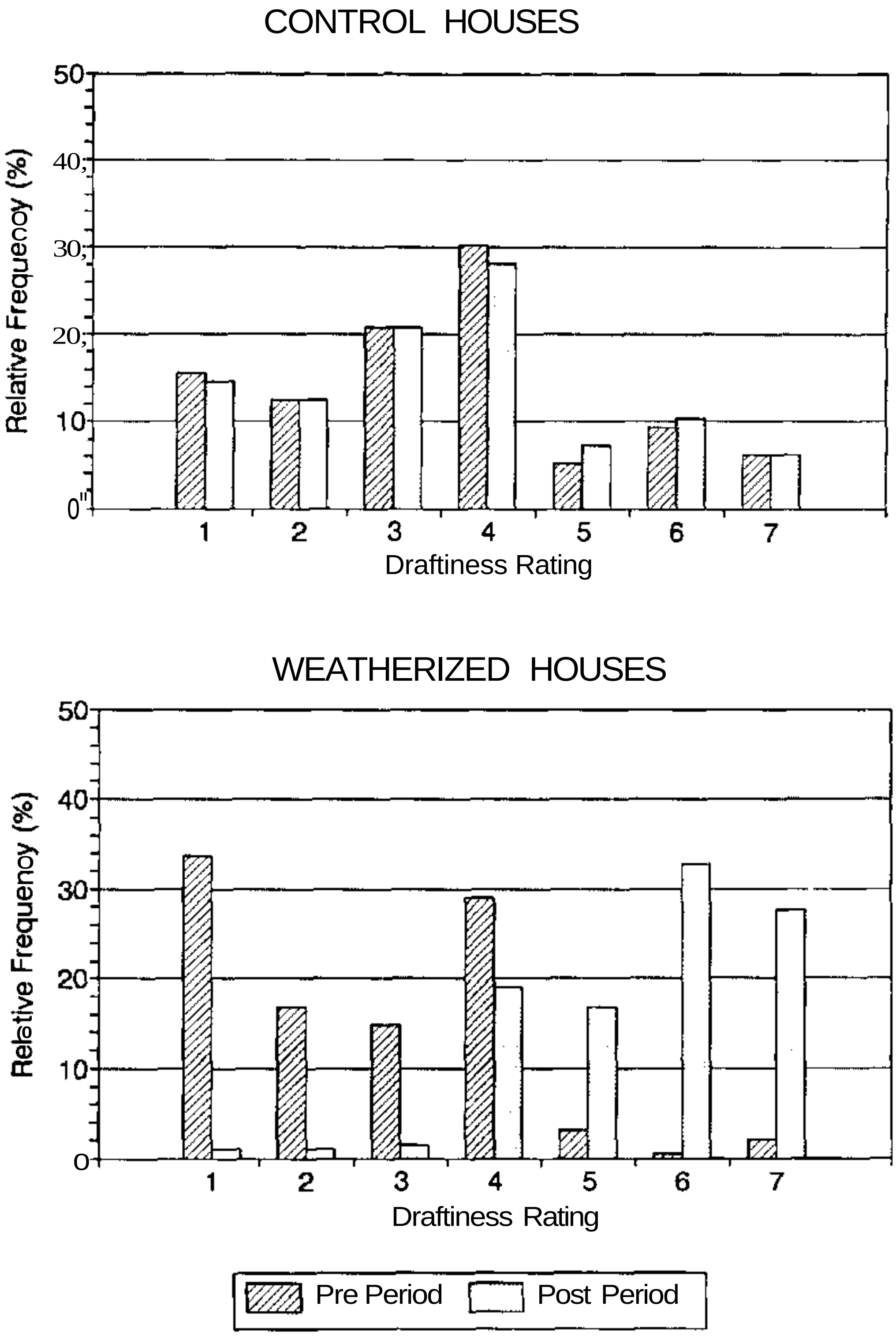


Fig. K.2. Distribution of occupant ratings for house draftiness for control and weatherized houses. A scale of 1 to 7 was used, where 1 was poor and 7 was excellent.

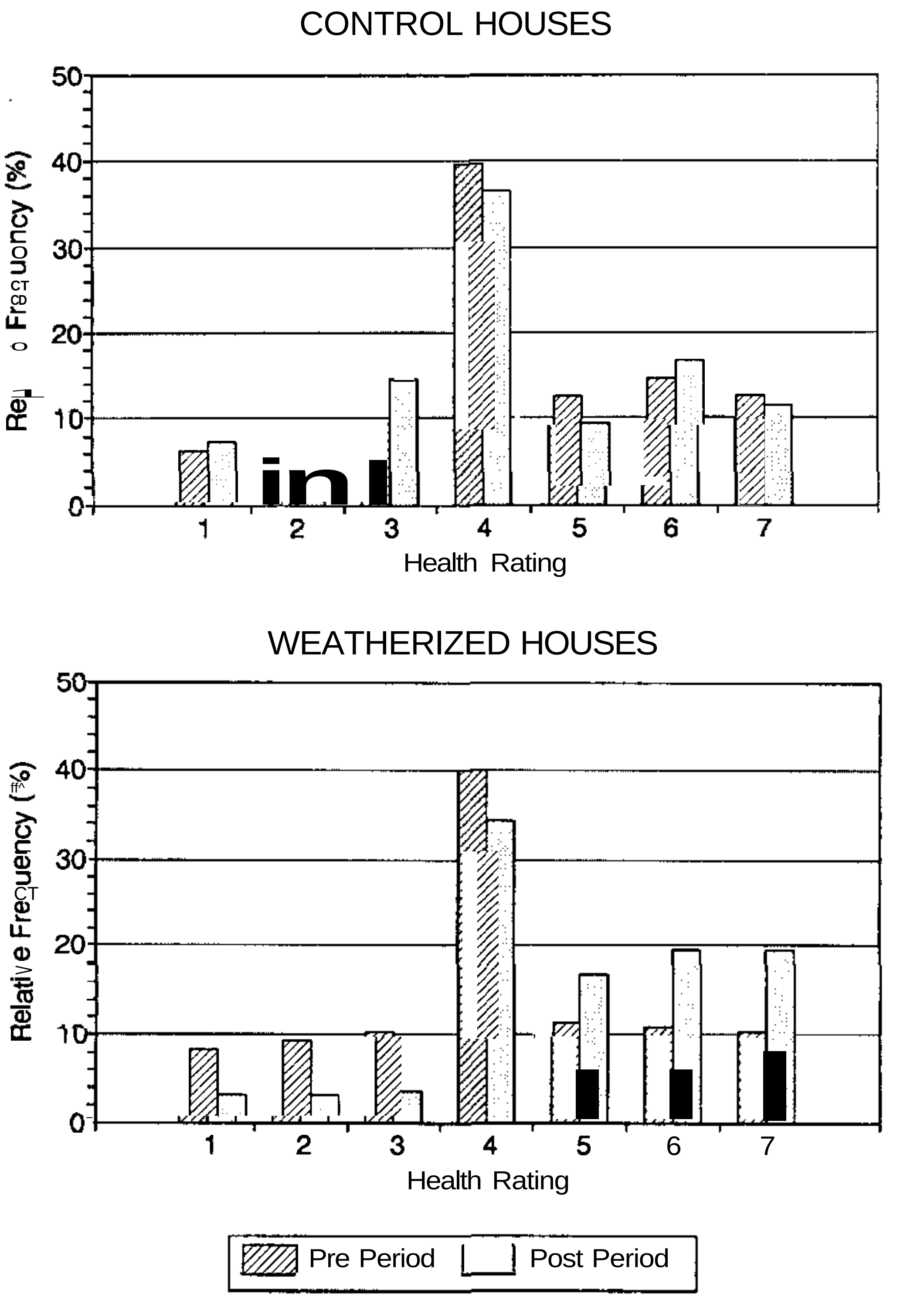


Fig. K.3. Distribution of occupant ratings for health of the occupants for control and weatherized houses. A scale of 1 to 7 was used, where 1 was poor and 7 was excellent

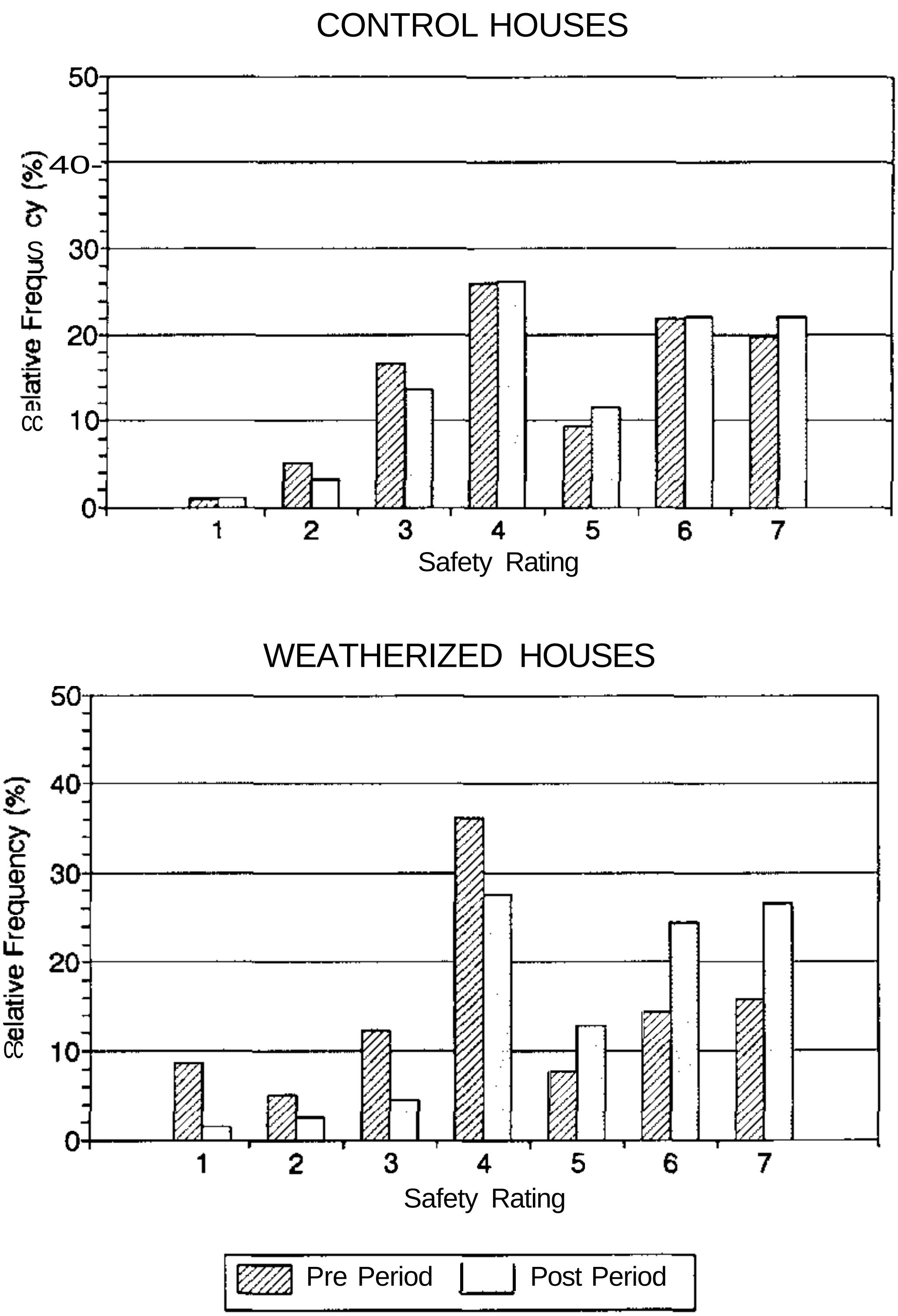
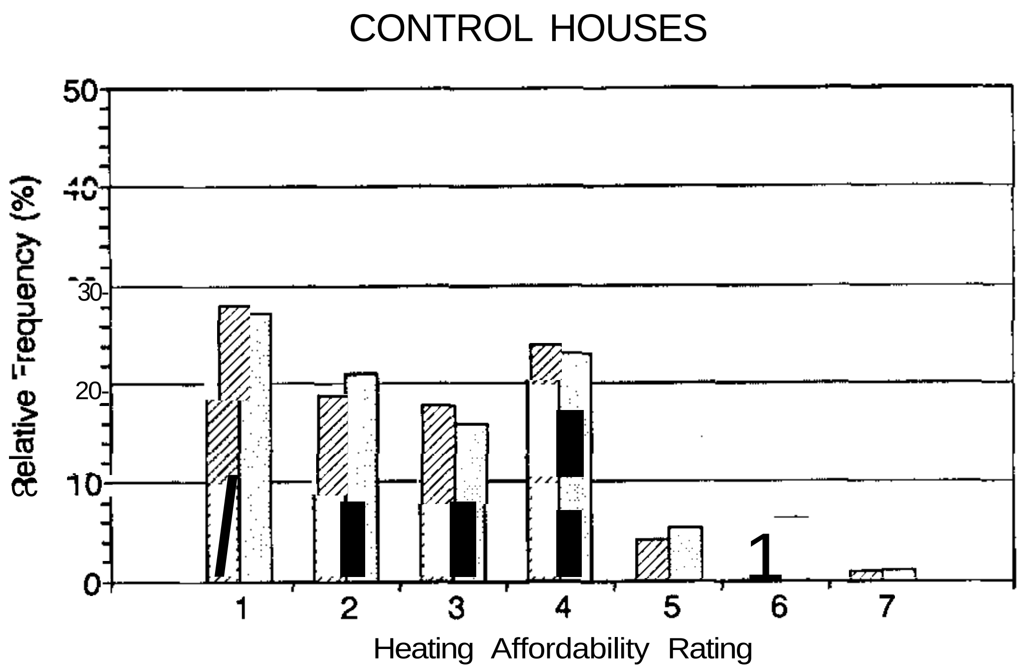


Fig. K.4. Distribution of occupant ratings for house safety for control and weatherized houses. A scale of 1 to 7 was used, where 1 was poor and 7 was excellent.



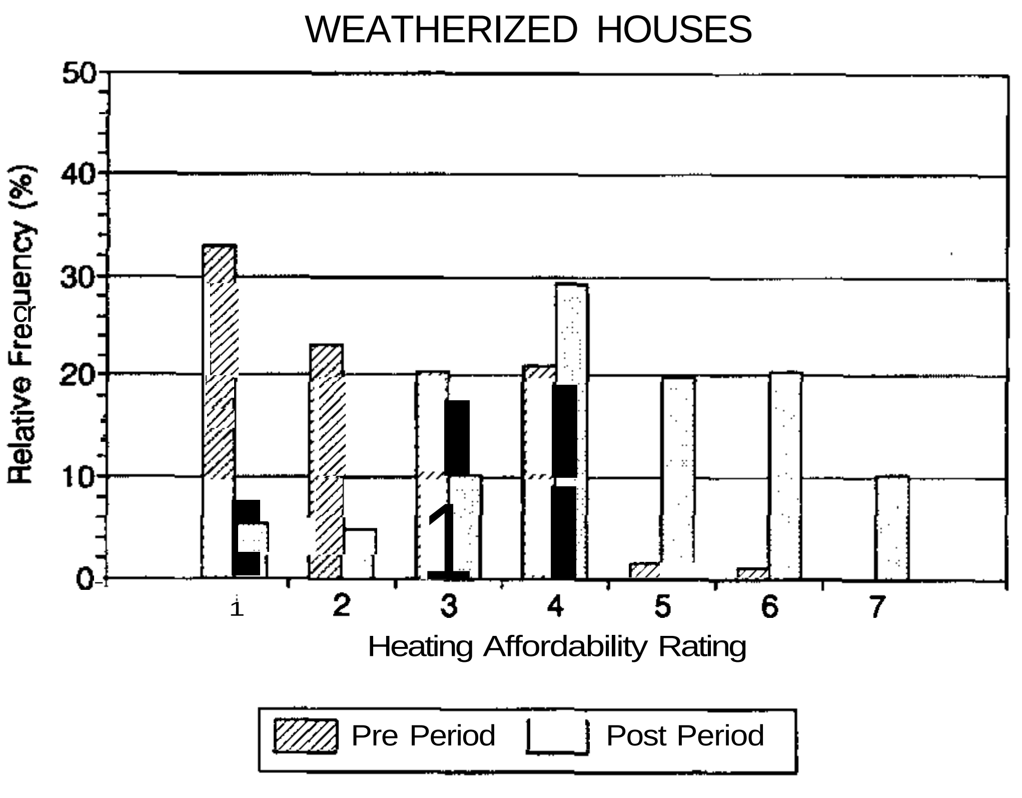


Fig. K.5. Distribution of occupant ratings for heating affordability for control and weatherized houses. A scale of 1 to 7 was used, where 1 was poor and 7 was excellent

Table K.1. Occupant survey summary

QUESTIONS FROM CLOSEOUT SURVEY	No.	PRE WEATHERIZATION: WEATHERIZED			PRE WEATHERIZATION: CONTROL			No.	POST WEATHERJZATION: WEATHERIZED			POST WEATHERJZATION: CONTROL		
	No.	Same	Changed	Percent	Same	Changed	Percent	Ho.	Same	Changed	Percent	Same	Changed	Percent
Was Home Kept at Same Temperature ALL Day?	E1a	92	106	53.5	42	54	56.3	E2a	95	100	51.3	43	53	55.2
		Avg Temp °F		Number	Avg Temp °F		Number		Avg Temp °F		Number	Avg Temp °F		Number
What Temperature (No Change Group)?	E1b	69.6		88	68.7		40	E2b	68.2		87	68.8		53
What Day Temperature when Occupied?	E1c	68.8		104	68.7		54	E2c	68.3		98	68.7		46
What Day Temperature when Unoccupied?	E1d	63.4		97	62.7		47	E2d	63.1		90	63.0		52
What Night Temperature when Sleeping?	E1e	64.0		101	63.9		54	E2e	63.1		95	64.2		52
		Yes	No	Percent	Yes	No	Percent		Yes	No	Percent	Yes	No	Percent
Any Heating System Problems?	F1a	31	163	16.0	16	80	16.7	F2a	25	169	12.9	11	85	11.5
Run out of Fuel?	F1a	28	162	14.7	11	80	12.1	F2a	21	175	10.7	a	86	8.5
Did Utility Disconnect Service?	F1a	9	161	5.3	0	80	0.0	F2a	6	169	3.4	5	77	6.1
Number of Times with No Heat?	F1b	1	2	3	4	5	8	F?h	1	2	3	4	5	8
Control Homes		14	4	3	1	1	0		11	5	0	2	0	0
Weatherized Homes		28	9	5	4	2	1		23	7	6	0	0	0

What was Total Time with No Heat? F1c

Pre Weatherization

Duration	Weather.	Control
< 4 Hrs	25	10
< 8 Hrs	7	3
< 12 Hrs	4	2
< 24 Hrs	7	4
1 Day	7	2
2 Days	7	1
3 Days	3	2
4 Days	1	1
5 Days	2	0
7 Days	0	1
8 Days	0	1
10 Days	1	0
13 Days	1	0
14 Days	3	0
21 Days	0	1
36 Days	2	0
:D ays	0	0
Σ No-Heat Days	196	57

Post Weatherization

Duration	Weather.	Control
< 4 Hrs	23	9
< 8 Hrs	4	3
< 12 Hrs	13	2
< 24 Hrs	3	2
1 Day	4	2
2 Days	5	3
3 Days	1	0
4 Days	0	0
5 Days	0	1
7 Days	0	0
8 Days	0	1
10 Days		
13 Days		
14 Days		
21 Days		
36 Days		
? Days	1	0
S No-Heat Days	31	26

Table K.1. Occupant survey summary (continued)

QUESTIONS FROM CLOSEOUT SURVEY		WEATHERIZED			CONTROL		
		Yes	No	Percent	Yes	No	Percent
Did Anyone Else Do Energy Repairs?	F3	39	141	21.7	25	68	26.9
		More	Same	Less	More	Same	Less
Were More People Home at Thanksgiving?	F5	12	160	24	4	79	12
Were More People Home at Christmas?	F6	15	148	33	4	76	16

		VERY POOR		ACCEPTABLE			VERY GOOD		
		1	2	3	4	5	6	7	Average
How Was Comfort Level Before Weatherization	F1b								
Control Homes		5	8	20	59	4	0	0	3.5
Weatherized Homes		25	45	59	61	4	1	0	2.9
How Was Comfort Level After Weatherization?	G1c								
Control Homes		4	6	22	60	3	1	0	3.6
Ueatherized Homes		2	1	14	135	32	12	0	4.2
How Was Draft Level Before Weatherization?	G2								
Control Homes		15	12	20	29	5	9	6	3.5
Weatherized Homes		66	33	29	57	6	1	4	2.6
How Was Draft Level After Weatherization?	G2								
Control Homes		14	12	20	27	7	10	6	3.6
Weatherized Homes		2	2	3	37	33	64	54	5.6
How Uas Health Level Before Weatherization?	G3								
Control Homes		6	5	9	38	12	14	12	4.4
Ueatherized Homes		16	18	20	78	22	21	20	4.1
How Uas Health Level After Ueatherization?	G3								
Control Homes		7	4	14	35	9	16	11	4.3
Weatherized Homes		6	6	7	67	33	38	38	5.0
How Uas Safety Level Before Weatherization?	G4								
Control Homes		1	5	16	25	9	21	19	4.8
Weatherized Homes		17	10	24	71	15	28	31	4.4
How Uas Safety Level After Weatherization?	G4								
Control Homes		1	3	13	25	11	21	21	5.0
Weatherized Homes		3	5	9	54	25	48	52	5.3
How Uas Heating Cost Before Weatherization?	G5								
Control Homes		27	18	17	23	4	6	1	2.8
Weatherized Homes		63	44	39	40	3	2	0	2.4
How Was Heating Cost After Weatherization?	G5								
Control Homes		26	20	15	22	5	6	1	2.8
Weatherized Homes		10	9	19	55	37	38	19	4.6

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