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NBS BUILDING SCIENCE SERIES 144

Optimal Weatherization of Low-Income Housing in the U.S.: A Research monstration Project

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NBS BUILDING SCIENCE SERIES 144

Optimal Weatherization of Low-Income Housing in the U.S.: A Research Demonstration Project

Richard Crenshaw and Roy E. Clark

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

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SI CONVERSION UNITS

In view of the present accepted practice for building technology in this country, common U.S. units of measurement were used throughout the report. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the International System of Units (SI) in 1960, the table below is presented to facilitate conversion to SI units. Readers interested in making further use of the coherent system of SI units are referred to: NBS SP 330, 1977 Edition, The International System of Units; and ASTM E621-78, Standard Practice for the Use of Metric (SI) Units in Building Design and Construction.

CUSTOMARY	INTERNATIONAL (SI) UNIT	U.S. CUSTOMARY UNITS	APPROXIMATE CONVERSIONS	
LENGTH	meter (m)	foot (ft)	1 m	= 3.2808 ft
	millimeter (mm)	inch (in)	1 m	= 0.0394 in
AREA	square meter (m^2)	square yard (yd^2)	1 m^2	= 1.1960 yd^2
		square foot (ft^2)	1 m^2	= 10.764 ft^2
VOLUME	cubic meter (m^3)	cubic yard (yd^3)	1 m^3	= 1.3080 yd^3
		cubic foot (ft^3)	1 m^3	= 35.315 ft^3
	cubic millimeter (mm^3)	cubic inch (in^3)	1 mm^3	= 61.024 x fl oz
CAPACITY	liter (L)	gallon (gal)	1 L	= 0.2642 gal
	milliliter (mL)	fluid ounce (fl oz)	1 mL	= 0.0338 fl oz
PRESSURE	pascal (Pa)	pound-force per square inch (lbf/in^2)	1 Pa	= 0.0015 lbf/in^2
WORK, ENERGY QUANTITY OF HEAT	megajoule (MJ)	kilowatthour (kWh)	1 MJ	= 0.2778 kWh
	kilojoule (kJ)	British thermal unit (Btu)	1 kJ	= 0.9478 Btu
POWER, HEAT FLOW RATE	watt (W)	British thermal unit per hour (Btu/h)	1 W	= 3.4121 Btu/h
		foot pound-force per second (ft·lbf/s)	1 W	= 0.7376 ft·lbf/s
COEFFICIENT OF HEAT TRANSFER [U-value]	watt per square meter kelvin ($W/m^2 \cdot K$) [=($W/m^2 \cdot °C$)]	Btu per hour square foot degree Fahrenheit ($Btu/ft^2 \cdot h \cdot °F$)	1 $W/m^2 \cdot K$	= 0.1761 $Btu/h \cdot ft^2 \cdot °F$
THERMAL CONDUCTIVITY [k-value]	watt per meter kelvin (W/m· K) [=(W/m·°C)]	Btu inch per hour square foot degree Fahrenheit ($Btu \cdot in/ft^2 \cdot hr \cdot °F$)	1 W/m·K	= 6.9335 $Btu \cdot in/h \cdot ft^2 \cdot °F$

NOTES: (1) The above conversion factors are shown to three or four places of decimals.

(2) Unprefixed SI units are underlined. (The kilogram, although prefixed, is an SI base unit.)

REFERENCES: NBS Guidelines for the Use of the Metric System, LC1056, Revised November 1977;
The Metric System of Measurement, Federal Register Notice of October 26, 1977, LC1078, Revised November 1977;
NBS Special Publication 330, "The International System of Units (SI)," 1977 Edition;
NBS Technical Note 938, "Recommended Practice for the Use of Metric (SI) Units in Building Design and Construction," Revised edition June 1977;
NBS Standard E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction," (based on NBS TN 938), March 1978;
ANSI Z210.1976, "American National Standard for Metric Practice;" also issued as ASTM E380-76$^{\epsilon}$, or IEEE Std. 268-1976.

Optimal Weatherization of Low-Income Housing in the U. S.: A Research Demonstration Project

By Richard Crenshaw and Roy E. Clark

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This report describes and presents the results of the Community Service Administration's (CSA's) Optimal Weatherization Demonstration Research Project carried out by the National Bureau of Standards (NBS). The CSA/NBS demonstration installed both architectural (building shell) and mechanical systems building weatherization options, and achieved, when both types of options were used, an average reduction in space heating fuel consumption of 41 percent, at an average weatherization cost of $1,862 per house.

The report explains the rationale used for selecting a sample of more than 200 houses at 12 sites across the United States, and for selecting optimal levels of weatherization for each of the houses. It presents measured energy consumption and detailed descriptive data on the houses before and after weatherization, the percentage savings achieved, and shows the costs of infiltration, conduction, furnace and water heater retrofits. Finally, it reports what options actually were installed in each house, and describes how data on the performance of those options were gathered and analyzed.

Key words: Community Action Agencies; Community Services Administration; costs of residential weatherization; energy conservation; field measurement of building energy consumption; optimal weatherization; residential energy consumption; weatherization.

1. INTRODUCTION

Today, the world recognizes that fossil fuels are non-renewable resources that will become increasingly scarce. The Nation recognizes that, as this trend continues, a country's economic well-being may be determined by its dependence on foreign sources of fuels. In the U.S. today, virtually all of the energy used comes directly or indirectly from fossil fuel sources. Only a small fraction is obtained from renewable sources -- such as hydroelectric, wind power, wood burning, or direct utilization of solar energy. Furthermore, within total U.S. energy usage, roughly 11 percent is consumed for the wintertime space heating of residences [12].*

The present 84 million residential units in the United States will constitute 85 percent of the Nation's inhabited dwellings in the year 2000. Experts have estimated that the energy consumption of these buildings could be cut 40 percent with no hazard to health or safety. Reducing the energy needed to heat these homes could have a major effect on the Nation's economy. Moreover, for low-income people who cannot afford a further rise in the cost of fuel, reduced energy consumption makes more money available for food and health care needs.

The Community Services Administration (CSA) was assisting a large number of low-income families with weatherization and fuel-subsidy services, and believed that it would be in the Nation's best interest to optimally weatherize their houses for a twenty year period, rather than continue to subsidize fuel payments. Twenty years was selected because it is the maximum physical life of most of the weatherization options. CSA considered alternate sources of energy such as wind, sun, and wood, but preliminary evaluation showed that energy conservation through "weatherization" retrofitting offered the greatest savings for a given cost. Moreover, it was a technology that was immediately available. CSA decided that energy conservation measures, only, should be installed in this Demonstration, and alternative ways of saving energy investigated later.

CSA selected the National Bureau of Standards (NBS) to plan and manage a field research effort on the weatherization of houses occupied by low-income people. NBS was chosen for its ability to organize an interdisciplinary team, and its experience in obtaining, testing, and analyzing data. This demonstration offered the chance not only to measure the overall savings associated with weatherization, but also to collect data with which to evaluate the optimization of weatherization packages. The results of that demonstration are presented in this report. It defines "optimal" weatherization, presents the energy savings achieved through weatherization of existing houses in twelve climate zones throughout the United States, and reports the costs associated with that weatherization. Other reports based on the demonstration discuss cost data [11], test methods for evaluating savings [8], comfort changes resulting from weatherization [3] and methods of installing weatherization options [7].

Although the project specifically sought information useful to the ten million low-income homeowners served by CSA, its results are of value to other homeowners. For example, many of the houses selected for the demonstration are occupied by people who became low-income as a consequence of retiring from work. Their houses -- as physical structures -- are probably typical of many middle-income residences.

---

*Numbers in brackets [] are keyed to the references in chapter 12.

● **The portability is obvious--field test equipment of Fargo, ND, Community Action Agency.**

2. AN OVERVIEW

The Community Services Administration (CSA) and the National Bureau of Standards (NBS) designed a demonstration/research project to measure changes in energy consumption resulting from "optimal weatherization" of residences occupied by low-income households. The project originally selected 222 houses for optimal weatherization and 68 houses as a control group (i.e., measured, but not weatherized--for "baseline" comparison), at 15 sites throughout the U.S. At the end of the Demonstration period, only twelve sites had submitted data for evaluation, covering 142 experimental and 41 control houses. Control houses were selected at each site to identify changes which occurred in energy consumption as a result of influences outside the Demonstration.

Of the 222 houses selected for weatherization, only 74 actually received "optimal weatherization", that is, the installation of all (feasible) prescribed architectural and mechanical options. Sixty-eight additional houses received architectural options only. Of the 56 houses selected for the control group, 15 were partially weatherized by their owners or had a change in occupants, leaving a control group of 41.

Originally, 16 sites representing all the inhabited climates in the U.S. were proposed to CSA by NBS. CSA reviewed this list (see p. 10) with NBS, and replaced Phoenix, AZ, with Albuquerque, NM; Pittsburgh, PA; with Easton, PA; and Boston, MA, with Portland, ME. Los Angeles, CA, was subsequently dropped without a replacement. During the demonstration Albuquerque, New Orleans, LA, and Miami, FL, dropped out, leaving 12 sites from which data was collected (see figure 1, next page).

CSA identified candidate demonstration houses from local Community Action Agencies' (CAAs') files of households eligible for CSA weatherization. (CAAs were administering fuel subsidy and weatherization grants from CSA.) Proposed houses had to meet criteria defined by NBS, as discussed on pages 10 through 15. The most important criterion was that an accurate record of heating-fuel consumption be available. The accuracy of the fuel records was checked by NBS by statistically correlating fuel consumption with degree days (see page 60). A fuel-use record giving a fuel consumption-degree day squared correlation coefficient (R^2) of 0.90 or better was considered acceptable.

In August, 1978, a week-long workshop was conducted by NBS staff to train CAA field personnel. Field personnel first were presented with an overview and plan of the project [5]. They then were instructed more specifically in the types of test equipment to buy, methods of collecting building dimensions and cost data, and methods of conducting the prescribed building tests. In the original plan, the options and the demonstration houses were to be selected during September, 1978, the options installed during the next six weeks, and measurements of savings started in December, 1978. This proved unrealistic. The only site funded for the installation of options by the fall of 1978 was Portland, ME, and therefore it was made a test site for the project. Options were installed and test procedures and data forms were field tested there while the funding of the other sites was completed.

During the spring of 1979, the field personnel at the other sites ordered test equipment, began pre-weatherization testing on both the experimental and control houses, and installed meters. The average cost of installing the meters was $300 per house; the average cost of performing the heating system tests was $300 per house; and the average cost of buying the equipment for performing other tests was $150 per house. During the testing and the installation of meters, NBS staff visited each of the sites to determine how the work was organized and how it was being performed. When the pre-weatherization tests were completed, the results were sent to NBS, and local project coordinators began installing weatherization options.

The NBS selected the architectural options to be installed by using modified ASHRAE-type heat load calculations performed on a hypothetical house.

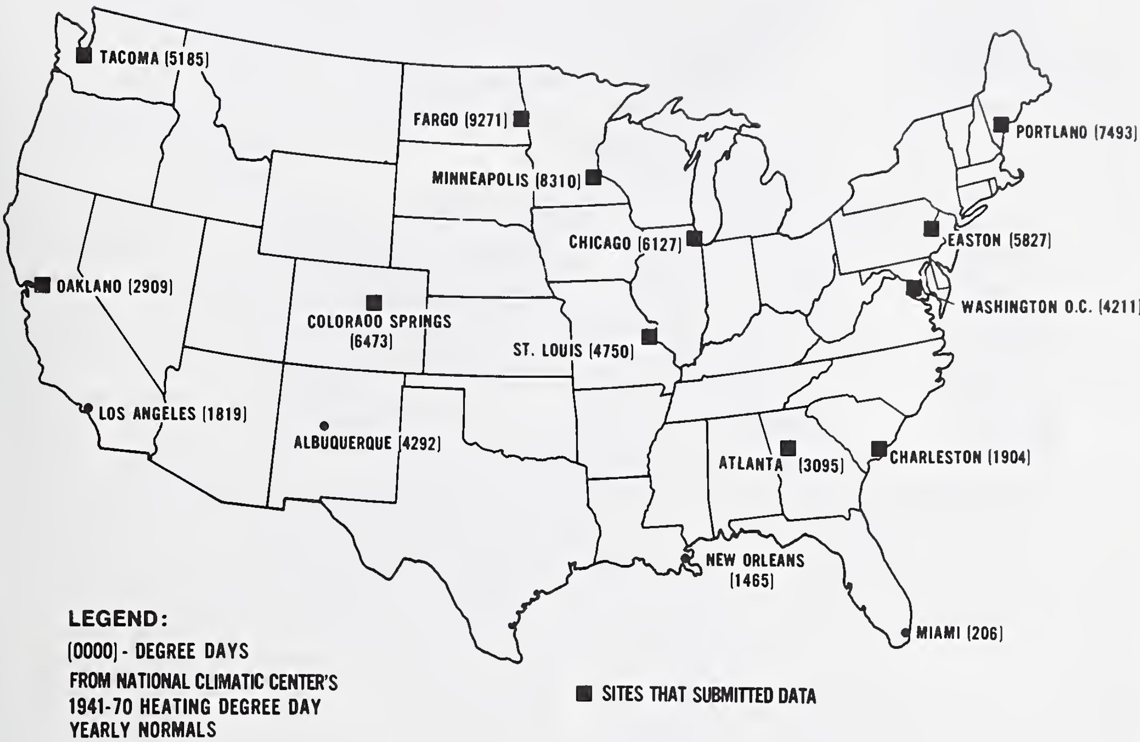


Figure 1. Sites selected for the demonstration.

Codes used to identity sites:

EAS	Easton/Allentown/Bethlehem, PA	MSP	Minneapolis/St. Paul, MN
ALB	Albuquerque, NM	NOR	New Orleans, LA
ATL	Atlanta, GA	OAK	Oakland, CA
CHA	Charleston, SC	POR	Portland, ME
CHI	Chicago, IL	STL	St. Louis, MO
CSP	Colorado Springs, CO	TAC	Tacoma, WA
FAR	Fargo, ND	WAS	Washington, DC (Hughesville, MD)
MIA	Miami, FL		

For details of the procedure used see page 69 [2]. Mechanical options were selected on the basis of calculations using pre-weatherization heating system efficiency tests and assumed optimal mechanical system efficiencies (see page 30). Fuel and options costs particular to a site were used in the selection of both architectural and mechanical options. The architectural options selected varied from site to site, and from house to house depending on the fuel used by the house, while mechanical options varied on a house-by-house basis, depending on the type of heating system and its efficiency. After the options were selected by the NBS, they were installed by local weatherization crews.

Optimal weatherization, to be successful, must be more than just a list of options to be installed. There must be a way of insuring the options are installed and used properly. This requires instructions on how to install the options, quality control to insure proper installation, and a user's manual to educate homeowners. To meet these needs, the project commissioned a Home Retrofit Manual [7]. Providing quality control for weatherization and educating the homeowner were beyond the scope of this project, but many of the procedures and tests developed here should be helpful to such an effort.

It was the responsibility of each local CAA, using the Home Retrofit Manual, to assure that the options were installed using appropriate materials and methods, and within cost limits set by the NBS. The local CAAs also were responsible for inspecting each house to identify and remedy any fire or health hazards, or possible code violations, before any options were installed.

During the installation of the options, another workshop was held to discuss experience to date and any problems with the demonstration and the Home Retrofit Manual. After this second workshop, the field personnel returned to complete five local tasks: installation of weatherization options, post-weatherization testing, obtaining building dimensions data, reading meters and administering a questionnaire about thermal comfort and energy-related activities in the houses. Finally, after all the options were installed and the building dimensions submitted, NBS staff visited each site again, made thermographs of insulated walls, inspected the quality of the weatherization work, and checked the accuracy of the reported building dimensions.

● Blowing in wall insulation near Washington, DC.

3. OPTIMAL WEATHERIZATION

To most people, "optimal weatherization" might mean retrofitting a house to conserve energy in the best way possible, in one site visit. To an economist, "optimal weatherization" means installing that level of weatherization which will generate the greatest dollar value of net savings possible over the life of the options. The group of options for a house is selected by determining for each increment of weatherization whether the additional dollars saved in fuel costs over the life of the increment, exceed the cost of installing that increment of weatherization. The optimal level is that set of options whose incremental cost equals the incremental savings (see figure 2). Because of the introduction of new materials, changes in costs of materials and labor, changes in the cost of fuel, differences in quality of workmanship and variation in initial condition of the house, optimal weatherization packages vary by location and over time. The CSA/NBS investigation of "optimal weatherization" addressed only the savings related to energy conserving weatherization strategies. There is no reason, however, why the concept of optimization cannot be extended to solar strategies, both active and passive. Further discussion of selecting optimal levels of weatherization is contained in the NBS report Optimizing Weatherization Investments in Low Income Housing: Economic Guidelines and Forecasts [3].

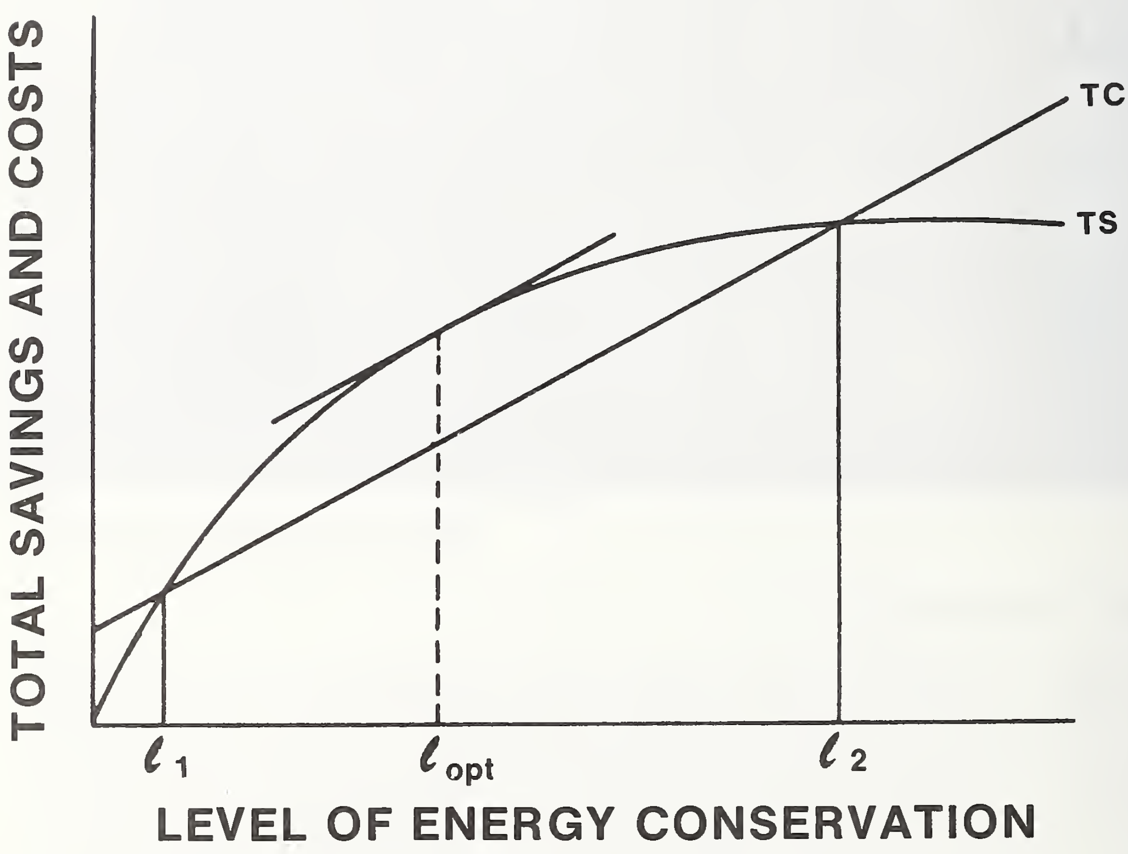


Figure 2. Optimizing weatherization investments

● Small, compact house
in Portland, ME.

4. SAMPLE SELECTION

Selecting a sample of dwellings required 1) selecting sites, 2) selecting houses to be weatherized, and 3) selecting a control group of houses at each site. The sites were selected primarily on the basis of information from the American Institute of Architects (AIA) Regional Climate Analysis and Design Data for the House Beautiful Climate Control Project [1]. The AIA project designated climate zones based on solar radiation, temperature, wind, humidity, and precipitation. The study suggests it is more practical, and not unreasonable, to use populated civil subdivisions within climate zones for designating the climate zones rather than general areas, because of the problem of identifying boundaries. It includes a recommended list of municipalities as being representative of the climate zones in the U.S. They are Albany, NY; Boston, MA; Charleston, SC; Chicago, IL; Columbus, OH; Denver, CO; Miami, FL; New Orleans, LA; New York, NY; Phoenix, AZ; Pittsburgh, PA; Portland, OR; St. Louis, MO; St. Paul, MN; and Washington, D.C.

The above cities were proposed to CSA, with the addition of a very cold city, Fargo, ND, and two cities on the west coast: San Francisco, and Los Angeles, CA. The proposed sites were reviewed by CSA with respect to the ability of local CAAs to install weatherization options quickly and properly, and to gather data. Cities meeting climatic and administrative criteria approved for the Demonstration were: New Orleans, LA; Atlanta, GA; Charleston, SC; St. Louis, MO; Oakland, CA: Albuquerque, NM (substituted for Phoenix); Minneapolis/St. Paul, MN; Tacoma, WA (substituted for Portland, OR); Chicago, IL; Miami, FL; Washington, DC (represented by Hughesville, MD); Fargo, ND; Portland, ME (substituted for Boston); Easton, PA (substituted for Pittsburgh, PA); and Colorado Springs, CO (see figure 1.*) Miami, Albuquerque, and New Orleans were later dropped.

The houses at each site were selected by NBS from a group of houses submitted by local CAAs. Houses were proposed by the CAAs, using criteria set by NBS to assure that the samples would exhibit a range of the parameters which might affect energy consumption. (Identifying the range of savings that could be achieved by optimal weatherization was one of the prime objectives of the Demonstration). The variables considered in selecting houses were: building size, type of construction, initial condition of house, orientation, building shape, building age, type of heating system, percentage of glass in the wall surfaces, and occupant behavior patterns. These variables were considered in the following ways:

Orientation and area of glass - These were assumed to vary within the sample of 10 to 27 houses at each site. (This can be checked in the recorded data for the houses.)

Age - Each site was asked to submit at least three houses built before World War I, three houses built between World Wars I and II and three built after World War II. (See table 1 for the actual distribution of building ages across the samples.)

Occupant behavior patterns - On the assumption that behavior with respect to winter energy use is reasonably stable for the same household, but varies from household to household, the effects of this parameter were minimized by requiring that the same people have occupied the house from April of 1975 to the end of the Demonstration. Houses having a change of occupants are not included in the results reported in Chapter 11, and are identified on the building data sheets in appendix A.

---

* For convenience, the sites were identified by a set of three-letter codes. These are listed at the bottom of figure 1, page 5.

Table 1. Age Distribution of Houses in Final Sample
Experimental/Control*

	ATL**	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS	TOTALS
0 to 10 years	3 /	5 / 3		7 / 1	2 /					1 /	2 / 1	/ 1	21 / 6
11 to 20 years	1 /	4 / 2	1 /	1 /	/ 1	2 / 2	2 /				1 /	/ 1	13 / 6
21 to 30 years	2 / 1		1 /	1 /	2 /	1 /	/ 1		2 /	1 /	3 /	1 /	15 / 3
31 to 40 years	/ 2	1 /				2 /	1 /	2 / 1	1 /	2 /	/ 2	1 /	11 / 6
41 to 50 years		2 /	1 /	/ 1	/ 2	6 / 2	4 / 1	2 / 1	1 / 1	2 /	2 / 1	1 /	22 / 9
51 to 60 years		1 /	3 /	3 /	2 /	1 /	1 / 1	3 /	1 / 1	6 / 1	/ 1		22 / 4
61 to 70 years	1 /		2 /	2 /	4 /		5 /	1 / 1	1 /	1 /		1 /	18 / 1
71 to 80 years				3 / 1	1 /	/ 1	2 / 2	/ 1	5 / 1	3 /	1 /		17 / 7
81 to 90 years										1 / 1			1 / 1
91 to 100 years													
100 + years	1 /		2 /	/ 1	2 /		2 /		3 / 1	1 /			11 / 2

* E (upper left) / C (lower right)

** See city/site code on page 5.

Building size - This variable was normalized by expressing the energy consumption results of the demonstration in Btu's per square foot.

Building shape - The effect of building shape on energy consumption seems minor based on analysis of heat loss calculations. The sites were encouraged to submit simple rectangular buildings, in order to minimize the effect of shape and to make heat loss calculations more straightforward, therefore probably more accurate.

Construction type - This was regarded as the most difficult variable to consider. It involved the quality of work, as well as types of materials used, the way the houses were built, and the way they were maintained. Each site was asked to submit at least five of each possible combination of one- or two-story detached, two- and three-story attached, and frame, solid masonry, adobe, and masonry veneer houses. (Five was the estimated minimum number of houses required to predict statistically, with 95 percent confidence, what range of savings might occur in a large population, given an expected range of 50 to 75 percent reduction in savings.) This provided nine possible combinations (12, if adobe were included). Each site could have submitted a minimum of 45 houses. No site, had all nine possible combinations of construction types. Table 2 shows the distributions of the final samples of houses for the demonstration. (These numbers reflect the attrition of the sample that occurred during the Demonstration -- discussed on pages 69 and 70.)

Initial condition of the house - Because this project was intended as a demonstration of energy savings that could be achieved through optimal weatherization and not as a rehabilitation project, all houses were required to be in a reasonable state of repair before they were accepted as part of the demonstration.

Heating system type - Because heating systems are not particularly climate dependent, it was necessary only to have a sample of five of each type of heating system across all sites, rather than five at each site. Data on houses submitted by all the sites were checked by NBS to insure that at least five heating systems of each type were included in the sample. The heating system types in the selected houses are presented in table 3. (Again, this is the "end of the Demonstration" sample.)

This selection process resulted in the identification of 222 experimental houses and 68 control houses at 14 sites across the country. The control houses were selected from among the houses submitted by each site, in order to measure any change in energy consumption which might occur as a result of factors other than the weatherization work, such as an oil embargo. All measurements performed on experimental houses were also to be performed on control houses, but the latter were not weatherized.

The experimental buildings included one-story detached frame buildings at all of the sites, and 1 1/2, 2- and 3-story frame structures at some sites. Buildings of masonry construction were selected at eight sites, including several concrete

Table 2. Distribution of Houses in Final Sample by Construction Type (Experimental houses, only)

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS	TOTALS
Detached 1 Story Frame	5	3	1	11	5	13	6	5	4	3	10	3	69
Detached 1.5 Story Frame				2			4		3	3		1	13
Detached 2 Story Frame			3	5	4		7		7	2			28
Detached 1 Story Masonry	2	6						4		6			18
Detached 2 Story Masonry										3			3
Detached 2.5 Story Masonry										2			2
Detached 1 Story Masonry Veneer	3	4	1										8
Detached 1.5 Story Masonry Veneer			3										3
Detached 2 Story Masonry Veneer			3										3
Attached (2 or 3 Story)					5								5
TOTALS	10	13	11	18	14	13	17	9	14	19	10	4	152

stucco houses. Brick veneer buildings were included at three sites, and row-type, attached houses in the Easton-Bethlehem-Allentown area (see table 2). At the end of the Demonstration, 73 percent of the experimental houses were frame, 18 percent masonry and 9 percent masonry veneer.

The ages of the houses were fairly uniformly distributed from 10 to 80 years, with a median age of about 45 years. Sixty percent of the houses used gas for fuel, 19 percent oil, 13 percent propane, four percent kerosene, and five percent electricity. Forty two percent had forced air heating systems, 24 percent space heaters, 16 percent hydronic or steam heat, 15 percent gravity feed heating systems (either air or water distribution), and three percent had electric baseboard heat (see table 3).

- Also in Portland, ME, a large house with large exposed surfaces.

Table 3. Distribution of Houses in Final Sample by Heating System Type and Fuel Used (Experimental houses, only)

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS	TOTALS
Forced Air	2	-	3	14	8	10	7	-	5	15	3	1	68
Gravity Air	-	-	2	1	1	2	2	2?	2	2	-	-	14
Circulated Hot Water	-	-	5	-	5	1	2	-	5	1	-	1	20
Gravity Hot Water	-	-	1	-	-	-	4	-	1	1	-	-	7
Floor Furnace*	3	-	-	3	-	-	-	-	-	-	-	-	6
Vented Space Heater*	2	5	-	1	-	-	2	7?	1	-	2	2	22
Unvented Space Heater*	4	10	-	-	-	-	-	-	-	-	2	-	16
Baseboard Heaters	2	-	-	-	-	-	-	-	-	-	3	-	5
Natural Gas	7	-	11	18	4	7	17	9	1	19	5	-	98
Oil*	-	-	-	-	8	6	-	-	13	-	-	2	29
Electricity	2	-	-	-	2	-	-	-	-	-	5	-	9
Propane*	1	13	-	-	-	-	-	-	-	-	-	2	16
Kerosene*	-	-	-	-	-	-	-	-	-	-	-	-	-

* These numbers include some double counting, since some houses had heaters of more than one type.

Loose insulation is installed in attic of Colorado Springs house.

5. ARCHITECTURAL OPTION SELECTION

Architectural options are those weatherization materials and methods, such as caulking, weatherstripping, storm windows and insulation, that are applied to the building's structure, as opposed to its heating system or water heater. Architectural options were selected by using marginal benefit/cost analysis. This procedure weighs future energy savings of each increment of weatherization against the cost of that increment, using a life cycle analysis approach. The last increment of weatherization that is cost effective over the period of time in question is that increment at which the group of options is optimized. All of the increments previously evaluated comprise a package called optimal weatherization. An increment of weatherization is a unit of weatherization which can be added to a building. It can be an inch of insulation, or storm windows over single glazing, or triple glazing over double glazing. In order to identify increments of weatherization which could be added to a house, the building was considered as areas of parallel heat flow. These are: cracks, holes, windows, doors, roof, walls, basement walls and floors. For each of these types of parallel heat flow, the following options were considered:

Cracks and Holes --
- Seal cracks and holes
- Replace broken glass
- Reset glazing
- Replace threshold .
- Weatherstrip and caulk windows
- Weatherstrip and caulk doors

Windows
- Storm windows
- Insulating drapes
- Insulating shutters
- Window film
- Triple glazing

Doors
- Metal storm door
- Second wood door
- Insulated door

Roof
- Various thicknesses of insulation

Walls
- Various thicknesses of insulation

Basement Walls and First Floor
- Carpet
- R-7 insulation on basement walls
- R-11 insulation in the floor

After the increments have been identified, the benefit/cost ratios associated with each increment are established and the optimal combinations selected. For each increment of weatherization, the benefit/cost ratio was calculated using the following formula.

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Fuel Savings x Present Value Factor x Cost of Fuel}}{\text{Replacement Factor x Cost of Option}} \quad (1)$$

The terms in the formula are explained below. The Present Value Factor takes into account a real fuel price escalation of five percent to eight percent, a real discount rate of six percent, and a life cycle of 20 years.

Fuel savings - The predicted saving of fuel from architectural options was calculated in Btu's, using a modified version of the ASHRAE steady state heat balance calculations. A summary of this approach, including formulas, is presented in appendix E of the CSA Weatherization Demonstration Project Plan (reference 5). The major differences between the ASHRAE method and the method used in this project are that infiltration was determined from experimental data and degree days were calculated separately for day and night, and for the basement. The method used in this project more realistically modeled infiltration, allowed for shutters which are open during the day and closed at night, and allowed for basements whose temperature is closer to ground temperature than outside air temperature. In order to allow for the interdependence between architectural and mechanical options, expected savings from architectural options were calculated assuming that the heating system had already been weatherized and would operate at 50 percent efficiency for oil, 70 percent for gas, and 100 percent for electricity. Expected savings from mechanical options were calculated assuming the load on the building was reduced by 50 percent by the installation of architectural options.

Present value factor - The present value factor for energy savings is a number (multiplier) that can be applied to the value of (in this case energy) cost savings that will occur in the future, in order validly to compare those savings to the present cost of an option. The present value factor used in formula (1) includes the real (i.e., excluding inflation) rate of fuel price escalation, the real discount rate, and the length of life cycle of the option under study. The project used real rates of fuel price escalation based on 1977 studies by the Department of Defense for the management of its own buildings. These rates depend on the type of fuel, and ranged from five percent for coal to eight percent for oil (see [2], p. 22).

A real (i.e., excluding inflation) discount rate is that rate of interest which reflects the time value of money. The time value of money is the difference between the value of a dollar today and its value at some future time if invested at a stated interest rate. That is to say, a dollar today is worth more than a dollar in ten years, apart from inflation. The discount rate may be used to bring any future costs and savings back to the present, so that options with different lifetimes can be compared on an equivalent basis. Since low-income families tend to be borrowers, the rate chosen to reflect their time value of money was tied to lending rates. Furthermore, since lending rates for home improvements tend to be somewhat lower than for those other goods and services, these rates are the most appropriate for use as a reference point. A typical lending rate for home improvements in 1978 was 12 percent. The anticipated long term (20-25 year) rate of inflation (six percent) was subtracted from this interest rate (12 percent), to give a real discount rate of six percent.

The cost of an option over the life cycle is equal to the first cost (i.e., the installation cost) plus any future costs resulting from maintenance, repair or replacement, discounted to a present value. A life of 20 years was used in the demonstration for selecting the last increment for an optimal weatherization package. An additional constraint of an 11-year payback for the whole package of options was imposed, in order to keep the usual time within which options would pay for themselves within the typical term of loans for home improvements. The additional requirement of an 11-year payback is seldom in conflict with the 20-year optimization, because of the high savings/cost ratio of the first increments of weatherization.

Cost of fuel - Fuel cost data was obtained from CAA representatives in each of the demonstration sites or, if the local representatives were unable to provide up-to-date information on energy prices, local suppliers of the different types of fuel were contacted. The prices collected in this survey are listed in table 4. These prices included local taxes, surcharges and block rates. Block rates are important in that they regulate the price of fuel depending on the amount of fuel consumed. They are used for natural gas and electricity in almost all of the demonstration cities. As a final check, the prices submitted by all sites were compared with the prices quoted in the U.S. Bureau of Labor Statistics' Retail Prices and Indexes of Fuels and Utilities: Residential Usage [13].

Table 4. Fuel Prices (1977) Used in Selecting Options

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS
GAS $/therm	.235		.263	.163	.318	.290	.216	.186		.273	.295	
OIL $/gal.					.490	.469	.482		.459			.492
ELECTRIC $/kWh	.035	.037			.036	.036				.044	.015	.037
PROPANE $/gal.	.480	.490										.520

Replacement factor - Some of the architectural options are not expected to have a 20-year physical life. In order to make the present costs of all the options compatible with the assumption of a 20-year life, the first cost of the options must be adjusted to reflect the present value of costs of any replacements needed within a 20-year period. A materials technologist reviewed the published literature, surveyed other authorities in the field, and surveyed existing standards to develop the frequency of replacement estimates listed in table 5. Options not listed in table 5 are not expected to require any replacement before the 20th year.

Table 5. Estimates of the Frequency of Replacement of Several Architectural Options to Achieve a 20-Year Physical Life

Options Not Having 20 Year Physical Life	Replacement estimate
Replace broken glass	Replace 2.5% of glass area at end of 10th year.
Reset glazing	Replace 10% of glazing at end of 10th year.
Low emissivity film	Replace 100% of film at years 9 and 18.
Weatherstrip windows	Replace 25% of weatherstripping at end of 10th year.
Caulk windows	Replace 25% of caulking at end of years 8 and 16.
Insulating drapes	Replace 100% of drapes at end of year 10.
Storm door	Replace 25% of door cost at end of year 10.
Weatherstrip doors	Replace 25% of weatherstripping at end of years 5, 10, and 15.
Caulk doors	Replace 50% of the caulking at the end of the 10th year.
Replace threshold	Replace 100% of the threshold at the end of the 10th year.
Attic insulation	Replace 25% of blow-in insulation at end of 15th year.
Weatherstrip attic hatch	Replace 100% at end of 15th year.
Carpet floor	Replace 100% at end of years 7 and 14.

Cost of option - Cost estimates for the weatherization options were collected from local community action groups or local contractors recommended by the community action groups, and were supplemented by construction suppliers catalogs, department store catalogs, an the 1978 Means Building Construction Cost Data Guide [14]. All estimates were on a square foot or linear foot basis for inplace options, and included the cost of labor, material, overhead and profit. Detailed assumptions made for each option are listed on pages 60-63 of the CSA Weatherization Demonstration Project Plan [5]. Table 6 contains the estimated first costs for installing weatherization options in 15 cities. Table 7 contains the 20-year cost of each option, allowing for expected replacements.

By applying formula (1) (page 18) to each increment of an option, one can evaluate the benefit/cost ratio of those increments over 20 years. All increments with 20-year benefit/cost ratios greater than 1 were selected as part of optimal weatherization. The architectural options selected by the economic analysis are listed in tables 8 through 10.

The Present Value Discounted Energy Savings Factors (PVDESF) listed in tables 6 and 7 reflect 1) the life of the option, 2) the current price of the fuel, 3) the (estimated) rate of escalation of the fuel price, and 4) the discount rate. To obtain the estimated total fuel cost savings that the package of options should produce over either 11 or 20 years, multiply the appropriate PVDESF by the yearly savings in fuel units.

● Caulking a window in Charleston, SC.

Table 6. Estimates of First Costs by Site Used in the Economic Analyses (Values in Dollars)

Architectural Option	ALB	ATL	CHA	CHI	CSP	EAS	FAR	LAS	MIA	MSP	OAK	POR	STL	TAC	WAS
Infiltration															
Replace Broken Glass in Window	7.00	7.00	5.00	10.00	8.50	6.00	8.00	5.00	7.00	8.00	9.00	6.30	6.30	6.20	4.76
Reset Glazing in Window	0.50	0.40	0.37	0.35	0.50	0.38	0.65	0.35	0.30	0.45	0.50	0.39	0.35	0.40	0.40
Install New Threshold	4.00	4.00	6.00	3.50	6.00	4.34	6.00	4.00	3.00	9.00	5.00	6.00	8.00	5.67	4.67
Seal Structural Cracks - Frame	0.90	0.90	0.80	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	0.80	1.00	1.00	1.25
Seal Structural Cracks - Masonry	1.20	1.50	1.30	1.60	1.30	1.30	1.30	--	1.20	--	1.30	1.60	1.30	--	2.00
Seal Structural Cracks - Veneer	1.20	1.50	1.30	1.60	1.30	1.30	1.30	--	1.20	--	1.30	1.60	1.30	--	2.00
Weatherstrip Windows	0.50	0.40	0.42	0.35	0.34	0.34	0.40	0.30	0.30	0.50	0.50	0.40	0.63	0.34	0.32
Caulk Windows	0.40	0.40	0.34	0.35	0.24	0.24	0.34	0.25	0.30	0.35	0.50	0.30	0.30	0.29	0.25
Weatherstrip Doors	0.40	0.40	0.42	0.35	0.33	0.33	0.42	0.30	0.30	0.40	0.50	0.40	0.63	0.38	0.41
Caulk Doors	0.40	0.40	0.34	0.35	0.24	0.24	0.33	0.25	0.30	0.35	0.50	0.30	0.30	0.22	0.25
Weatherstrip Attic Hatch	0.40	0.40	0.42	0.35	0.34	0.34	0.42	0.50	0.30	0.50	0.50	0.40	0.60	0.38	0.58
Window Options															
Install Standard Storm Window	2.00	2.25	2.83	3.00	3.00	2.37	2.40	2.62	2.62	3.25	2.62	2.40	2.20	2.62	1.50
Install Insulating Drape	1.00	1.00	1.50	1.00	1.20	1.50	1.50	1.50	1.50	1.00	1.00	1.50	1.50	1.50	1.00
Install Insulating Shutter	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	4.00
Install Window Film	1.50	1.50	1.70	1.50	1.50	1.70	1.70	1.50	1.50	1.50	1.50	1.70	1.70	1.70	1.25
Provide Triple Glazing	4.00	4.50	5.66	6.00	6.00	4.74	4.80	5.24	5.24	6.50	5.24	4.80	4.40	5.24	7.00
Door Options															
Install Storm Door	3.60	3.00	6.00	6.00	3.50	4.25	4.00	6.00	3.75	6.00	3.75	4.00	4.00	3.50	3.25
Install 2nd Wood Door	5.50	5.50	6.50	6.50	5.50	6.50	5.20	6.50	5.50	6.50	5.50	5.20	5.20	6.50	4.76
Replace Door w/Insulating Door	6.50	6.50	9.50	7.00	6.50	9.50	5.70	9.50	6.50	6.00	6.50	5.70	5.70	9.50	7.14
Attic Insulation															
R-11	0.25	0.20	0.15	0.25	0.24	0.14	0.19	0.20	0.15	0.35	0.15	0.17	0.17	0.14	0.24
R-19	0.35	0.30	0.28	0.35	0.32	0.27	0.32	0.30	0.20	0.45	0.25	0.30	0.30	0.24	0.32
R-30	0.45	0.40	0.41	0.45	0.40	0.40	0.45	0.45	0.30	0.55	0.35	0.43	0.43	0.34	0.40
R-38	0.55	0.50	0.54	0.58	0.48	0.53	0.58	0.58	0.40	0.60	0.45	0.56	0.56	0.44	0.48
Wall Insulation															
R-11: Frame	0.80	0.80	0.85	1.00	0.90	0.80	0.90	1.33	1.04	1.00	1.04	0.80	0.60	0.85	0.75
R-11: Masonry	1.20	1.50	--	1.50	1.50	1.30	1.50	--	--	--	--	--	1.30	--	1.00
R-11: Veneer	1.20	--	0.85	0.90	0.90	0.80	0.90	--	--	--	--	--	0.80	--	1.00
Basement Insulation															
R-7	0.70	0.70	0.70	0.75	0.70	0.70	0.70	0.75	0.65	0.75	0.70	0.70	0.70	0.70	0.70

Table 7. Estimates of 20-year Costs by Site Used in the Economic Analysis

City:	ALB	ATL	CHA	CHI	CSP	EAS	FAR	LAS	MIA	MSP	OAK	POR	STL	TAC	WAS
Architectural Option:															
Infiltration															
Replace Broken Glass in Window	7.10	7.10	5.07	10.14	8.62	6.08	8.11	5.07	7.10	8.11	9.13	6.39	6.39	6.29	4.83
Reset Glazing in Window	0.53	0.42	0.39	0.53	0.53	0.40	0.69	0.37	0.32	0.48	0.53	0.41	0.41	0.42	0.42
Install New Threshold	6.23	6.23	9.35	5.45	9.35	6.76	9.35	6.23	4.68	14.03	7.79	9.35	12.47	8.84	7.28
Seal Structural Cracks - Frame	0.90	0.90	0.80	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	0.80	1.00	1.00	1.25
Seal Structural Cracks - Masonry	1.20	1.50	1.30	1.60	1.50	1.30	1.30	--	1.20	--	1.30	1.60	1.30	--	2.00
Seal Structural Cracks - Veneer	1.20	1.50	1.30	1.60	1.60	1.30	1.30	--	1.20	--	1.30	1.60	1.30	--	2.00
Weatherstrip Windows	0.57	0.46	0.48	0.40	0.57	0.39	0.46	0.34	0.34	0.57	0.57	0.46	0.72	0.39	0.36
Caulk Windows	0.50	0.50	0.43	0.44	0.31	0.30	0.43	0.31	0.38	0.44	0.44	0.38	0.38	0.36	0.31
Weatherstrip Doors	0.57	0.57	0.60	0.50	0.72	0.47	0.60	0.43	0.43	0.57	0.57	0.57	0.90	0.54	0.59
Caulk Doors	0.51	0.51	0.43	0.45	0.32	0.31	0.42	0.32	0.38	0.45	0.45	0.38	0.38	0.28	0.32
Weatherstrip Attic Hatch	0.57	0.57	0.60	0.50	0.71	0.48	0.60	0.71	0.43	0.71	0.71	0.57	0.85	0.54	0.82
Window Options															
Install Standard Storm Window	2.00	2.25	2.83	3.00	3.00	2.37	2.40	2.62	2.62	3.25	2.62	2.40	2.20	2.62	1.50
Install Insulating Drape	1.56	1.56	2.34	1.56	1.87	2.34	2.34	2.34	2.34	1.56	1.56	2.34	2.34	2.34	1.56
Install Insulating Shutter	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	4.00
Install Window Film	2.91	2.91	3.30	2.91	2.91	3.30	3.30	2.91	2.91	2.91	2.91	3.30	3.30	3.30	2.43
Provide Triple Glazing	4.00	4.50	5.66	6.00	6.00	4.74	4.80	5.24	5.24	6.50	5.24	4.80	4.40	5.24	7.00
Door Options															
Install Storm Door	4.10	3.42	6.84	6.84	3.99	4.64	4.56	6.84	4.27	6.84	4.27	4.56	4.56	3.99	3.70
Install 2nd Wood Door	5.50	5.50	6.50	6.50	5.50	6.50	5.20	6.50	5.50	6.50	5.50	5.20	5.20	6.50	4.76
Replace Door w/Insulating Door	6.50	6.50	9.50	7.00	6.50	9.50	5.70	9.50	6.50	6.00	6.50	5.70	5.70	9.50	7.14
Attic Insulation															
R-11	0.28	0.22	0.17	0.28	0.27	0.15	0.21	0.22	0.17	0.39	0.17	0.19	0.17	0.15	0.27
R-19	0.39	0.33	0.31	0.39	0.35	0.30	0.35	0.33	0.22	0.50	0.28	0.33	0.33	0.27	0.35
R-30	0.50	0.44	0.45	0.50	0.44	0.44	0.50	0.50	0.33	0.61	0.39	0.47	0.47	0.38	0.44
R-38	0.61	0.55	0.60	0.64	0.53	0.59	0.64	0.64	0.44	0.66	0.50	0.62	0.62	0.49	0.53
Wall Insulation															
R-11: Frame	0.80	0.80	0.85	1.00	0.90	0.80	0.90	1.33	1.04	1.00	1.04	0.80	0.80	0.85	0.75
R-11: Masonry	1.20	1.50	--	1.50	1.50	1.30	1.50	--	--	--	--	--	1.30	--	1.00
R-11: Veneer	1.20	--	0.85	0.90	0.90	0.80	0.90	--	--	--	--	--	0.80	--	1.00
Basement Insulation															
R-7	0.70	0.70	0.70	0.75	0.70	0.70	0.70	0.75	0.65	0.75	0.70	0.70	0.70	0.70	0.70

Table 8. Optimal Weatherization Packages for Houses Heated by Natural Gas

OPTIONS	SITES: ALB	ALT	CHA	CHI	CSP	EAS	FAR	LAS	MIA	MIN	NOR	OAK	STL	TAC
Degree Days	4292	3095	1904	6127	6473	5827	9271	1819	206	8310	1465	2909	4750	5185
$/Therm	.276	.235	.30	.263	.163	.318	.332	.20	.31	.216		.186	.273	.295
20 YR - PVDESF*	6.76	5.75	7.34	6.44	3.99	7.78	8.13	4.90	7.59	5.29	5.14	4.55	6.68	7.22
11 YR - PVDESF	3.40	2.90	3.70	3.24	2.01	3.92	4.90	2.47	3.82	2.66	2.59	2.29	3.37	3.64
INFILTRATION														
Replace Broken Glass	X	X	X	X	X	X	X	X		X		X	X	X
Reset Glazing	X			X	X	X	X			X			X	X
Install New Threshold	X	X	X	X	X	X	X	X		X		X	X	X
Seal Structural Cracks	X	X	X	X	X	X	X	X	X	X		X	X	X
Weatherstrip Windows	X			X	X	X	X			X				X
Caulk Windows	X			X	X	X	X			X			X	X
Weatherstrip Doors	X			X		X	X			X				X
Caulk Doors	X			X	X	X	X			X			X	X
Weatherstrip Attic Hatch	X			X	X	X	X			X			X	X
WINDOWS														
Storm Windows	X			X	X					X			X	X
Storm + Film														
Storm + Shutter														
Triple Glazing						X								
Triple + Shutter							X							
Doors														
Storm Door (60% Glass)														
Second Wood Door "														
New Insulating Door "														
Storm Door (30% Glass)														
Second Wood Door "							X							
New Insulating Door "														
ATTIC														
R-11 Insulation			X					X						
R-19 Insulation		X										X		
R-30 Insulation	X			X	X	X							X	X
R-38 Insulation							X			X				
WALLS														
R-11 Insulation	X			X	X	X	X			X			X	X
BASEMENT WALLS														
R-7 Insulation	X	X	X	X	X	X	X			X			X	X

* Present Value Discounted Energy Savings Factor (see page 22 for explanation).

Table 9. Optimal Weatherization Packages for Houses Heated by Fuel Oil

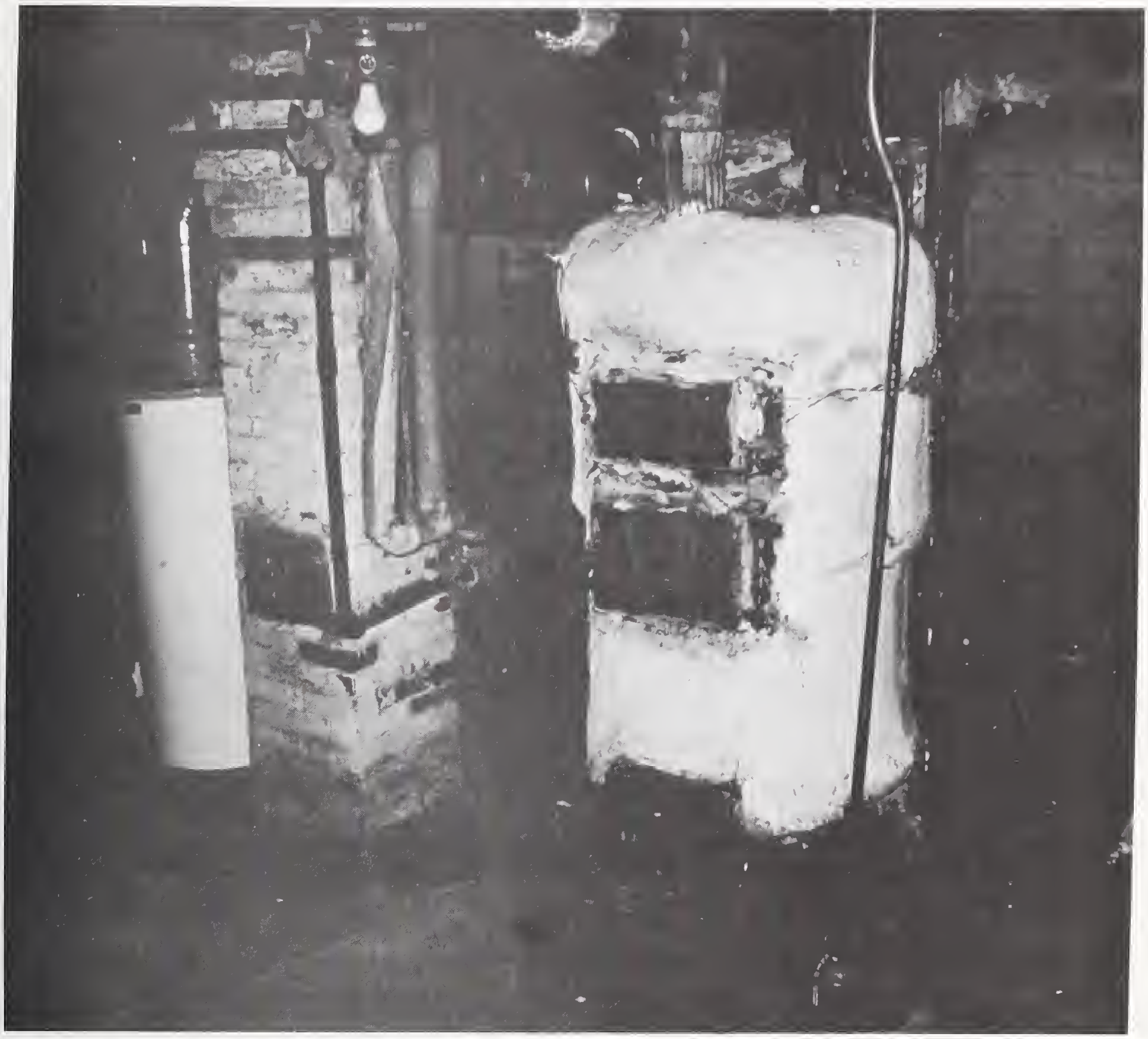
OPTIONS	CHA	CHI	EAS	FAR	MIN	DOR	TAC	WDC
Degree Days	1904	6127	5827	9271	8310		5185	4211
$/gallon	.52	.479	.49	.469	.482		.479	.492
20 YR-PVDFSF*	12.73	11.73	12.00	11.48	11.80	11.24	11.73	12.04
11 YR-PVDFSF	6.41	5.90	6.04	5.78	5.94	5.66	5.90	6.07
INFILTRATION								
Replace Broken Glass	X	X	X	X	X	X	X	X
Reset Glazing	X	X	X	X	X	X	X	X
Install New Threshold	X	X	X	X	X	X	X	X
Seal Structural Cracks	X	X	X	X	X	X	X	X
Weatherstrip Windows		X	X	X	X	X	X	X
Caulk Windows	X	X	X	X	X	X	X	X
Weatherstrip Doors		X	X	X	X	X	X	X
Caulk Doors		X	X	X	X	X	X	X
Weatherstrip Attic Hatch	X	X	X	X	X	X	X	X
WINDOWS								
Storm Windows								X
Storm + Shutter		X			X			
Triple Glazing			X			X	X	
Triple + Shutter				X				
DOORS								
Storm Door (60% Glass)		X	X				X	X
Second Wood Door "		X						
New Insulating Door "								
Storm Door (30% Glass)					X	X		
Second Wood Door "				X				
New Insulating Door "					X			
ATTIC								
R-11 Insulation	X							
R-19 Insulation								
R-30 Insulation		X	X			X	X	X
R-38 Insulation				X	X			
WALLS								
R-11 Insulation	X	X	X	X	X	X	X	X
BASEMENT WALLS								
R-7 Insulation	X	X	X	X	X	X	X	X

* See note on p. 25

Table 10. Optimal Weatherization Packages for Houses Heated by Electricity, Propane or Kerosene

OPTIONS	ELECTRICITY (kWh)					PROPANE (gal.)				KEROSENE (gal.)
Sites	ATL	CHA	EAS	MIA	TAC	ATL	CHA	CSP	WAS	WAS
Degree Days	3095	1904	5827	206	5185	3095	1904	6473	4211	4211
$/Unit		.037		.038	.015	.48	.49	.359	.525	.52
20 YR - PVDESF*		.74		.76	.33	11.75	12.00	8.79	12.85	12.73
11 YR - PVDESF		.40		.42	.18	5.92	6.04	4.43	6.47	6.41
INFILTRATION										
Replace Broken Glass	X	X	X		X	X	X	X	X	X
Reset Glazing	X	X	X		X	X	X	X	X	X
Install New Threshold	X	X	X	X	X	X	X	X	X	X
Seal Structural Cracks	X	X	X	X	X	X	X	X	X	X
Weatherstrip Windows	X	X	X		X	X	X	X	X	X
Caulk Windows	X	X	X		X	X	X	X	X	X
Weatherstrip Doors	X	X	X		X	X	X	X	X	X
Caulk Doors	X	X	X		X	X	X	X	X	X
Weatherstrip Attic Hatch	X	X	X		X	X	X	X	X	X
WINDOWS										
Storm Windows		X		X	X					
Storm + Film									X	X
Storm + Shutter								X		
Triple Glazing	X					X				
Triple + Shutter			X							
Doors										
Storm Door (60% Glass)	X					X		X		X
Second Wood Door "										
New Insulating Door "										
Storm Door (30% Glass)			X							
Second Wood Door "									X	
New Insulating Door "										
ATTIC										
R-11 Insulation										
R-19 Insulation		X					X			
R-30 Insulation	X			X	X	X				X
R-38 Insulation			X					X	X	
WALLS										
R-11 Insulation	X	X	X	X	X	X		X	X	X
BASEMENT WALLS										
R-7 Insulation	X	X	X	X	X	X	X	X	X	X

* See note on p. 25



● Service hot water and heating systems offer mechanical options.

6. MECHANICAL OPTION SELECTION

Mechanical options are those energy conserving retrofits that are applied to the heating system or service hot water system. They include such things as flue dampers, electronic ignition, or a new burner or water heater. Mechanical options also were selected using marginal benefit/cost analysis. The heating system and hot water system were considered separately and each option was evaluated as an increment of weatherization using the life cycle analysis approach. The options considered were:

Heating System

- Install flue damper
- Install flue restrictor
- Install electronic ignition
- Install two-stage gas valve
- Derate furnace
- Replace burner
- Replace furnace
- Insulate ducts and pipes
- Install radiator reflectors
- Install night setback thermostat
- Relocate thermostat

Hot Water System

- Insulate water heater
- Replace water heater
- Reduce hot water temperature
- Install shower flow restrictor
- Install water heater timer

In order to evaluate the expected fuel savings from installing an option, furnaces, distribution systems, control systems and water heaters were evaluated by a series of tests on a house-by-house basis. The tests used are discussed in the Demonstration Plan [5], pages 42 through 54. In general, the tests measured:

1. The steady state efficiency of the furnace before and after cleaning, using flue gas temperatures and carbon monoxide levels. Cleaning included tuning the furnace, balancing the distribution system, replacing nonfunctioning traps, flow valves and air valves and installing a barometric damper if required.

2. Percent of carbon dioxide in the flue gas.

3. The amount of particulates in the exhaust gas, known as the smoke number.

4. The draft above the fire and in the flue.

5. The plenum temperatures that activate/deactivate the circulating fan.

6. The velocity and temperature of the air at each register, measured under steady state conditions, on forced or gravity air systems.

7. The outlet and return temperatures measured under steady state conditions, on hot water and steam systems, and inoperable cells of radiators or inoperable steam traps and air vents recorded.

8. The steady state combustion efficiency of the (fuel-fired) water heater.

9. The temperature of the exterior jacket of the heater and of the ambient air in the space where the water heater is located.

10. The temperature of hot and cold water at the faucet nearest to the hot water heater.

11. The amount of time required to heat 20 gallons of water, to determine the recovery efficiency of the water heater.

12. The amount of time in seconds required for shower to fill a five gallon bucket, for the shower flow rate.

Based on the results of these tests, each option which could be physically added to the existing heating system or hot water system was assigned a percentage efficiency improvement value (EIV) or a specific savings (see table 11). The efficiency improvement values were then multiplied by the energy load of the building, after the heating load had been reduced by 50 percent to allow for architectural retrofit to calculate expected savings. These savings, and the costs from table 12, were then entered in the formula shown in the Project Plan [5], formula 1, page 16) to calculate benefit/cost ratios. Next, the options were ranked and the savings recalculated to allow for reduced load resulting from the installation of successive options. Options were selected until the reduced load on which savings for the next option were calculated was no longer large enough to support the initial cost of that option. The results of this selection process are shown on table 13. This shows which options were selected for some of the houses and which for all of the houses.

Table 11. Efficiency Improvement Value for Mechanical Options

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS
Flue or Vent Damper			.07	.07	.07	.07	.07		.07	.07	.07	.07
Flue or Vent Restrictor	.07					.07				.07		
Electronic Ignition	.07		.07	.07	.07	.07				.07	.07	
Two Stage Gas Value			.066	.066		.066				.066	.066	
Derate Furnace			.046	.046	.046	.046	.046		.046	.046		.046
Replace Burner					A	A			A			A
Replace Furnace	A		A	A		A			A	A		A
Insulate Ducts & Pipes			A	A					A	A	A	A
Radiator Reflector							U			U		
Night Setback Thermostat	.11	.11	.07	.07	.08	.05	.05	.10	.06	.08	.08	.09
Insulate Water Heater	B	B	B	B	B	B	B	B	B	B	B	B
Replace Water Heater or Aquabooster		A	A		A	A			A			A
Reduce Temp Water Heater	B	B	B	B	B	B	B	B	B	B	B	B
Shower Flow Restrictor	C	C		C			C	C	C		C	C
Timer on Electric Water Heater (kWh/yr)	18.75	18.75			18.75	18.75	18.75	18.75	18.75		18.75	18.75
Flue Damper on Water Heater			.07	.07	.07		.07	.07		.07		

U = Unknown
A = See page 55-59 of the Project Plan
B = 365 kWh/yr for electric; 36.5 therms/yr for gas; 25.5 gal/yr for oil
C = 221 kWh/yr for electric; 10.8 therms/yr for gas; 7.70 gal/yr for oil

Table 12. Estimated Costs for Installing Mechanical Options
(Values in Dollars)

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS
Flue or Vent Damper			140	110	150	200	80		190	75	120	120
Flue or Vent Restrictor	135					100				50		
Electronic Ignition	135		200	200	150	150				181	200	
Two Stage Gas Value			160	185		75				292	105	
Derate Furnace			95	170	75	55	75		25	100		50
Replace Burner					50	400			440			360
Replace Furnace	465		1400	1400		725						
Insulate Ducts & Pipes			350	300					150	300	250	100
Radiator Reflector							10			60		
Night Setback Thermostat	80		120	90	80	75	100	80	125	120	120	100
Insulate Water Heater	75	20	20	30	20	90	20	20	65	20	0	20
Replace Water Heater or Aquabooster									490			300
Reduce Temp Water Heater	0	0	0	0	0	0	0	0	0	0	0	0
Shower Flow Restrictor	55	20		20			25	20	20		20	20
Timer on Electric Water Heater	65	75			75	65	80	80	25		80	50
Flue Damper on Water Heater			140	110	80		80	80		75		

Table 13. Mechanical Options Selected for Optimum Weatherization

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS
Flue or Vent Damper			●	●	●	●	●		all	●	●	●
Flue or Vent Restrictor	●					●				●		
Electronic Ignition	●		●	●	●	●				●	●	
Two-Stage Gas Value			●	●		●				●	●	
Derate Furnace			●	●	●	●	●		●	●		●
Replace Burner					●	●			●			●
Replace Furnace	●		●	●		●			●	●		●
Insulate Ducts & Pipes			●	●						●	●	●
Radiator Reflector							●			●		
Night Setback Thermostat	●	●	●	●	●	●	all	all	all	●	●	●
Insulate Water Heater	all	all	all	all	all	all	all	all	all	all	all	all
Replace Water Heater or Aquabooster		●	●		●	●			●			●
Reduce Temp Water Heater	all	all	all	all	all	all	all	all	all	all	all	all
Shower Flow Restrictor	all	●		●			●	all	●		all	●
Timer on Electric Water Heater	all	all			all	all	all	all	●		all	all
Insulate Hot Water Pipes from Water Heater										●		●
Flue Damper on Water Heater			●	●	all		all	all		●		

● - installed on a few of the sample homes
all - installed on all of the sample homes

Basement storm window is installed in Washington, DC.

7. OPTION INSTALLATION

In order to understand the significance of the savings reported in tables 28 through 39, the reader needs some knowledge of what options were installed, how they were installed, and some indication of the direct results of the work. Because each house was constructed differently and had different degrees of weatherization already in place, very few houses had the same options installed or had all of the prescribed options installed. Tables 14 through 25, on pages 36 through 47, show which options were installed on each house.

The options were installed either by contract labor, or by the Community Action Agency using CETA labor. Generally, mechanical options were installed by

Table 14. Options Installed - Atlanta

HOUSE NUMBERS	1	2	17	22	23	29	31	32
TYPE OF HEATING FUEL								
INFILTRATION								
Replace Broken Glass			X					
Reset Glazing							X	
Replace Threshold	X						X	
Seal Cracks & Holes	X		X				X	
Weatherstrip Windows	X		X				X	X
Caulk Windows	X		X	X			X	X
Weatherstrip Doors	X		X	X			X	X
Caulk Doors	X		X	X			X	X
Weatherstrip Attic Hatch	X		X				X	X
CONDUCTION								
Storm Windows	X	X		X	X		X	
Triple Glazing			X				X	X
Storm Doors			X					
Attic R-19 Insulation	X	X		X	X	X		
Attic R-30 Insulation			X				X	X
Wall Insulation			X				X	X
Basement Wall, Slab or Crawl Space Insulation		X	X	X		X	X	X

Table 15. Options Installed - Charleston

HOUSE NUMBERS	2	3	8	16	18	20	23	25	33	39	44	47	49
INFILTRATION													
Replace Broken Glass		X	X	X	X	X		X	X		X		
Reset Glazing					X	X	X	X	X		X		
Replace Threshold	X	X	X	X	X	X	X	X	X	X	X	X	X
Seal Cracks & Holes	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Windows	X		X	X	X	X	X	X	X	X	X		
Caulk Windows	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors	X	X	X	X	X	X	X	X	X	X	X	X	
Caulk Doors	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Attic Hatch	X	X	X	X	X		X	X	X	X	X		X
CONDUCTION													
Storm Windows												X	
Attic R-11 Insulation													
Attic R-19 Insulation	X	X	X	X	X	X	X	X	X	X	X		X
Basement Wall, Slab or Crawl Space Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X
HEATING SYSTEM													
Night Setback Thermostats			X										X
WATER HEATER													
Water Heater Insulation	X			X		X	X		X		X		
Replace Water Heater													
Timer		X	X	X		X					X	X	X
Shower Flow Restrictor			X			X	X				X		X

Table 16. Options Installed - Chicago

HOUSE NUMBERS	5	9	11	12	14	19	25	29	32	38
INFILTRATION										
Replace Broken Glass		X	X							X
Reset Glazing		X				X	X			X
Replace Threshold		X				X		X	X	
Weatherstrip Windows		X	X	X		X	X	X	X	X
Caulk Windows		X		X			X		X	X
Weatherstrip Doors		X	X	X	X	X	X	X	X	X
Caulk Doors		X							X	
CONDUCTION										
Storm Windows		X	X	X		X	X	X	X	X
Attic R-30 Insulation		X		X	X	X	X	X	X	X
Wall Insulation				X		X	X	X	X	
HEATING SYSTEM										
Replace Furnace				X						
Flue or Vent Damper	X	X	X	X		X	X		X	
Electronic Ignition	X	X	X	X	X	X	X		X	
Derate Furnace	X	X	X		X	X	X		X	X
Duct & Pipe Insulation	X	X								
Night Setback Thermostat	X	X	X	X	X	X	X	X	X	
WATER HEATER										
Replace Water Heater				X					X	
Water Heater Insulation	X	X	X			X	X			X
Reduce Temperature	X	X	X	X		X	X	X	X	X
Flue Damper	X	X	X	X	X	X	X	X	X	X

Table 17. Options Installed - Colorado Springs

HOUSE NUMBERS	7	11	13	14	17	20	23	24	26	31	37	41	43	44	47	49
INFILTRATION																
Replace Broken Glass	X	X	X	X	X	X	X	X	X	X	X		X		X	
Reset Glazing	X		X	X	X				X						X	
Replace Threshold	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Seal Cracks & Holes	X	X	X		X	X			X		X	X	X	X	X	
Weatherstrip Windows	X		X		X			X	X						X	
Caulk Windows	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Attic Hatch			X	X			X		X	X				X	X	
Fireplace Damper																
CONDUCTION																
Storm Windows	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Attic R-30 Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wall Insulation	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Basement Wall, Slab, or Crawl Space Insulation	X	X	X	X	X		X		X	X	X	X	X	X	X	X
HEATING SYSTEM																
Flue or Vent Damper	X			X			X	X	X	X	X			X	X	X
Electronic Ignition					X	X	X		X	X		X	X	X		X
Two Stage Gas Valve								X							X	
Derate Furnace								X							X	
Duct & Pipe Insulation	X	X							X		X	X				X
Night Setback Thermostat	X	X		X			X			X	X			X		X
WATER HEATER																
Water Heater Insulation	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Reduce Temperature			X	X			X		X	X		X		X		
Shower Flow Restrictor							X	X	X			X		X		X
Flue Damper	X			X			X	X	X	X	X			X	X	X
APPLIANCES																
Dryer Vent Diverter				X			X			X				X		X

Table 18. Options Installed - Easton

HOUSE NUMBERS	4	12	20	22	23	25	27	28	31	33	39	42	44
INFILTRATION													
Replace Broken Glass	X	X		X	X	X	X	X	X		X	X	X
Reset Glazing	X	X			X	X	X		X	X	X		X
Seal Large Cracks & Holes						X							
Weatherstrip Windows	X	X			X	X	X	X	X	X	X		X
Caulk Windows		X			X			X		X	X		X
Weatherstrip Doors	X	X			X	X	X	X	X	X	X		X
Caulk Doors	X	X			X			X		X	X		X
Weatherstrip Attic Hatch	X	X	X		X		X	X	X		X		X
CONDUCTION													
Attic R-30 Insulation	X	X		X	X	X	X	X	X	X			X
Wall Insulation		X	X	X	X		X	X	X	X			X
HEATING SYSTEM													
Flue or Vent Damper				X		X			X	X	X		
Derate Furnace				X		X				X	X		
Replace Burner								X					
Night Setback Thermostat	X	X				X	X	X	X	X	X		X
WATER HEATER													
Replace Water Heater													X
Water Heater Insulation			X										
Reduce Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X
Timer			X									X	

Table 19. Options Installed - Fargo

HOUSE NUMBERS	2	6	10	11	15	17	25	27	30	32	35	36
INFILTRATION												
Seal Cracks & Holes				X								
Weatherstrip Windows		X	X	X	X		X	X	X	X	X	X
Caulk Windows		X	X	X	X	X	X	X				X
Weatherstrip Doors	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors		X	X	X	X	X	X	X				X
Weatherstrip Attic Hatch	X	X	X	X	X	X	X	X	X	X	X	X
CONDUCTION												
Triple Glazing	X	X	X	X	X	X	X	X	X	X	X	X
Attic R-38 Insulation	X	X	X	X	X	X	X	X	X	X	X	X
Wall Insulation	X	X	X	X	X	X	X	X	X		X	X
Basement Wall, Slab or Crawl Space Insulation	X	X	X	X	X	X	X	X	X	X		X
Insulating Shade						X	X	X				
HEATING SYSTEM												
Flue or Vent Damper	X					X			X	X		
Electronic Ignition						X			X	X		
Derate Furnace	X					X	X		X	X		X
Replace Furnace		X	X									
Night Setback Thermostat	X	X	X	X		X	X		X	X		
WATER HEATER												
Water Heater Insulation	X	X	X	X	X	X	X	X	X			
Replace Water Heater										X		
Timer		X	X			X		X				
Flue Damper	X			X	X		X		X	X	X	X

Table 20. Options Installed - Minneapolis/St. Paul*

HOUSE NUMBERS	1	2	3	4	8	13	20	21	23	26	33	34	40	42	44	45	46
INFILTRATION																	
Replace Broken Glass	X	X	X	X	X	X		X	X	X	X		X		X	X	
Reset Glazing	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Weatherstrip Windows	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Windows	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Weatherstrip Doors	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Caulk Doors			X	X	X		X	X	X		X	X	X	X	X	X	X
Weatherstrip Attic Hatch	X	X	X	X	X	X	X	X		X	X		X		X		X
CONDUCTION																	
Storm Windows	X	X		X	X				X							X	
Attic R-38 Insulation	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X
Wall Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Basement Wall, Slab or Crawl Space Insulation									X						X	X	X
Install Insulating Door on Doors with Greater than 30% Glass																	

* NOTE - confirmation of what was installed, and detailed cost data were not submitted.

Table 21. Options Installed - Oakland

HOUSE NUMBERS	17	19	26	31	33	34	35	38
INFILTRATION								
Replace Broken Glass		X	X	X	X		X	X
Reset Glazing							X	
Replace Threshold	X	X	X	X	X	X	X	X
Seal Cracks & Holes							X	
Weatherstrip Doors	X	X	X	X	X	X	X	X
CONDUCTION								
Attic R-19 Insulation	X	X	X	X	X	X	X	X

Table 22. Options Installed - Portland*

HOUSE NUMBERS	7	9	10	11	12	15	16	17	20	21	23	25	26	28
INFILTRATION														
Replace Broken Glass				X	X		X	X	X	X	X		X	
Reset Glazing			X	X	X		X	X	X	X	X		X	
Replace Threshold										X				
Seal Cracks & Holes			X						X	X	X		X	
Caulk Windows	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors				X				X	X	X	X	X		
Weatherstrip Attic Hatch	X	X			X		X		X		X	X		
Repair Fireplace Damper									X	X				
CONDUCTION														
Storm Windows	X	X	X	X		X	X	X		X	X	X	X	
Triple Glazing					X									X
Attic R-30 Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wall Insulation	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Basement Wall, Slab, or Crawl Space Insulation	X	X	X	X	X	X	X		X	X	X		X	
Storm Doors			X		X	X						X	X	
HEATING SYSTEM														
Flue or Vent Damper	X	X		X	X	X	X	X	X	X	X		X	X
Derate Furnace						X	X				X	X		
Replace Burner	X	X							X				X	X
Replace Furnace				X	X			X		X				
Duct & Pipe Insulation									X				X	
Night Setback Thermostat	X	X		X	X	X	X	X	X	X	X	X	X	X
WATER HEATER														
Timer	X	X				X	X			X				X
Water Heater Insulation	X	X		X		X	X	X		X	X		X	
Replace Water Heater or Install Aquabooster					X			X	X		X		X	

* NOTE - confirmation of what was installed and detailed cost data were not submitted.

Table 23. Options Installed - St. Louis

HOUSE NUMBERS	5	6	7	17	28	29	34	38	40	41	42	46	49	55	56	77	92	93
INFILTRATION																		
Caulk Windows	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X
Weatherstrip Doors	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X
CONDUCTION																		
Storm Windows	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X
Attic R-30 Insulation	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Wall Insulation	X		X				X	X			X		X	X		X		X
Basement Wall, Slab, or Crawl Space Insulation			X				X	X			X			X	X	X		X

Table 24. Options Installed - Tacoma

HOUSE NUMBERS	4	21	39	45	49	55	81	83	87
INFILTRATION									
Replace Broken Glass		X				X			
Reset Glazing		X				X			
Replace Threshold				X					
Seal Cracks & Holes				X					
Caulk Windows	X	X	X	X	X	X	X	X	X
Weatherstrip Doors	X	X	X	X		X	X	X	X
Caulk Doors	X	X	X	X	X	X	X	X	X
Gaskets on Electric Plugs & Switches	X	X		X					
Weatherstrip Attic Hatch	X	X	X			X	X		
Glass Doors on Fireplace		X		X					
CONDUCTION									
Storm Windows	X	X	X	X	X	X	X	X	X
Attic R-30 Insulation	X	X	X	X	X	X	X	X	X
Wall Insulation	X	X	X	X		X		X	X
Basement Wall, Slab, or Crawl Space Insulation	X	X	X	X	X	X	X	X	X
HEATING SYSTEM									
Duct & Pipe Insulation		X				X		X	X
Night Setback Thermostat								X	
WATER HEATER									
Water Heater Insulation	X	X	X				X	X	
Reduce Temperature	X	X	X		X	X	X	X	X
Shower Flow Restrictor	X		X				X	X	
Timer	X		X				X	X	
Repair Water Heater	X								

Table 25. Options Installed - Washington

HOUSE NUMBERS	2	7	41	53
INFILTRATION				
Reset Glazing				
Replace Threshold	X	X		
Weatherstrip Windows				X
Caulk Windows	X	X	X	X
Weatherstrip Doors	X	X	X	X
Caulk Doors	X	X	X	X
CONDUCTION				
Storm Windows	X	X	X	X
Attic R-30 Insulation	X	X	X	X
Wall Insulation	X	X	X	X
Basement Wall, Slab, or Crawl Space	X	X	X	X
Install Storm Doors		X		X
HEATING SYSTEM				
Flue or Vent Damper		X	X	X
Derate Furnace		X		X
Replace Burner				
Replace Furnace			X	
Duct & Pipe Insulation				X
Night Setback Thermostat	X	X	X	X
WATER HEATER				
Water Heater Insulation	X	X	X	
Reduce Temperature			X	
Shower Flow Restrictor	X		X	
Timer	X	X		
Aqua Booster				X

contractor labor, while infiltration work was done by the CAA. Insulation work was handled both ways. The insulation work done under contract was usually better than that done by the CAA. In Easton for example, where both the CAA and contract labor insulated attics, the contractor knew stair wells as well as attics had to be insulated, while the CAA did not realize that the attic stair well was a break in the thermal envelope. A general description of the quality of the work done for the demonstration follows.

Infiltration - All broken windows were replaced and large holes filled. Most doors, but few windows were weatherstripped. At one site for example, only two of 20 windows inspected were weatherstripped. This was often because the CAA was unable to weatherstrip in-place aluminum slider windows, and wooden windows were usually too tight to allow room for weatherstripping. Caulking was haphazard. One CAA, for example, tried to caulk the horizontal crack between pieces of wood siding and all of the cracks around the window trim, while another only caulked halfway up the first floor windows because of the limit on the height above ground at which CETA labor could work. Tacoma did the most thorough job on infiltration. Its CAA replaced light fixtures which leaked air into the attic, installed glass doors on fireplaces, placed styrofoam gaskets on light switches and wall outlets, installed special lock sets to seal up open key holes, and replaced base and cap moldings.

Attic insulation - Attic insulation and storm windows were probably the best installed of the weatherization options. However, even with attic insulation there were several situations which made installation difficult. Low attics and flat roof areas, for example, were difficult to reach. They were either blown, like walls, (with uncertain results) or not done at all. Several attics had floors in them, which limited the amount of insulation that could be installed to between 6 and 8 inches, or R=19 to 25. Other attics were used for storage. Stored items had to be removed before and replaced after installing the insulation. In Minneapolis/St. Paul, which is cold and wet, project workers found that when insulation to R=38 was installed in attics, they needed more ventilation than is normally supplied by builders in that area, to prevent condensation in the attic. As many as four additional roof vents had to be installed to insure that the attics had 1/150 of their floor area in vent area. On the other hand, in Colorado Springs, which is cold and dry, insulation to R=30 was installed without any attic vents and proved to be no problem.

Wall insulation - Wall insulation, either ureaformaldehyde or cellulose, was usually installed by outside contractors. Subsequent thermography showed that 10 to 20 percent of the insulation was missing in these walls [8]. The insulation was usually installed from the outside. This was preferred, to avoid the problems of dragging hoses inside and refinishing walls to cover up holes drilled to pump insulation into the wall. Installing insulation from the inside was usually limited to attic walls which were inaccessible from the outside. In Fargo, aluminum foil was found inside walls, and insulation had to be pumped in from both the inside and outside in order to fill the wall. Replacing siding after a wall had been insulated or sealing up access holes seemed to be real problems. Often the exterior of the house was marred in some way, and there were a few cases where plugs, used to seal holes cut for installing insulation, popped out.

No solid masonry walls were insulated, despite the economic analysis showing that a price as high as $\$3.50/ft^2$ could have been cost effective in Portland, Minneapolis, and Fargo and $\$3.00/ft^2$ in Chicago and Easton. Homeowners would not agree to have their "beautiful brick walls" covered or have their interior spaces modified. In addition, it was hard to find a contractor who was capable and willing to do the work.

Storm doors - The economic analysis found installation of storm doors not cost effective if the prime door is a well weatherstripped, 1-3/4 inch, solid core door. Despite being told this, several project coordinators installed some storm doors, and homeowners were usually delighted to have their front door "spruced up." Putting on a storm door may have generated savings which the project was not able to evaluate by comparing heat loss through the door before and after the storm door is installed.

Glass panels in exterior doors were considered worth double glazing if more than a small view panel. While this could be done by installing a storm door, it was more effective to double glaze only the window itself. One very effective method used in the demonstration was to adhere a piece of plastic over the prime window with magnetic tape.

Window Insulation - Usually nothing more than storm windows were installed on windows as part of the optimal weatherization package. Inconvenience seemed to be the major hurdle to installing more then double glazing on windows. In cases where nonmoveable sashes or plastic inserts were installed for storm windows to save money, they were usually removed for summer and not replaced. In many cases where plastic film was stretched between the prime and secondary windows to provide triple glazing, the plastic was sagging, and will probably be removed rather than be continually re-tightened. CAA's could not find a suitable way of double or triple glazing large panes of glass or sliding glass doors.

Basement Insulation - Thermographs revealed that basements, crawl spaces, and slabs on grade are areas of serious thermal leakage. Getting them properly insulated, however, proved to be a difficult problem. Often a house has a combination of crawl space, slab on grade, and basement, the latter with pipes, ducts, and non-uniform surfaces. The variety of conditions found in the field make it difficult to arrive at a simple, uniform method for treating all surfaces. Because of all of these problems, it is difficult to accomplish the task cost effectively.

Overall

The quality of work, while hard to measure, probably varied widely. By the end of the first winter after weatherization of many of the houses (1978/79), thermographic surveys of 65 houses had been conducted. In addition to "looking" for missing wall insulation, these surveys recorded a number of other sources of heat loss. The incidences of these energy-wasting deficiencies in the 65 houses are shown in table 26.

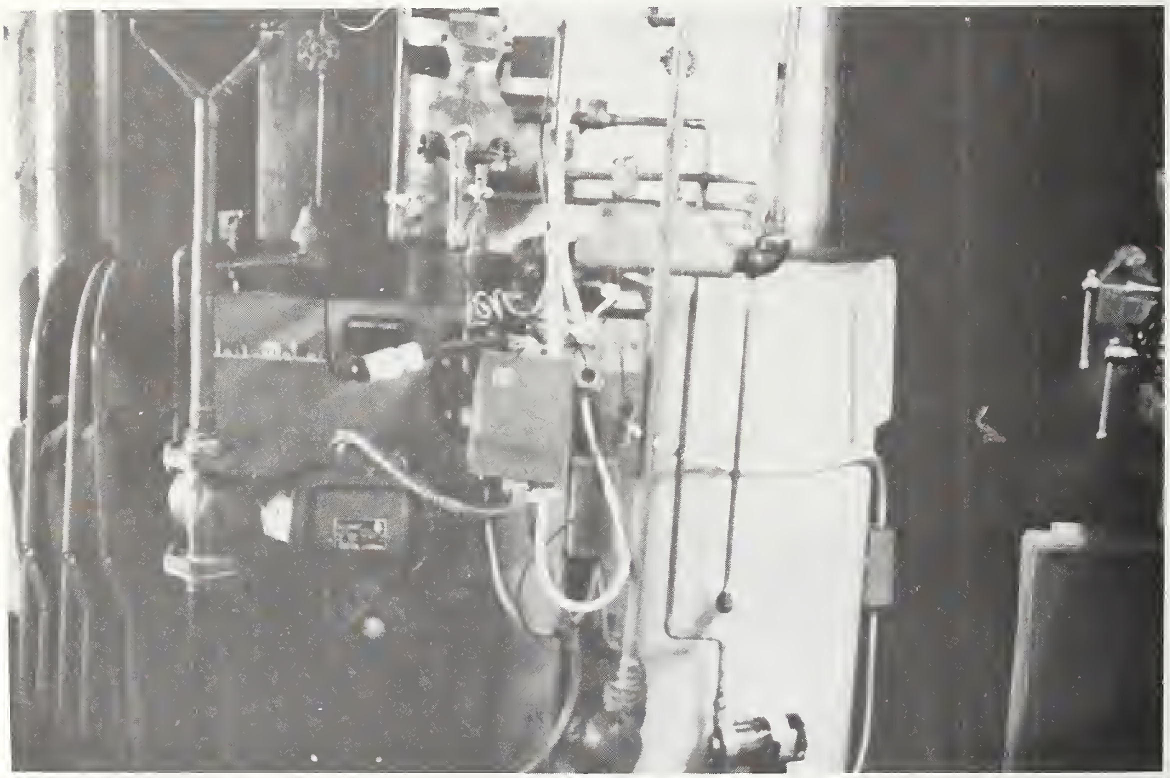
Table 26. Thermal Deficiencies Remaining After Weatherization (65 Houses)

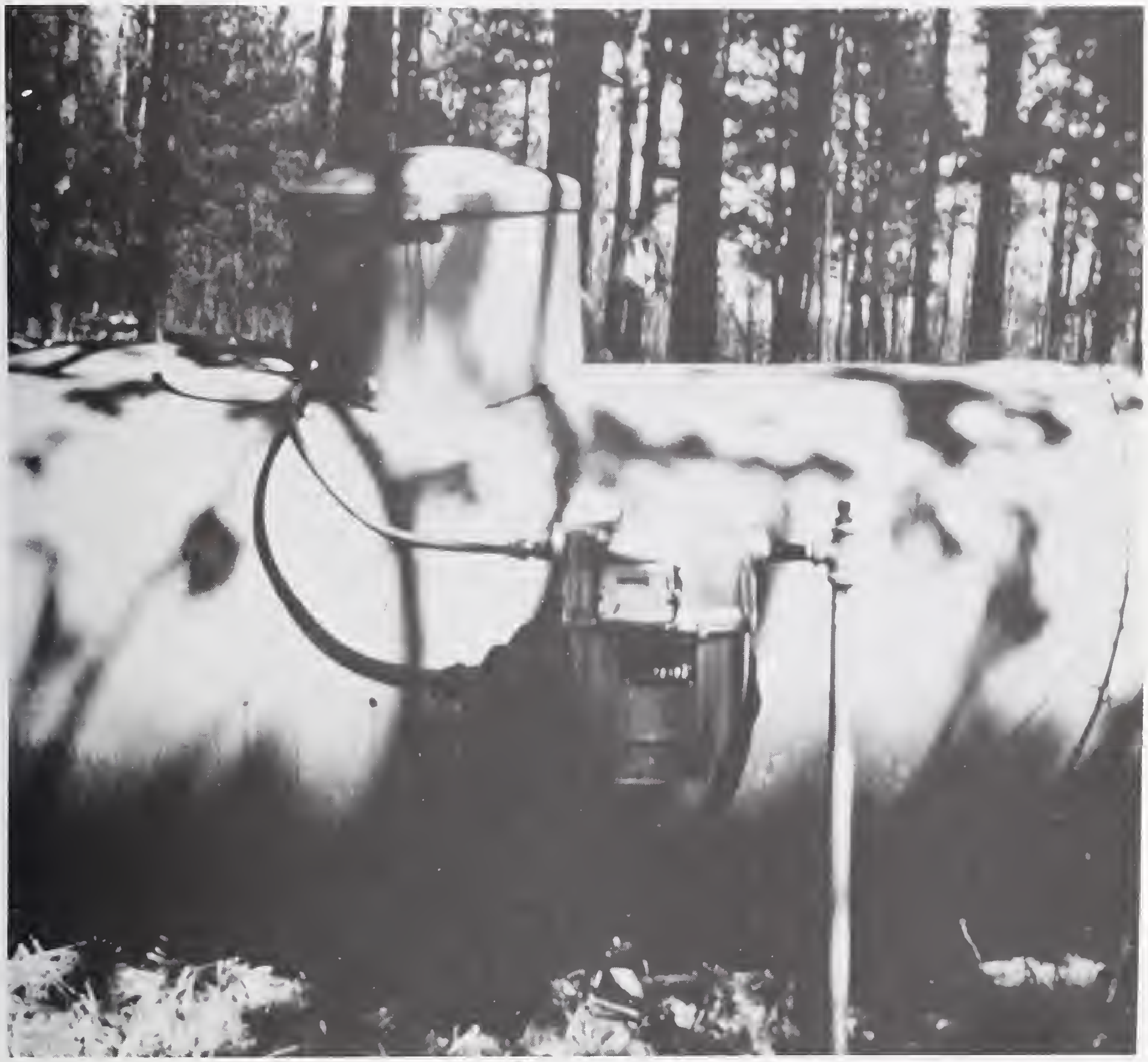
Problem	Percent of Houses
Insulation missing:	
0-5%	50
5-10	30
10-15	10
15-20	2
20-25	4
25-30	2
30-35	2
Insulation shrinkage/fissures	64
Defective ceiling insulation	33
Air leakage at doors	52
Frame heat loss at: doors	31
windows	72
Joint heat loss: wall-wall	74
wall-ceiling	51
wall-floor	23
Heat loss at soffits	26
Heat loss at eaves	6
Heat loss at basement/crawl space	15
Cold air penetration: ceiling	44

Heating and Hot Water Systems - The heating and hot water system options were usually installed by a licensed heating contractor. The options in general seemed to be installed properly. In one case, however, a furnace flue was mistaken for a duct and insulated. In several houses flue dampers could not be installed for lack of space between the furnace and the chimney, and in another case the flue damper was installed five feet from the furnace. Often, night setback thermostats were made inoperable by the homeowner pushing the two time indicators together. In Charleston, SC, cockroaches got into the thermostats, causing them to malfunction.

● Spraying cellulosic insulation on a block wall from a crawl space in Portland, ME.

● Metered mechanical equipment in a typical test house.





Propane gas use is metered in Charleston, SC.

8. METERING

CAA personnel (under NBS guidance) collected most of the energy-use and energy-related data in the field, using various meters. Existing utility meters on the house (e.g., electric, gas) or on oil trucks were used as backup in the data collection process. In general, special meters were installed on the furnace (energy source, running-time, cycle counter) and on the hot water heater (energy source and cold water supply). These meters were usually installed by utility companies using their own meters, in some cases at no cost, or by local heating contractors. The cost of metering the houses averaged about $300 per house. Meters were installed as follows:

Furnaces and Space Heaters

1. A gas meter with one cubic foot resolution in the gas supply piping to a furnace or heater.

2. A kilowatt-hour meter with 1 KWH dial resolution in the branch circuit of an electric furnace or individual electric space heaters. (Meter constant not to be larger than 3.6 watt-hours.)

3. A furnace running-time meter with a one minute resolution in the hot air fan circuitry or hot water circulatory pump circuitry. In gravity circulating systems, the running-time meter will be installed in the branch circuit to the furnace.

4. A cycle counter in the gas valve circuitry of gas furnaces (coordinate installation with the local gas company representative).

5. For oil-fired furnaces, a cycle counter and a run time meter with a one minute resolution in the oil pump circuitry.

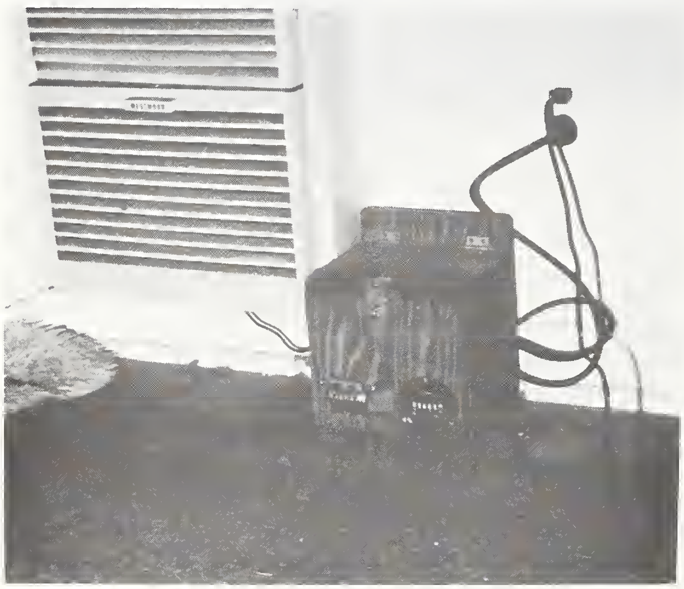
Water Heaters

1. A gas meter in the gas supply piping to a gas fired water heater.

2. A kilowatt-hour meter in the branch circuit of an electric hot water heater (meter constant should not be larger than 3.6 watt-hours).

3. A running-time meter on oil pump of an oil water heater.

4. A water meter on the cold water supply to the hot water heater (meter shall have 0.1 gallon resolution).



Metering an "in-wall" electric resistance space heater.

● CAA worker in Washington, DC, completes weekly data log.

9. DATA COLLECTION

Valid measurements of actual energy use are essential to developing correct and efficient energy conservation programs. To begin to address this need, the CSA/NBS project collected data from across the U.S. on the energy consumed by single family residences before and after weatherization. The project aimed at collecting a broad range of approximate measurements for many buildings, rather than highly detailed measurements of a few buildings. The data are intended not only to provide immediately useful field information, but also to provide a context for future data collection efforts.

Several types of data were collected. These were: building dimensions, energy consumption data, temperature data, infiltration data, cost data, heating systems data, hot water system data, and homeowner response data.

Energy Consumption Data - Energy consumption data were collected in order to evaluate the savings attributable to an optimal package of weatherization options. The savings were determined by subtracting the energy consumption of the house after weatherization (normalized to "standard" degree days) from that of the same house before weatherization (similarly normalized). Since this was the principal data to be reported by the demonstration, an effort was made to collect the consumption data in several ways. The redundancy would help to ensure that some reliable data would be available to evaluate savings. The same type of information which had been used for pre-weatherization energy use evaluation was collected from the whole house utility meter or fuel delivery records after weatherization. In addition, each furnace and hot water heater was supposed to be individually metered. All of these meters were read weekly.

Given that energy consumption data could always be collected, assuming sufficient funding, on the post weatherization condition of the house, great effort was put into insuring that pre-weatherization whole house meter readings were accurate. This was done by correlating fuel consumption against degree days over a two year period, and requiring that the data be predictable by a straight line with 90 percent certainty (i.e., R^2 -- squared correlation coefficient -- ≥ 0.90). (See pp. 9, 10 of the Project Plan [5].)

To insure that the data would be collected on a regular basis in a systematic way, each site was asked to submit a data collection schedule. These schedules showed on a house-by-house basis when the meters were to be read (weekly) and when tests such as the temperature stratification and bag tests would be conducted (monthly). A modified 80-column computer data coding sheet was used to collect the weekly data. This form worked both as a data collection form and coding form, and made it possible to key-punch the data directly from the form.

Several problems were encountered in trying to install meters on the various types of heating systems in the demonstration. Most gas meters had to be modified to read to 1 cubic foot. Standard gas meters used by the utility companies use 100 ft^3. (e.g., 1 therm) as their smallest unit of measurement. This was too large a unit to provide useful weekly data. Hot water heaters had to be metered not only for their energy consumption, but also for water consumption, in order to differentiate changes in energy consumption from changes in demand for hot water.

Space heaters without electric thermostatic controls offered no means of connecting running-time or cycle meters to the unit. Propane-fired space heaters had a supply pipe on which a gas meter could be installed. However, with gravity-fed kerosene heaters, no satisfactory means of obtaining measurements except at fuel deliveries was found -- and these tended to be several months apart after weatherization! Oil and kerosene flow meters of sufficient accuracy were too expensive for the project, so oil or kerosene consumption was measured using run time meters (and nozzle flow rates), verified, where possible, with truck meter readings. Float-type gauges on oil or kerosene storage tanks were tried, but found to be inaccurate.

The before- and after-weatherization consumption data are presented in chapter II "normal year" consumption. The values obtained from the analysis of fuel consumption records against degree days used to calculate the data are presented in appendix B.

Cost Data - Cost data were collected in order to evaluate the cost effectiveness of the various optimal packages of options. The separate costs of labor, material, overhead and profits were collected for each architectural option. For furnace and hot water options, the contract costs, which included labor, material, overhead and profit, were obtained. The sum of these two equals the total amount spent on optimally weatherizing a house. Material costs could usually be assigned directly to a specific option. Labor costs on the other hand, were broken down into direct labor costs which could be associated with one particular option, and indirect labor costs which could not be assigned to any particular options but were associated with a particular contract. An example of an indirect labor cost is the time spent picking up building materials at a warehouse or lumber yard. Overhead costs were those costs incurred by a contractor regardless of whether he undertook a specific job or not (e.g., rental payments, debt service payments, payments for equipment, payments for clerical and secretarial labor and payments for management).

To collect the data, two cost forms, presented in the Project Plan [5] (page 8), were used. The first was for collecting direct cost, charges which can be assigned to a specific house, and the second was concerned with indirect labor charges. Project coordinators were instructed to collect the cost data in the field while the options were being installed. When the first forms were completed they were to be sent to NBS for review and comment. This process made it possible for the project staff to identify any misunderstanding or incompleteness in NBS instructions. The costs are presented as total house costs in the result portion of this report and on a per unit basis (i.e., per square foot or per linear foot) in the report on cost findings [11].

Heating System Data - Data was collected on the heating systems to determine their effectiveness at delivering useful heat to the house. Data on the heating system was collected in three places, at the furnace, at the beginning of the distribution system (the plenum) and at the end of the distribution system (the registers or radiators).

Several types of heating systems had to be evaluated: forced and gravity air systems, vented and unvented floor furnaces and space heaters, and pumped or gravity circulated steam or water systems. Data had to be collected somewhat differently from each of these systems.

Unvented space heaters and floor furnaces, for example, not only provided radiant heat but also dumped all of their combustion products into a house; consequently, they were not measured, but assumed 100 percent efficient. Vented space heaters had no distribution system and were evaluated based on seasonal efficiencies calculated from combustion efficiency tests. Forced and gravity air systems were originally to be evaluated based on combustion efficiency tests, and temperature and flow rate measurements made at the plenum and room register. Because efficiencies at the registers were often so low, on the order of 10 percent, and it was obvious that much of the heat delivered by the furnace ended up in the heated space from air leaks in the distribution network, it was decided to use the steady state efficiences at the furnace, rather than at the register.

Circulating and gravity feed water systems, although their inlet and outlet temperatures were measured and radiators inspected, also were finally evaluated on furnace efficiency, on the presumption that most heat loss from the system remained in the house. More details on these measurements are provided on pages 42-45 of the Project Plan [5]. Seasonal combustion efficiencies obtained for each house are shown in appendix B of the present report.

Data were collected on carbon monoxide concentrations in rooms with unvented space heaters. It was not unusual in mild climates to have two or three 30,000 Btu/hr unvented units in one dwelling. NBS recognized that, if houses were unduly tightened, air infiltration for heating fuel combustion would be reduced and indoor oxygen depletion would occur. This condition could result in the generation of hazardous amounts of carbon monoxide gas (CO). In order to investigate the carbon monoxide levels associated with unvented space heaters, the heaters were turned on "full" for 30 minutes, and a sample of house air was collected and sent to NBS for analysis. (No dangerously high CO concentrations were found.)

Water Heating Systems Data - Data on the fuel used for heating water was collected for two reasons. One was to permit calculation of energy used for space heating from whole house utility readings, by deducting energy used for heating water. The other was to evaluate the effectiveness of water heater retrofit options. Data were collected using the tests described on p. 46 of the Project Plan [5]. These tests were designed to measure the efficiency of the water heater at heating water, the standing losses from the storage tank and the losses in the pipes which deliver the water to a faucet. This was done by conducting a steady state efficiency test like that done on the furnace, measuring the recovery rate of the water heater, measuring the temperature difference between the room and the jacket of the water heater, and measuring the temperature of the hot water at the nearest faucet. These data were used only for selecting water heater options. The water heating data has yet to be analyzed.

Temperature and Humidity Data - In order to compare the thermal environment before with that after weatherization, interior temperature and humidity data were collected. Representative temperatures and humidities were collected once a week on each occupied floor, in the attic and in the basement by reading a thermometer installed near the center of each of these spaces. These data were reported on the special form provided by NBS for weekly data. Detailed data was collected once a month by measuring temperatures in each room using a digital thermometer. The temperature was measured at the ceiling, at the floor, and at a three foot level, in the center and at each exterior wall of each room. These data were recorded and reported on another specially-designed form.

Infiltration Data - Infiltration data were collected, to field test new methods of measuring air infiltration in buildings, and to provide data for calculating the energy consumption of the Demonstration houses. Infiltration data were collected using the fan and bag tests described on pages 34-35 of the Project Plan [5]. A fan test was performed in almost all houses both before and after weatherization. However, in many houses, not enough "before and after" bag tests were conducted. The measured average infiltration rates are included in appendix A of this report.

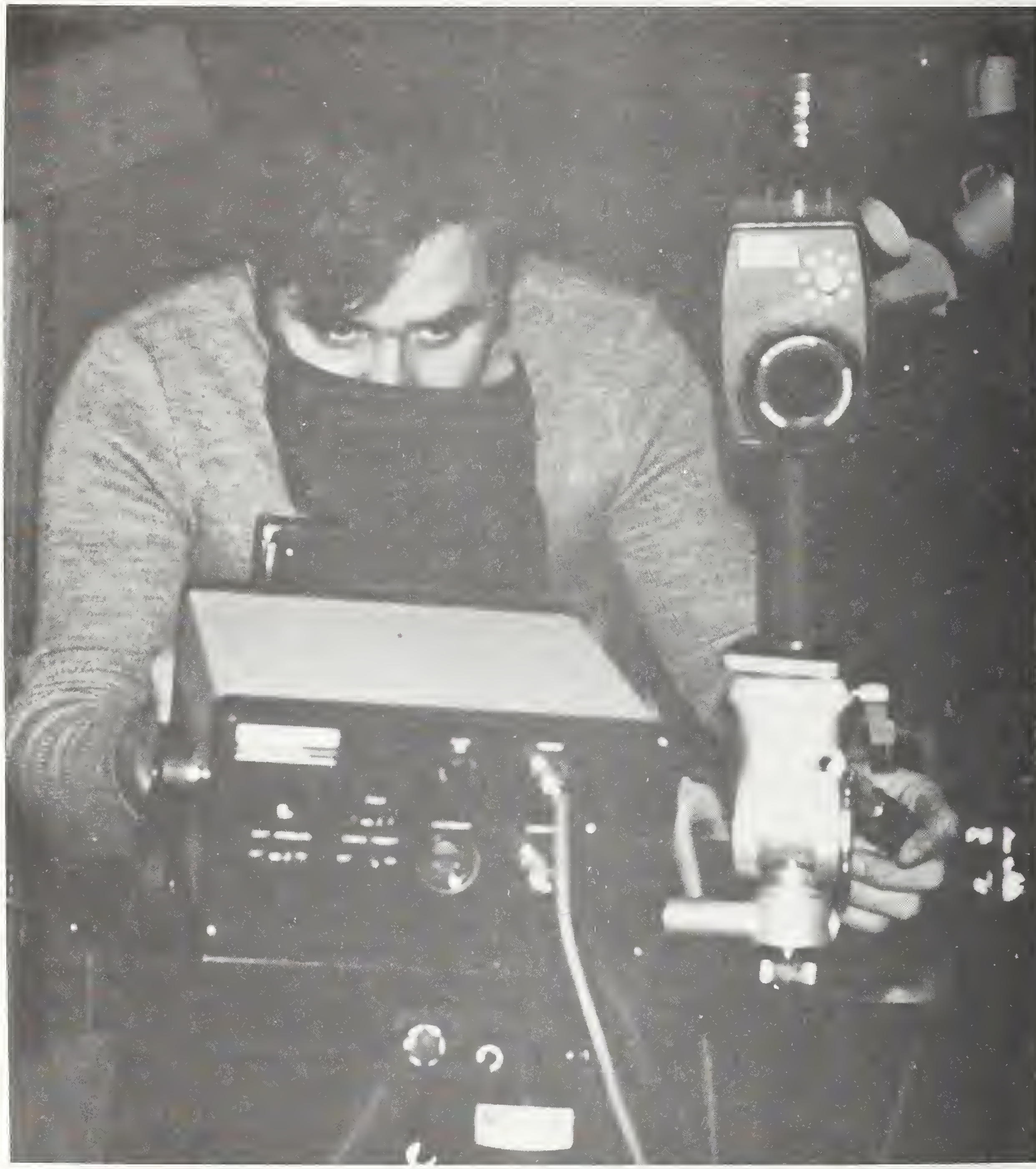
Building Dimension Data - Building dimension data were collected mainly to provide bases for calculating energy consumption of the houses as a check on measured data. These data were collected using an NBS-developed form, shown on page 69 of the Project Plan [5]. Photos of each side of the building were collected. Building dimension data were collected by physically measuring each structure and carefully describing wall sections. The buildings were measured in plan on the outside of each house. The length of each wall on each floor was to be measured, continually around the building. This was done for each floor. The height of the building was arrived at by summing interior ceiling heights. Windows were listed by orientation, and the overall rough opening dimensions measured. When windows were measured from the inside, a bathroom or closet window was often missed. For this reason, data collectors were instructed, when they measured the window sizes on the inside, to count the number of windows on the outside.

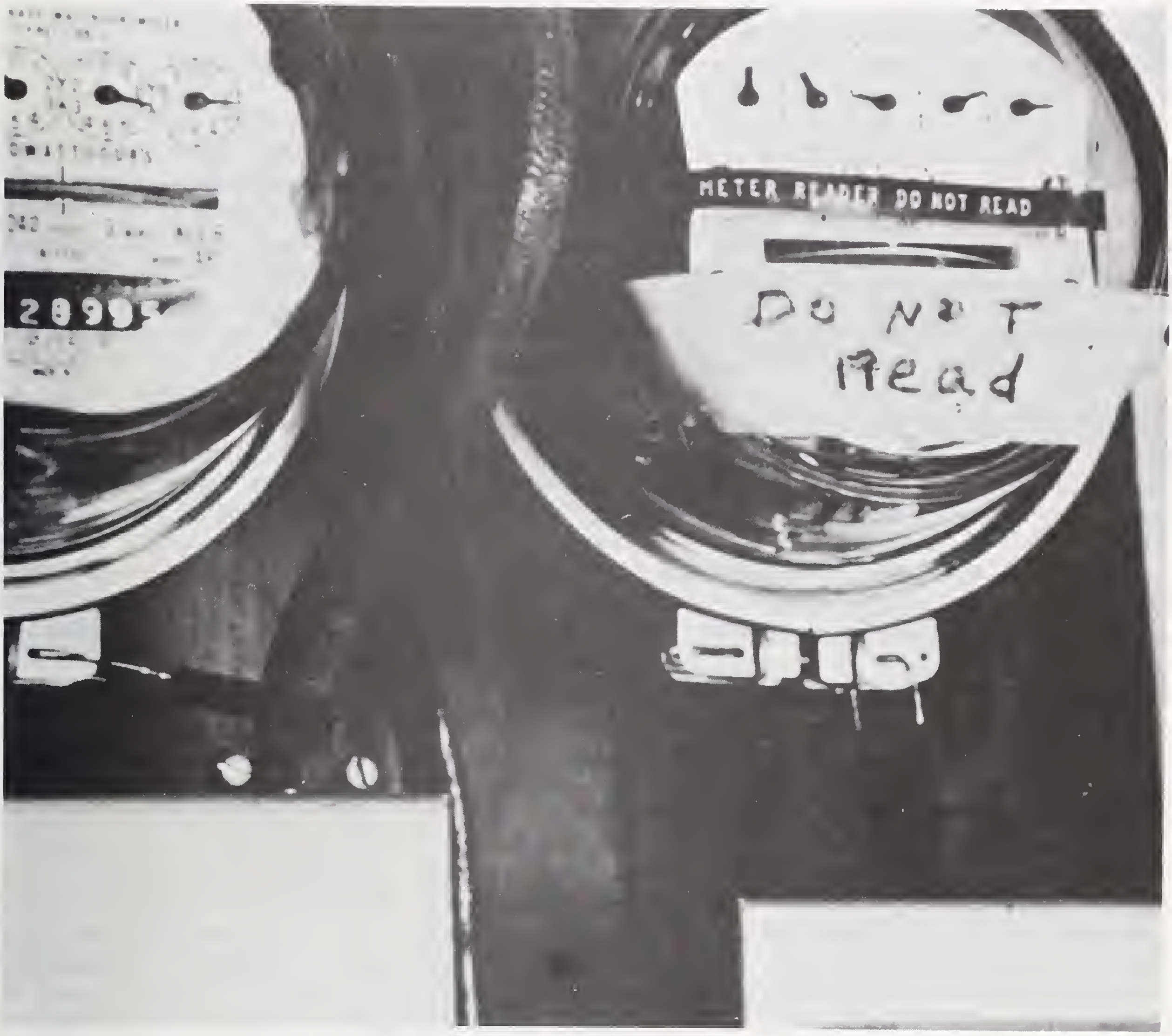
Describing wall sections required a certain amount of detective work. Window and door openings were carefully examined to determine overall wall thickness, as a check on what the cumulative thickness of the components should be. Electric switch boxes were removed and wall cores from wall insulation were examined further to determine materials and their thickness. The most common mistake made in collecting wall composition data was to overlook structural members and their spacing. The areas and U-values for various components of the building before and after weatherization are presented in appendix B.

Homeowner Response Data - The CAAs used an NBS-developed questionnaire-guided interview of each homeowner to obtain such information as: how many people were living in the house over the period of the Demonstration; whether usual thermostat settings were different before and after weatherization; whether thermostats tended to be set higher during unusually cold weather; whether occupants noticed any differences in the wintertime comfort in their homes over the period of the Demonstration; whether they changed the amount of clothes they usually wore inside in winter over that time, and specific comfort and temperature ratings the various rooms in the house. These data are extensively discussed and analyzed in [3].

Thermographs - Interior thermographs of exterior walls were obtained on all the houses in which walls were insulated as part of the Demonstration (see tables 14 through 25).

● NBS engineer makes thermograph inside Portland, ME, house.





● Meter reader is asked to ignore meter on right which records only that electricity used for domestic hot water.

10. DATA ANALYSIS

The objects of this project were to develop testing tools for local project coordinators to measure energy consumption in low-income houses before and after weatherization, to demonstrate energy savings, and to provide a much-needed data base for further energy research. The principal new understanding that the project intended to provide concerned cost effectiveness of weatherization. The project aimed to do this by showing that optimal weatherization could reduce energy consumption in low-income houses by 50 percent, and that it would pay for itself in 11 years. To this end, the fuel consumed for heating the house before and after weatherization had to be determined, along with the cost of the weatherization. As a further check on measured savings, building dimension's were used to calculate predicted savings and homeowners responses were use to confirm improved thermal conditions. Other project-related reports listed in the Chapter 12 have analyzed some of the collected data.

Data analysis took place at a number of levels. First the data was reviewed as it was received from the field, to check for obvious inconsistencies or other problems. Then data analysis was necessary to convert field data to meaningful information. Sulfur hexafloride and time readings, for example, are not directly useful for evaluating air leakage. These have to be converted into infiltration rates. Finally, data analysis was employed to combine the separate measurements into meaningful wholes which could provide the researcher with a better understanding of the thermal performance of a residence.

Consumption before and after weatherization were determined by analyzing pre- and post-weatherization fuel data. Houses for which a reliable set of pre-weatherization heating fuel data could not be obtained were not accepted in the project. Post-weatherization heating fuel data was collected in a variety of ways, to increase the chances of having reliable data for analysis. Reliable data was defined as fuel consumption readings which, when plotted against degree days, could be fitted to a straight line, using standard regression techniques, with an $R^2 \geq .90$. For most houses, the post-weatherization heating fuel consumption data was collected in three ways: 1) by the whole house meter (or delivery records, in the case of oil or propane); 2) by a furnace fuel meter; and 3) by a running time meter on the furnace. As described under meter installation, collecting the data in these ways was not always possible. However, the strategy did give at least one measure of fuel consumed for heating on most houses.

For the final analysis, weekly readings from the whole house utility meter (gas or electricity) or running-time meter (for oil) were usually used, and combined into 21 day periods to make them comparable to pre-weatherization data. For oil-fueled houses, readings from running time meters were multiplied by nozzle flow rate (gallons/hour), or oil supply company readings from the trucks were used to give fuel consumption. In some cases, oil tanks were not completely filled, or only one or two oil deliveries were made because of reduced consumption after weatherization, thus the delivery data were insufficient to determine the after consumption. Where there were only a few oil delivery readings during the period covered by the run-time meter readings, they were used to check the (reported) burner nozzle size (rate). Then weekly running-time readings could be used to derive reasonably accurate fuel consumption. Using weekly whole house consumption data was possible on most of the houses except those in Chicago and Minneapolis/St. Paul. In Chicago and Minneapolis, many weekly readings were missing or provided a poor fit to degree days, and bills from the utility company had to be used.

Energy Savings

The amount of energy saved was measured in three different ways: 1) regression analysis; 2) graphic tracking; and 3) heat load calculations. A fourth check on results was homeowner response.

Regression Analysis - The regression analysis technique established, through standard regression methods, the parameters of a simple linear model that relates amount of fuel consumed to degree days -- a measure of the amount of coldness in a heating season.* Since the analysis technique we used allowed the "balance point" for determining degree days to "float", and sought the "best fit" solution, three parameters were obtained: 1) B_ϕ -- the "intercept", representing daily consumption with no heating load; 2) B_1 -the "slope", representing consumption per degree day, and 3) T_ϕ -- the balance point that gave the "best fit" of fuel consumption to degree days. Once the straight line that best fits the data has been determined, then the B_1, B_ϕ and T_ϕ can be used to predict energy consumption, from the degree days for any given time period, by using the following formula:

$$Q_m = (B_1 \times DD_{bm}) + (B_\phi \times 365) - [HW] \text{ [where the same fuel is used for heating water]} \qquad (2)$$

where: Q_m = projected "normal" year-total space heating consumption.

B_1 = The amount of fuel consumed per degree day for heating.

DD_{bm} = Degree days for the measured balance point (T_o) of the house.

T_o = The balance point of the house (roughly, the outside temperature at which the furnace turns on).

B_ϕ = The base heating fuel consumption in Btu per day, which is unrelated to degree days. It is the fuel consumed by the stove, hot water heater, dryer, pilot light, etc.

HW = Btu's consumed for heating water.

In order to eliminate the effects of variations in climate between one year and another and to make the data as generalizable as possible, average degree day data for 1973-80 were used to calculate "normal year" "before" and "after" consumption. The B_1, B_o, Balance Point and HW for each house are presented in appendix B.

Graphic Tracking - The graphic tracking technique plotted predicted fuel consumption, calculated using the B_o, B_1 and T_o from the regression analysis

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* "Degree days" are calculated on a daily basis (and cumulated) by taking the difference between the average temperature for a day and a reference or "base" temperature. If the day average is equal to or greater than the reference (called "balance point") no (heating) degree days are counted for that day. When the average lies below the balance point, the difference constitutes the degree days for the day. Customarily, 65°F is assumed as the base temperature. However, our analysis allowed the reference temperature to "float" from 45°F to 85°F, and found that "balance point" value which gave the best fit of the fuel data to degree days (as shown by the R^2).

of pre-weatherization consumption, on a time scale through both the pre-weatherization and post-weatherization periods (see figure 3). The actual consumption data was superimposed on this graph. For most weatherized houses, the actual consumption plot followed the predicted fuel consumption line closely during the pre-weatherization period and then moved lower when weatherization began.

By comparing the integrated area under the post-weatherization plot of actual consumption with the area under the "predicted" plot, percentage savings was derived. These consumption figures, however, often included stove, pilot light, water heating, as well as space heating, which would tend to reduce the percentage savings from that obtained for space heating alone.

Heat Load Calculations - Savings were also assessed using heat load calculations, by determining the theoretical amount of fuel consumed before weatherization and after weatherization with ASHRAE-type calculations. The following formulas were used for calculating fuel consumption (Q_c) before and after weatherization:

$$Q_c = [24DD_b\ (UA_c + UA_i)]/M_e \qquad (3)$$

$$T_b = T_i - [(I + S)/24\ (UA_c + UA_i)] \qquad (4)$$

DD_b = The number of degree days in the month for the calculated balance point (T_b) of the house (from the "before" or "after" year data, as appropriate). See formula three on this page for calculating the balance point T_b.

UA_c = Heat loss (in Btu per degree hour) due to conduction. It is calculated by summing the areas times their respective U-values for all the surfaces of the house. Areas were measured in the field and U-values were derived from ASHRAE tables by using the field descriptions of walls, roof and floor sections.

UA_i = Heat loss (in Btu per degree hour) due to infiltration. It is calculated by multiplying the volume of the building by the air changes per hour, the specific heat of air and the density of air. Air changes were derived by averaging the readings from the bag tests done on the house. Infiltration rates used are shown on the tables. Where there were less than four bag tests either before and after, all were averaged and the same rate used both and after. Where there were only four bag test either before or after weatherization, the same infiltration rate was used both before and after.

M_e = The mechanical efficiency of the heating system. The before and after efficiency of the furnace derived from submitted mechanical test data.

T_i = Interior temperature. An average of all the stratification tests for the house was used for this parameter. The same number was used for both before and after weatherization.

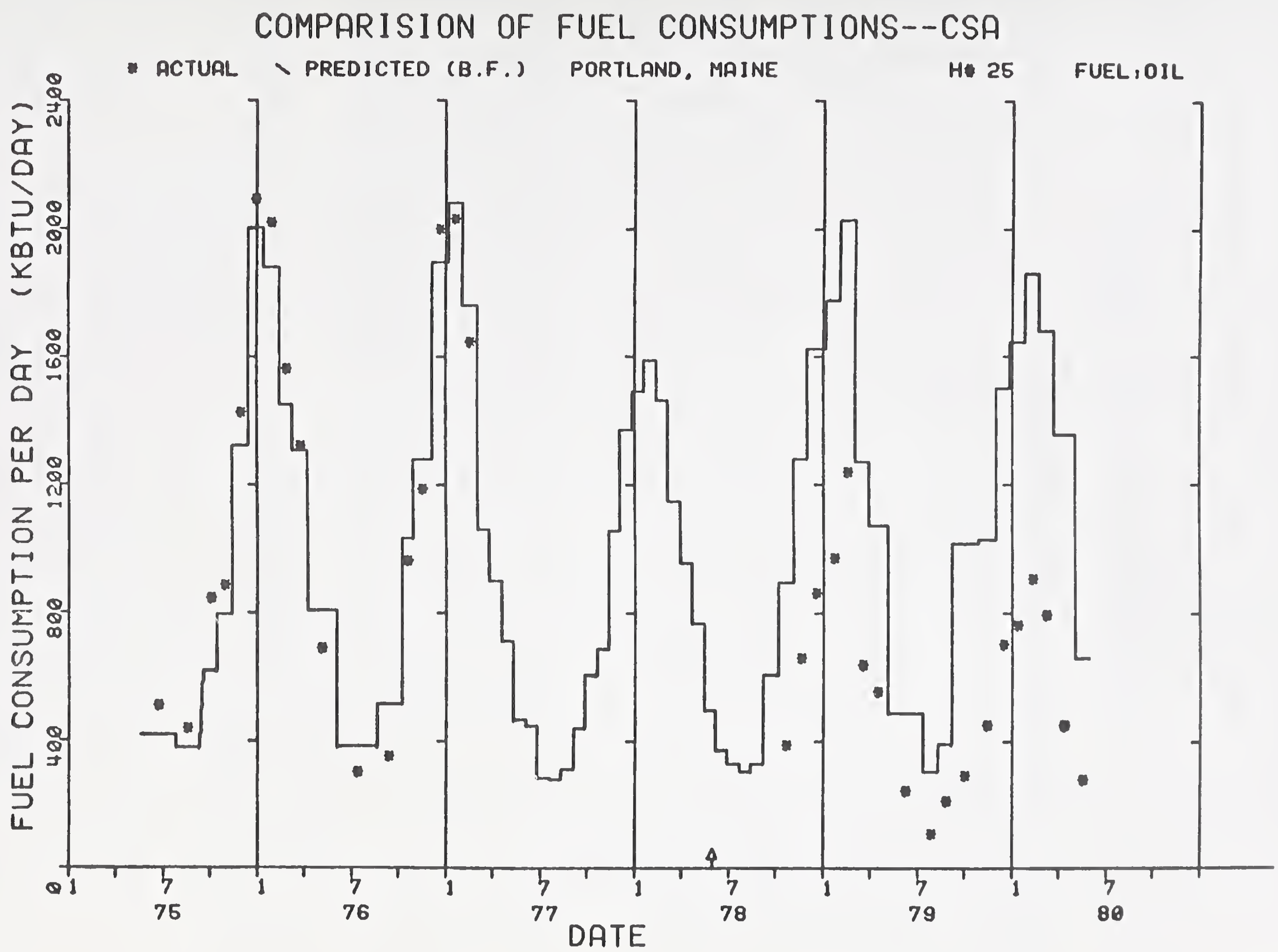

Figure 3. Example of graphic tracking of fuel consumption

I = Assumed internal gains. A constant number of 53,000 Btu/per day taken from DoE 2 was used.

S = Assumed solar gains. Data from NBS BSS 96 [10] were used.

The calculation was carried out for each month of the year before weatherization and similarly for after weatherization. The two sets of 12 monthly figures were added to give yearly totals used in calculating savings.

Home Owner Response - The actual success of weatherization could not be determined from occupants' response to weatherization of their house, but the improvement in wintertime comfort in the house, which is likely to result from weatherization, could be evaluated. Data for this evaluation were obtained by means of a questionnaire administered to each homeowner, asking them, among other things, to rate the wintertime comfort of their home before and after weatherization on a scale of 1 to 5. A comfort improvement index was also derived from the comfort ratings and such indirect indicators of comfort change as thermostat-setting practices and amount of clothing worn in the house in winter. Both of these measurements indicated a noticeable improvement in wintertime comfort in the weatherized houses. Comfort change rating indexes are reported on a house-by-house basis in the Results Tables (pp.72-101). More detailed discussion of these data is available in Effects of Home Weatherization on Occupant Comfort: First Report of a Field Study [3]. That report found that the mean comfort rating for houses before weatherization was 2.75 and the mean comfort rating for the same houses after weatherization was 4.38, while the rating of the control houses changed less than 1 percent for the same time periods.

Cost Data - Cost data were analyzed by dividing raw cost per job by the number of square feet or linear feet in the job. The numbers derived for each house in this way were then compared across houses in each city to identify any large variations. When variations were found the data was rechecked with the site for possible inaccuracies. Once the data had been checked, the amount of money spent on infiltration, conduction, hot water heater and furnace were retotaled. These data are reported in the results tables. The per square foot and per linear foot data is reported in Weatherization Investment Costs for Low-Income Housing [11].

Simple payback was calculated by dividing the total cost of weatherizing a house by the product of the number of units of fuel saved times the cost per unit shown in table 27.

Table 27. Fuel Prices (1979/80) Used to Evaluate Savings

	ATL	CHA	CHI	CSP	EAS	FAR	MSP	OAK	POR	STL	TAC	WAS
GAS $/therm.	.335		.294	.243	.433	.620	.285	.672	.430	.235	.461	
OIL $/gal.					.987	.962	.980		.985			.999
ELECTRIC $/kWh.	.039	.039			.030	.035				.039	.018	.038
PROPANE $/gal.	.681	.868										.750

● Stucco walls await patching after the installation of insulation in this Minneapolis house.

11. RESULTS

There is no doubt that weatherization can bring considerable savings for low income households, especially weatherization which involves both architectural and mechanical systems retrofits. Tables 28 through 41 present the results of the project. Table 28 and 29 are summaries of those results. The results are presented in terms of costs and energy consumption data associated with each of the houses for which adequate data was obtained. Originally 222 houses were selected for the Demonstration experimental group and 68 houses for the Demonstration control group. Of these, we had received adequate data at the end of the measurement period from 142 weatherized sample houses and 42 control houses. Houses were lost from the sample because their owners no longer

Table 28. Overall Summary Results

	EXPERIMENTAL			
	ARCHITECTURAL OPTIONS ONLY*	ARCHITECTURAL AND MECHANICAL OPTIONS	ENTIRE GROUP	CONTROL GROUP
Number of Houses	68	74	142	41
Percent Savings**	17	41	31	5
Dollar Cost	1336	1862	1610	-
Years Payback**,***	15	6	8	-

* As discussed earlier in this report, houses did not receive mechanical options for one of three reasons: 1) no options were found cost-effective for the particular heating system, thus none were prescribed for installation. 2) Prescribed options could not be installed in the house due to some field condition. For either of these situations the house would be termed "optimally weatherized" by the definition employed by the Demonstration. 3) The site CAA simply did not get the mechanical systems work done. Such houses were not "optimally weatherized." Thus this column contains both optimally- and non-optimally-weatherized houses.

** These are "global" averages, obtained by first adding up the total costs of "normalized" annual fuel consumption and the total costs of weatherization work for the houses, and <u>then</u> carrying out the division to obtain averages. If one averages the individual house "percent savings" and "years payback" figures, one obtains somewhat different overall averages. Such figures are in a sense "biased toward the mean" -- or under-weighted -- since the significant difference in fuel savings between, say, a 33% reduction in a house that started out consuming 185.3 MBtu/hr (e.g., CSP 23) and the same percentage reduction in a house that started out consuming 99.9 MBtu/yr (e.g., CSP 14) is not reflected. When individual house percentage savings are averaged, both of these houses contribute the same entry: 33 percent. However, when "global" averages are calculated by first summing the actual fuel consumption before and after, the almost twice as large fuel savings of the first house above is better reflected in the result. The authors feel that, in view of the wide variation exhibited by the individual house consumption and savings figures, the "global average" percent savings and years payback figures probably are a better guide to a weatherization project manager as to what overall results he might expect to obtain from weatherizing, 1,000 or 10,000 houses.

*** This is simple payback, as defined on page 66.

Table 29. Site-by-Site Summary Results

City	CHA	OAK	ATL	WAS	STL	TAC	EAS	CHI	CSP	POR	MSP	FAR
Degree Days	1904	2909	3095	4211	4750	5185	5827	6127	6473	7493	8310	9271
Averages for Experimental Houses												
Consumption Before** Btu/DD·ft^2·yr	26	20	23	34	27	20	14	30	20	25	16	15
Consumption After** Btu/DD·ft^2·yr	17	20	20	18	25	11	11	17	11	14	12	8
Savings** (+ = savings)	35	3	16	47	10	45	24	41	46	44	22	40
Costs: Dollars	977	274	1211	2924	1781	1807	1035	2347	1765	2215	—	1626
Payback:** Years	7	19*	19*	6	44*	8	6*	7*	12	4*	—	6
Sample Size	13	8	8	4	18	9	13	10	16	14	17	12
Averages for Control Houses												
Consumption Before** Btu/DD·ft^2·yr	19	37	11	19	26	9	23	—	22	14	16	17
Consumption After** Btu/DD·ft^2·yr	15	41	9	28	31	9	21	—	21	12	14	15
Percent Change (- = savings)**	-15	+10	-23	+46	+16	-16	-10	—	0	-12	-8	-10
Sample Size	5	4	2	2	2	5	3	0	4	4	5	5

* Houses exhibiting increased "after" consumption (i.e., negative "savings" — see the city tables) were disregarded in calculating these averages -- necessary since there were no savings against which to relate the weatherization costs.

**These are "global averages", calculated as described in the second note to table 28 (p. 70).

wanted to participate or the house was physically abandoned. Houses were lost from the control group for the same reasons, and also in some cases, because the house was partially weatherized. Of the 142 weatherized houses, only 74 were optimally weatherized (receiving both architectural and feasible mechanical options).

The results show a wide range of energy savings and costs. Energy savings range from negative to 70 percent. Costs vary from $24 to $4000. As would be expected, the highest energy savings were achieved when both architectural and mechanical options were installed in more northerly climates This may be partially due to the fact that many southern homes had space heaters which could not be upgraded. Table 28 demonstrates the significant increase in savings when mechanical as well as architectural options were installed.

Forty-one percent was the average savings achieved by the 74 houses weatherized with both architectural and mechanical options. This figure is about ten percent lower than the staff expected at the beginning of the project, based on calculations based on a hypothetical house. As it turned out, houses in the north were already weatherized to a greater degree than expected when they entered the Demonstration. Most houses in Fargo for example, had not only R-30 insulation in the attic and storm windows, but also wall insulation. Despite this, savings on the order of 40 percent were achieved in Fargo. Also the level of existing weatherization in any one city could be very uneven. In some cities several houses would have storm windows, attic insulation, even wall insulation, while other houses would have no weatherization. By comparing the list of options which were to be installed, in tables 8 through 10, with those which were actually installed, listed in tables 13 through 24, the reader can see the great variation. These variations are probably similar to what occurs in normal weatherization, and the results, therefore, are probably generalizible to much of the nation's single-family housing stock.

While the Demonstration documented only 40 percent savings, rather than the 50 percent estimated, savings of 50 to 70 percent seem achievable through optimal weatherization plus "house doctoring"* and solar heating. Thirty percent of the weatherized houses demonstrated "post" consumption levels of 9 Btu per square foot-degree day or less. Thus, this seems an unreasonable goal for weatherization efforts. If this level of consumption had been attained in all of the weatherized houses, it would have resulted in an overall savings of 60 percent.

House doctoring alone might achieve an additional 10 percent. The thermography surveys and air tightness fan tests done in the Demonstration were mainly used to evaluate the effects of the work done, rather than to improve it. The houses could be visited again, the wall insulation filled in where it was missing, and the fan and/or thermographic equipment used to find air leaks and

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* Housing doctoring uses furnace tests, fan tests and thermography for diagnosing and prescribing cures for energy inefficient houses. The term was first coined in the Princeton University Twin Rivers project, and later popularized by the staff of the DoE's Lawrence Berkeley Laboratory.

thermal by-passes, but the Demonstration research design did not include this step.

Originally, the researchers intended to report the Demonstration results in percentage savings and cost. The project, however, found no good statistical relationship between weatherization cost and percentage fuel savings. Because of the optimizing techniques used, more money might have intentionally been spent on a house with a lower percentage savings and higher fuel prices, to achieve higher dollar savings. Perhaps the best indicator of the success of the project is the simple payback period (see page 66). The project aimed for payback periods of 11 years. The mean payback was 11.4 years for all houses (see figure 4). This average however is affected by a few unusally bad performers with high payback periods. A close examination of figure 4 shows that one-half (53 percent) of the retrofit jobs demonstrated a payback period of less than 9 years.

If the total dollars spent on all the houses is divided by the total dollars saved, rather than averaging the individual house payback periods, an average payback of 8 years is realized. If the total dollars spent on optimally-weatherized houses is divided by the total dollars saved by those houses, a payback period of 6 years is achieved. The achievement in the optimally-weatherized houses exceeded expectations, and indicates the importance of treating the mechanical systems as a part of weatherization efforts (see table 28).

Table 29 and figure 5 present an overview of the data. Figure 5 shows the correlation between dollars spent and Btu's saved on experimental and control houses. The control houses are shown along the zero-dollar-spent line. The data seem to fit a straight line better below $2700 than above. Along the MBtu saved/year axis, there are more houses to the right side of the graph, representing higher savings, which received both architectural and mechanical options, than those which received only architectural options. Along the dollars-spent axis there is a broad distribution of both houses that received only architectural options and those that received architectural and mechanical options. Table 29 summarizes the data in tables 30 through 41 on a city-by-city basis. Those sites which achieved the least savings, Oakland, St. Louis, and Minneapolis/St. Paul, were the poorest performers, in terms both of getting the options installed and collecting data. Atlanta is a special case in which the field people did an excellent job, but unfortunately much of the fuel consumption data was unusable.

Significant information will be found, not only in the Results tables, but also in the tables in Appendix A, Building Data. With the data in the tables, savings can be related to increased R-value for various building components and to reductions in UA's. While few houses had sufficient air infiltration measurements made both before and after the weatherization work, averaging of air infiltration data from any site will show: 1) clear reductions in mean infiltration rates, 2) that infiltration rates before weatherization were generally lower than expected, and 3) that infiltration rates in the more northerly, colder climates measured lower than those in the south. (For more information on this subject see [15].) All of the data obviously deserves further analysis.

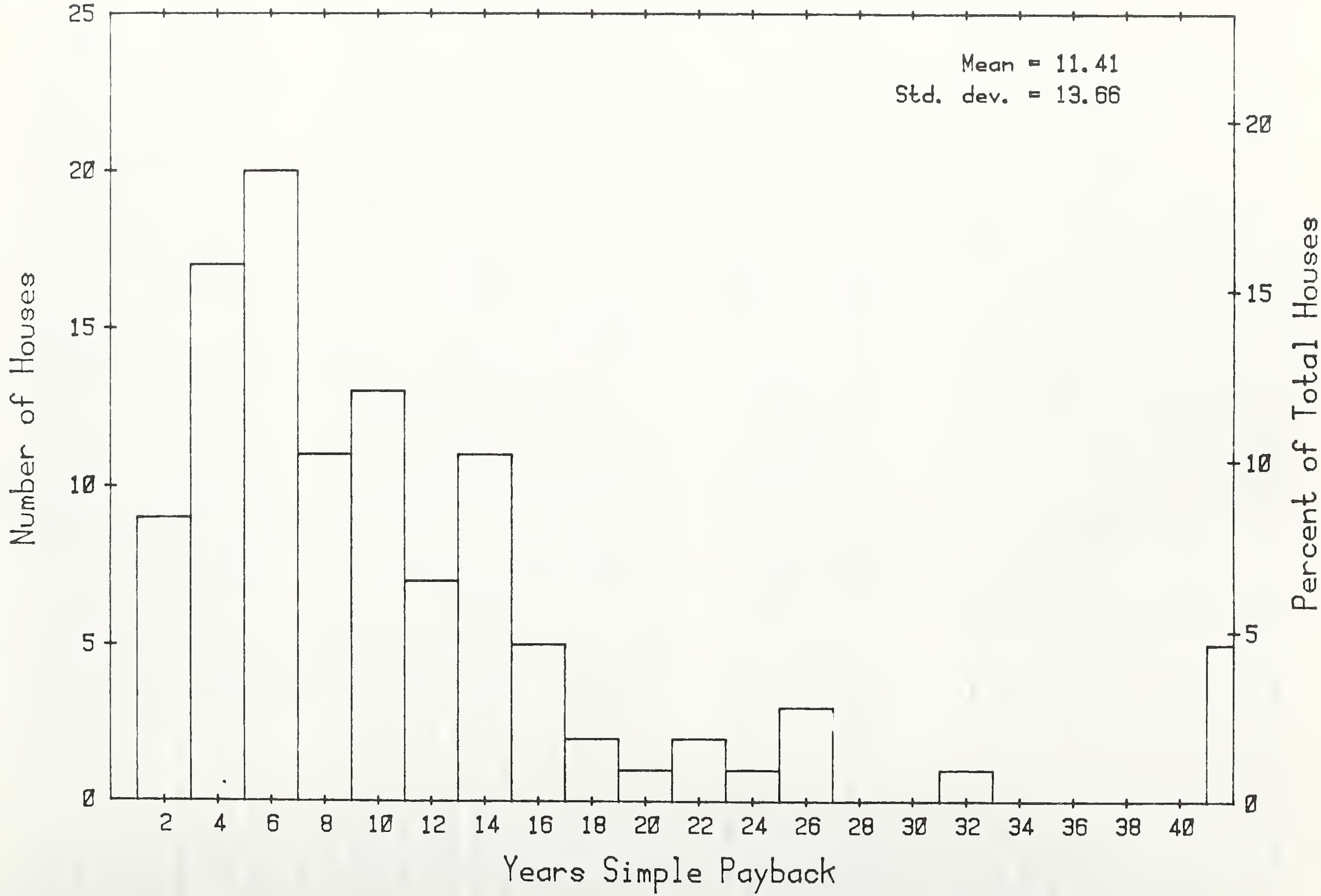


Figure 4. Distribution of simple payback periods of weatherized houses.

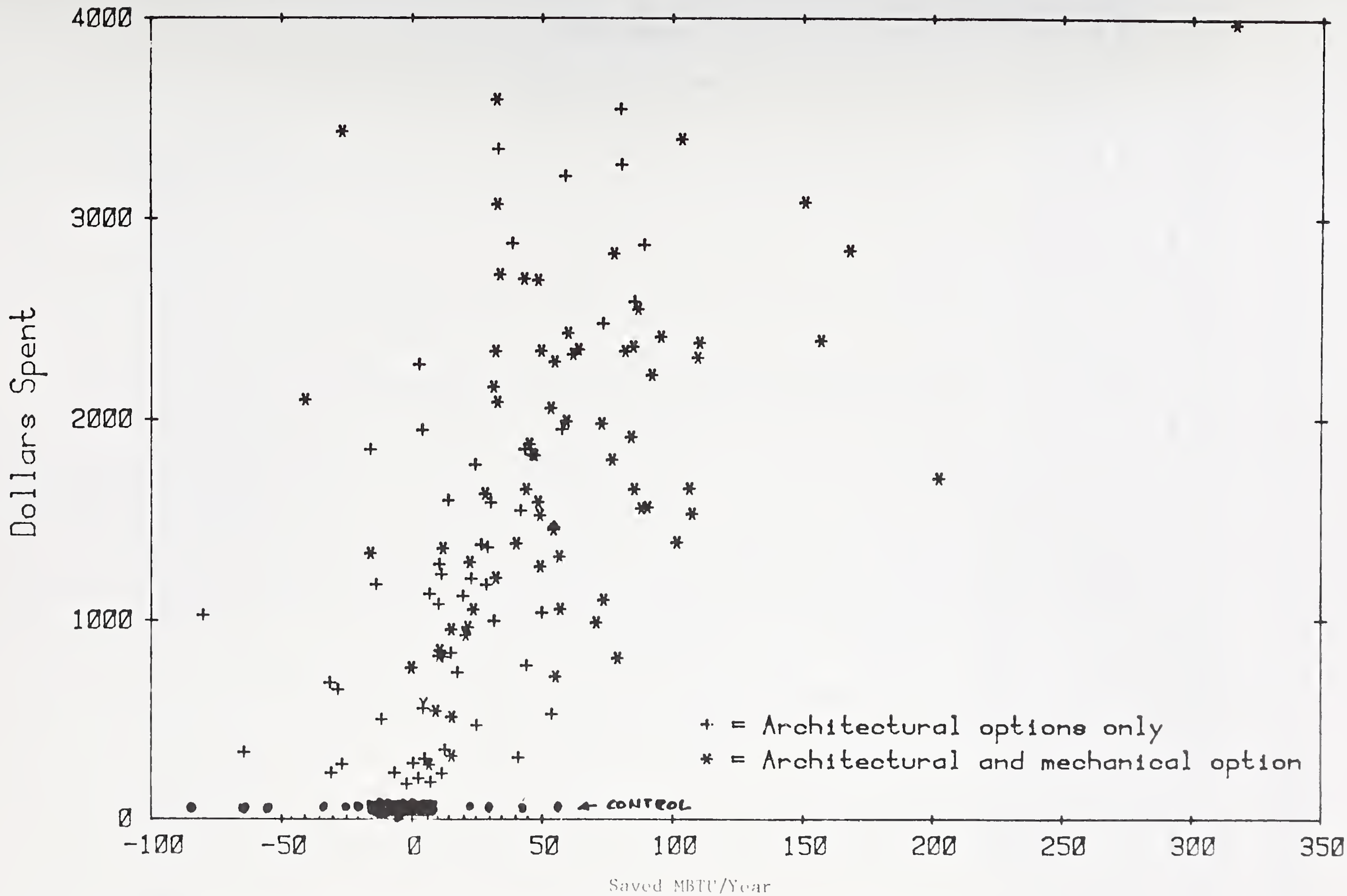


Figure 5. Scatter plot of cost effectiveness of house weatherization.

A report which describes the data and tells where it is available has been published by NBS [4].

Since the Demonstration began in 1977, oil prices have risen substantially, and natural gas prices are expected to do so over the next several years. Consequently, weatherization retrofit packages that were "optimal" in 1977 are becoming increasingly "sub-optimal" (i.e., even larger investments would have been cost-effective). On the assumption that fuel prices are increasing faster than prices of architectural and mechanical options, 11 year or shorter paybacks should be expected from optimal weatherization packages selected using 1981 fuel and options prices. This is probably the most significant overall finding of this Demonstration for national energy policy makers, Community Action Agencies, and all individual homeowners.

Table 30

Atlanta Results

(3095 DD_{65})*

Weatherized Houses

House Number		1	2	17	22	23	29	31	32
Measured Consumption Before (See Note 1)	MBtu/yr	95.2	85.1	42.8	52.7	78.6	99.6	83.0	67.1
Measured Consumption After (1)	MBtu/yr	82.7	81.1	38.9	64.5	80.6	46.0	49.9	64.4
Measured Consumption Before (1)	$Btu/ft^2 \cdot DD$	35	20	14	15	30	29	30	19
Measured Consumption After (1)	$Btu/ft^2 \cdot DD$	31	19	12	18	31	13	18	18
Measured Change (1,2)	MBtu/yr	-12.5	-4.0	-3.9	11.8	2.0	-53.6	-33.1	-2.7
Percentage Change (2) Regression Analysis	%	-13	-5	-9	+22	+3	-54	-40	-4
Percentage Change (2) Tracking Method	%	-43	UNA(4)	-2	0	-11	UNA	UNA	UNA
Percentage Change (2) Load Calculations	%	UNA(4)	UNA	-64	-11	UNA	-44	UNA	-60
Composite Comfort Improvement Index(3)	(0.0-1.0)	UNA	1.00	UNA	0.80	0.80	UNA	0.75	1.00
Total Cost	$	351.63	559.98	1948.71	502.67	178.45	528.29	3347.13	2274.28
Cost of Infiltration Options	$	135.21	-	221.19	29.34	-	-	228.92	101.44
Cost of Conduction Options	$	216.42	559.98	1727.52	473.33	178.45	528.29	3118.21	2172.84
Cost of Heating System Options	$	-	-	-	-	-	-	-	-
Simple Payback Period	yr	8	42	44	-	-	3	14	74

* Thirty year "normal" degree days at base temperature 65°F.

NOTES:

1 "Normalized" to seven-year average (1973/80) Degree Days.
2 - values = savings; + values = increased consumption.
3 Values near 0.0 indicate little or no reported comfort change; values near 1.0 represent strong indications of comfort improvement.
4 = Unavailable

Table 30 (Cont.)

Atlanta Results

(3095 DD_{65})*

Control Houses

House Number		11	21
Measured Consumption Before	MBtu/yr	57.2	35.8
Measured Consumption After	MBtu/yr	52.5	18.9
Measured Consumption Before	$Btu/ft^2 \cdot DD$	9	16
Measured Consumption After	$Btu/ft^2 \cdot DD$	9	8
Measured Change	MBtu/yr	-4.7	-16.9
Percentage Change: Regression Analysis	%	-8	-47
Percentage Change: Tracking Method	%	UNA	UNA
Percentage Change: Load Calculations	%	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	0.0	UNA

Table 31

Charleston Results

($1904\ DD_{65}$) Weatherized Houses

House Number		2	3#	8#	16	18	20	23	25	33	39
Measured Consumption Before	MBtu/yr	70.0	61.4	59.1	60.8	58.7	48.0	56.8	49.3	69.1	76.6
Measured Consumption After	MBtu/yr	52.6	40.9	37.8	41.3	47.5	37.6	42.9	34.4	25.2	26.8
Measured Consumption Before	$Btu/ft^2 \cdot DD$	27	30	29	25	28	20	22	38	36	37
Measured Consumption After	$Btu/ft^2 \cdot DD$	21	20	18	17	22	15	16	27	13	13
Measured Change	MBtu/yr	-17.4	-20.5	-21.3	-19.5	-11.2	-10.4	-13.9	-14.9	-43.9	-49.8
Percentage Change Regression Analysis	%	-25	-33	-36	-32	-19	-22	-24	-30	-64	-65
Percentage Change Tracking Method	%	-21	UNA	-34	-38	-19	-23	-18	-30	UNA	-64
Percentage Change Load Calculations	%	-29	-5	-5	-22	-18	-14	-29	-16	-26	-12
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.80	0.50	UNA	0.50	0.50	0.25	UNA	0.75	0.75
Total Cost	$	740.75	926.66	965.78	1122.51	1231.06	1281.09	1600.11	837.07	773.47	1038.24
Cost of Infiltration Options	$	195.72	123.54	149.33	224.35	391.26	313.33	508.04	234.77	238.80	207.89
Cost of Conduction Options	$	545.03	732.65	730.35	898.16	839.80	959.76	1092.07	602.30	534.67	830.35
Cost of Heating System Options	$	-	70.47	86.10	-	-	-	-	-	-	-
Simple Payback Period	yr	4	5	5	6	12	13	12	6	2	2

NOTE: # Houses that received mechanical, as well as architectural options.

Table 31 (Cont.)

Charleston Results

($1904\ DD_{65}$) Weatherized Houses (Cont.)

House Number		44	47#	49#
Measured Consumption Before	MBtu/yr	50.3	35.2	33.5
Measured Consumption After	MBtu/yr	38.6	26.3	23.4
Measured Consumption Before	$Btu/ft^2 \cdot DD$	26	18	17
Measured Consumption After	$Btu/ft^2 \cdot DD$	20	13	12
Measured Change	MBtu/yr	-11.7	-8.9	-10.1
Percentage Change Regression Analysis	%	-23	-25	-30
Percentage Change Tracking Method	%	-34	-14	-35
Percentage Change Load Calculations	%	-27	UNA	-5
Composite Comfort Improvement Index	(0.0-1.0)	1.00	0.60	0.40
Total Cost	$	817.12	545.57	821.02
Cost of Infiltration Options	$	269.26	96.86	104.28
Cost of Conduction Options	$	547.86	338.94	606.97
Cost of Heating System Options	$	-	109.77	109.99
Simple Payback Period	yr	7	5	9

See note, page 79.

Table 31 (Cont.)

Charleston Results

(1904 DD_{65})

Control Houses

House Number		5	19	21	24	28
Measured Consumption Before	MBtu/yr	29.0	36.9	37.9	40.6	37.0
Measured Consumption After	MBtu/yr	25.5	31.9	27.5	25.6	43.2
Measured Consumption Before	$Btu/ft^2 \cdot DD$	11	24	17	32	12
Measured Consumption After	$Btu/ft^2 \cdot DD$	9	20	12	20	14
Measured Change	MBtu/yr	-3.5	-5.0	-10.4	-15.0	+6.2
Percentage Change: Regression Analysis	%	-12	-14	-27	-37	+17
Percentage Change: Tracking Method	%	-18	-4	-18	-23	+7
Percentage Change: Load Calculation	%	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.00	0.00	0.00	0.00

Table 32

Chicago Results

($6127\ DD_{65}$) Weatherized Houses

House Number		5#	9#	11#	12#	14#	19#	25#	29#	32#	38#
Measured Consumption Before	MBtu/yr	290.4	253.8	334.3	439.0	149.6	236.5	233.0	178.5	150.8	381.82
Measured Consumption After	MBtu/yr	189.0	97.2	260.8	122.4	70.8	133.2	156.3	68.4	177.7	275.6
Measured Consumption Before	$Btu/ft^2 \cdot DD$	28	24	30	63	12	16	34	18	10	29
Measured Consumption After	$Btu/ft^2 \cdot DD$	18	9	24	18	6	9	23	7	11	21
Measured Change	MBtu/yr	-101.4	-156.6	-73.5	-316.6	-78.8	-103.3	-76.7	-110.1	26.9	-106.2
Percentage Change Regression Analysis	%	-35	-62	-22	-72	-53	-44	-33	-62	18	-28
Percentage Change Tracking Method	%	-19	-18	-18	-50	-14	-27	-1	-21	-18	-28
Percentage Change Load Calculations	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Total Cost	$	1390.66	2757.97	1692.69	3976.21	813.01	3398.71	1803.46	2380.22	3434.09	1845.00
Cost of Infiltration Options	$	--	344.49	--	277.00	97.00	282.90	153.12	268.06	356.58	225.00
Cost of Conduction Options	$	--	1405.00	792.00	1818.00	480.00	2370.00	1048.68	1957.08	2331.50	1228.00
Cost of Heating System Options	$	1390.66	1008.48	900.69	1881.21	813.01	745.81	601.66	147.08	746.01	392.00
Simple Payback Period	yr	4	6	8	4	4	11	8	7	-	6

See note, page 79.

Table 33

Colorado Springs Results

($6473\ DD_{65}$) Weatherized Houses

House Number		7#	11#	13#	14#	17#	20#	23#	24#	26#	31#
Measured Consumption Before	MBtu/yr	116.6	88.8	75.2	99.9	106.6	82.5	185.3	255.5	145.7	149.3
Measured Consumption After	MBtu/yr	68.4	32.4	65.0	67.2	61.6	67.5	123.7	184.8	82.0	67.7
Measured Consumption Before	$Btu/ft^2 \cdot DD$	26	16	21	10	24	14	18	41	20	29
Measured Consumption After	$Btu/ft^2 \cdot DD$	15	6	19	7	14	12	12	30	11	13
Measured Change	MBtu/yr	-48.3	-56.4	-10.2	-32.7	-45.0	-15.0	-61.6	-70.7	-63.7	-81.6
Percentage Change Regression Analysis	%	-41	-64	-14	-33	-42	-18	-33	-28	-44	-55
Percentage Change Tracking Method	%	-24	-46	0	-30	-29	-13	-30	-30	-18	-47
Percentage Change Load Calculations	%	-45	-47	-62	-76	-63	-27	-58	-34	-55	-61
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	0.80	1.00	0.60	0.60	1.00	0.40	0.60	1.00
Total Cost	$	1591.21	1319.52	1081.52	2087.53	1878.84	954.40	2325.65	989.70	2348.26	2340.28
Cost of Infiltration Options	$	169.46	75.53	132.79	71.17	132.34	51.50	142.79	105.06	111.61	141.49
Cost of Conduction Options	$	1129.03	1207.99	948.73	1803.50	1576.50	732.90	1800.00	522.76	1669.08	1816.23
Cost of Heating System Options	$	292.72	36.00	-	212.86	170.00	170.00	382.86	361.88	567.57	382.86
Simple Payback Period	yr	14	10	43	26	17	26	16	6	15	12

See note, page 79.

Table 33 (Cont.)

Colorado Springs Results

(6473 DD_{65}) Weatherized Houses (Cont.)

House Number		37#	41#	43#	44#	47#	49#
Measured Consumption Before	MBtu/yr	147.0	83.2	117.1	141.6	181.5	136.5
Measured Consumption After	MBtu/yr	61.8	34.2	63.9	44.9	72.1	48.7
Measured Consumption Before	$Btu/ft^2 \cdot DD$	25	20	20	28	48	24
Measured Consumption After	$Btu/ft^2 \cdot DD$	10	8	11	9	19	9
Measured Change	MBtu/yr	-85.2	-49.0	-53.2	-96.7	-109.4	87.8
Percentage Change Regression Analysis	%	-58	-59	-45	-68	-60	-64
Percentage Change Tracking Method	%	-36	-35	-38	-47	-40	-57
Percentage Change Load Calculations	%	-58	-49	-34	-59	-68	-47
Composite Comfort Improvement Index	(0.0-1.0)	0.20	0.80	UNA	UNA	0.80	UNA
Total Cost	$	1655.14	1525.19	2056.46	2223.34	2308.13	1560.41
Cost of Infiltration Options	$	83.44	54.86	77.46	38.82	166.13	47.16
Cost of Conduction Options	$	1324.84	1190.33	1809.00	1801.65	1793.07	1137.53
Cost of Heating System Options	$	246.86	280.00	170.00	382.86	349.03	375.72
Simple Payback Period	yr	8	13	16	10	9	7

See note, page 79.

Table 33 (Cont.)

Colorado Springs Results

(6473 DD_{65})

Control Houses

House Number		1	5	8	10
Measured Consumption Before	MBtu/yr	137.7	286.1	90.2	145.1
Measured Consumption After	MBtu/yr	135.3	329.4	75.5	118.3
Measured Consumption Before	$Btu/ft^2 \cdot DD$	19	32	19	19
Measured Consumption After	$Btu/ft^2 \cdot DD$	19	37	16	15
Measured Change	MBtu/yr	-2.4	+43.3	-14.7	-26.8
Percentage Change: Regression Analysis	%	-2	+15	-16	-18
Percentage Change: Tracking Method	%	-2	+19	-12	-11
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	0.40	UNA	UNA	0.00

Table 34

Easton Results
($5827\ DD_{65}$) Weatherized Houses

House Number		4#	12#	20#	22#	23#	25#	27#	28#	31#	33#
Measured Consumption Before	MBtu/yr	125.8	136.2	36.7	121.9	122.2	146.0	110.4	103.4	87.1	90.8
Measured Consumption After	MBtu/yr	110.6	108.2	30.1	82.0	67.8	90.6	53.5	91.6	72.0	91.3
Measured Consumption Before	$Btu/ft^2 \cdot DD$	22	15	6	10	14	26	15	10	12	14
Measured Consumption After	$Btu/ft^2 \cdot DD$	19	12	5	7	8	16	7	9	10	14
Measured Change	MBtu/yr	-15.2	-28.0	-6.6	-39.9	-54.4	-55.4	-56.9	-11.8	-15.1	0.5
Percentage Change Regression Analysis	%	-12	-21	-18	-33	-45	-38	-52	-11	-17	+1
Percentage Change Tracking Method	%	0	-23	-8	-12	-18	-18	-42	-19	-7	-14
Percentage Change Load Calculations	%	-8	-29	-21	-44	-57	-11	-45	UNA	-53	-49
Composite Comfort Improvement Index	(0.0-1.0)	0.40	UNA	0.50	0.20	UNA	0.40	0.20	UNA	UNA	UNA
Total Cost	$	318.70	1631.72	1131.65	1384.04	1466.17	718.50	1057.04	1358.75	516.01	762.77
Cost of Infiltration Options	$	144.72	106.01	-	77.55	502.90	167.51	66.61	72.00	41.12	47.66
Cost of Conduction Options	$	118.62	1469.75	1131.65	1198.97	963.27	405.91	935.07	1089.53	336.70	550.67
Cost of Heating System Options	$	55.36	55.36	-	107.52	-	145.08	55.36	197.22	138.19	164.44
Simple Payback Period	yr	3	13	21	5	6	2	4	16	5	-

See note, page 79.

Table 34 (Cont.)

Easton Results

($5827\ DD_{65}$) Weatherized Houses (Cont.)

House Number		39#	42	44#
Measured Consumption Before	MBtu/yr	180.7	35.3	114.6
Measured Consumption After	MBtu/yr	174.3	29.3	67.7
Measured Consumption Before	$Btu/ft^2 \cdot DD$	17	8	15
Measured Consumption After	$Btu/ft^2 \cdot DD$	16	7	9
Measured Change	MBtu/yr	-6.4	-6.0	-46.9
Percentage Change Regression Analysis	%	-4	-17	-41
Percentage Change Tracking Method	%	-18	-10	UNA
Percentage Change Load Calculations	%	0	0	-15
Composite Comfort Improvement Index	(0.0-1.0)	0.00	0.25	UNA
Total Cost	$	274.74	24.17	1823.48
Cost of Infiltration Options	$	125.33	24.17	68.68
Cost of Conduction Options	$	-	-	1699.44
Cost of Heating System Options	$	149.41	-	55.36
Simple Payback Period	yr	6	1	9

See note, page 79.

Table 34 (Cont.)

Easton Results

(5827 DD_{65})

Control Houses

House Number		32	38	46
Measured Consumption Before	MBtu/yr	174.9	128.1	269.3
Measured Consumption After	MBtu/yr	160.9	125.2	232.1
Measured Consumption Before	$Btu/ft^2 \cdot DD$	20	15	33
Measured Consumption After	$Btu/ft^2 \cdot DD$	19	15	28
Measured Change	MBtu/yr	-14.0	-2.9	-37.2
Percentage Change: Regression Analysis	%	-8	-2	-14
Percentage Change: Tracking Method	%	UNA	-12	UNA
Percentage Change Load Calculations	%	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	0.00

Table 35

Fargo Results

(9271 DD_{65}) Weatherized Houses

House Number		2#	6#	10#	11#	15	17#	25#	27	30#	32#
Measured Consumption Before	MBtu/yr	101.3	128.2	116.0	124.0	114.1	115.7	111.5	70.4	117.3	110.6
Measured Consumption After	MBtu/yr	52.1	50.8	56.1	80.2	85.2	56.6	80.2	46.1	63.1	78.5
Measured Consumption Before	$Btu/ft^2 \cdot DD$	18	22	19	11	13	16	18	13	17	13
Measured Consumption After	$Btu/ft^2 \cdot DD$	9	9	9	7	9	8	13	9	9	9
Measured Change	MBtu/yr	-49.2	-77.4	-59.9	-43.8	-28.9	-59.1	-31.3	-24.3	-54.2	-32.1
Percentage Change Regression Analysis	%	-49	-60	-52	-35	-25	-51	-28	-35	-46	-29
Percentage Change Tracking Method	%	-36	-35	-13	-18	-43	-42	-12	-34	-40	-14
Percentage Change Load Calculations	%	-42	-62	-53	-47	-24	-26	-52	+9	UNA	-25
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.60	0.60	UNA	0.80	UNA	UNA	1.00	0.40	UNA
Total Cost	$	1268.67	2825.40	2429.02	1654.35	1365.57	1992.80	2161.48	1776.00	1454.62	1212.62
Cost of Infiltration Options	$	28.95	157.18	175.45	199.04	157.53	64.50	169.56	83.53	103.33	104.39
Cost of Conduction Options	$	1082.05	1349.05	1029.40	1401.14	1208.04	1615.63	1907.75	1692.47	1048.62	800.56
Cost of Heating System Options	$	157.67	1319.17	1224.17	54.17	-	312.67	84.17	-	302.67	307.67
Simple Payback Period	yr	4	5	6	5	7	5	10	11	4	6

See note, page 79.

Table 35 (Cont.)

Fargo Results

($9271\ DD_{65}$) Weatherized Houses (Cont.)

House Number		35	36#
Measured Consumption Before	MBtu/yr	125.1	79.6
Measured Consumption After	MBtu/yr	84.2	56.1
Measured Consumption Before	$Btu/ft^2 \cdot DD$	11	17
Measured Consumption After	$Btu/ft^2 \cdot DD$	7	12
Measured Change	MBtu/yr	-40.9	-23.5
Percentage Change Regression Analysis	%	-33	-30
Percentage Change Tracking Method	%	+24	-24
Percentage Change Load Calculations	%	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.80
Total Cost	$	311.95	1054.00
Cost of Infiltration Options	$	71.09	74.35
Cost of Conduction Options	$	240.86	934.65
Cost of Heating System Options	$	-	45.00
Simple Payback Period	yr	1	7

See note, page 79.

Table 35 (Cont.)

Fargo Results

(9271 DD_{65})

Control Houses

House Number		13	22	23	26	34
Measured Consumption Before	MBtu/yr	134.8	86.3	275.0	133.6	96.0
Measured Consumption After	MBtu/yr	124.8	87.2	221.7	123.7	98.9
Measured Consumption Before	$Btu/ft^2 \cdot DD$	16	19	19	16	13
Measured Consumption After	$Btu/ft^2 \cdot DD$	15	19	15	15	13
Measured Change	MBtu/yr	-10.0	+0.9	-53.3	-9.9	+2.9
Percentage Change: Regression Analysis	%	-7	+1	-19	-7	+3
Percentage Change: Tracking Method	%	-6.5	-2	-14	-12	-0.3
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	0.00	0.00	UNA	0.20	0.00

Table 36

Minneapolis/St. Paul Results

(8310 DD_{65}) Weatherized Houses

House Number		1	2	3	4	8#	13	20	21	23	26
Measured Consumption Before	MBtu/yr	145.0	169.3	96.0	186.6	192.6	311.6	154.5	211.2	354.0	195.2
Measured Consumption After	MBtu/yr	165.3	146.2	82.4	155.7	145.2	192.6	109.7	134.6	311.1	108.0
Measured Consumption Before	$Btu/ft^2 \cdot DD$	15	16	12	12	15	22	15	14	18	17
Measured Consumption After	$Btu/ft^2 \cdot DD$	17	14	10	10	11	14	10	9	16	10
Measured Savings	MBtu/yr	+20.3	-23.1	-13.6	-30.9	-47.4	-119.0	-44.8	-76.6	-42.9	-87.2
Percentage Change: Regression Analysis	%	+14	-14	-14	-17	-25	-38	-29	-36	-12	-45
Percentage Change: Tracking Method	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Percentage Change: Load Calculations	%	-47	-39	-18	-35	-22	-35	-51	-31	-50	-45
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Total Cost*	$										
Cost of Infiltration Options	$										
Cost of Conduction Options	$										
Cost of Heating System Options	$										
Simple Payback Period	yr										

* Complete cost data never was received from this site. # See note, page 79.

Table 36 (Cont.)

Minneapolis/St. Paul Results

($8310\ DD_{65}$) Weatherized Houses (Cont.)

House Number		33	34	40	42	44	45	46	
Measured Consumption Before	MBtu/yr	172.0	131.0	106.0	173.3	148.1	182.5	147.2	
Measured Consumption After	MBtu/yr	109.4	122.2	68.9	164.0	91.6	159.7	141.4	
Measured Consumption Before	$Btu/ft^2 \cdot DD$	31	7	11	18	14	17	18	
Measured Consumption After	$Btu/ft^2 \cdot DD$	20	6	7	17	8	15	17	
Measured Savings	MBtu/yr	-62.6	-8.8	-37.1	-9.3	-56.5	-22.8	-5.8	
Percentage Change: Regression Analysis	%	-36	-7	-35	-5	-38	-12	-4	
Percentage Change: Tracking Method	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	
Percentage Change: Load Calculations	%	-18	-30	-42	-26	-48	-52	-57	
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA	UNA	UNA	UNA	
Total Cost*	$								
Cost of Infiltration Options	$								
Cost of Conduction Options	$								
Cost of Heating System Options	$								
Simple Payback Period	yr								

See note, page 79.

Table 36 (Cont.)

Minneapolis/St. Paul Results (Cont.)

(8310 DD_{65})

Control Houses

House Number		25	28	31	36	37
Measured Consumption Before	MBtu/yr	161.5	135.5	422.7	366.6	344.4
Measured Consumption After	MBtu/yr	164.8	110.8	356.1	306.6	375.0
Measured Consumption Before	$Btu/ft^2 \cdot DD$	16	11	13	12	21
Measured Consumption After	$Btu/ft^2 \cdot DD$	16	9	11	10	23
Measured Change	MBtu/yr	+3.3	-24.7	-66.6	-60.0	+30.6
Percentage Change: Regression Analysis	%	+2	-18	-16	-16	+9
Percentage Change: Tracking Method	%	+2	-16	-15	-16	-8
Percentage Change: Load Calculation	%	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA	UNA

Table 37

Oakland Results

(2909 DD_{65})

Weatherized Houses

House Number		17	19	26	31	33	34	35	38
Measured Consumption Before	MBtu/yr	51.8	82.8	141.5	83.1	66.4	75.6	30.1	77.6
Measured Consumption After	MBtu/yr	44.6	78.1	168.5	89.9	63.9	64.2	29.7	52.7
Measured Consumption Before	$Btu/ft^2 \cdot DD$	27	9	46	36	17	25	13	18
Measured Consumption After	$Btu/ft^2 \cdot DD$	23	8	55	39	17	21	13	12
Measured Change	MBtu/yr	-7.2	-4.7	+27	+6.8	-2.5	-11.4	-0.4	-24.9
Percentage Change: Regression Analysis	%	-14	-6	+19	+8	-4	-15	-1	-32
Percentage Change: Tracking Method	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	0.40	UNA	0.40	UNA	0.00	0.40	0.0	0.75
Total Cost	$	186.77	304.83	276.79	234.18	207.22	230.75	280.70	472.58
Cost of Infiltration Options	$	40.77	85.48	73.08	124.43	52.84	102.01	190.00	272.86
Cost of Conduction Options	$	146.00	219.35	203.71	109.75	154.88	128.74	90.70	199.72
Cost of Heating System Options	$	-	-	-	-	-	-	-	-
Simple Payback Period	yr	4	10	-	-	12	3	104	3

Table 37 (Cont.)

Oakland Results

(2909 DD_{65})

Control Houses

House Number		5	6	9	37
Measured Consumption Before	MBtu/yr	111.2	140.2	102.5	113.5
Measured Consumption After	MBtu/yr	141.4	120.9	136.5	114.6
Measured Consumption Before	$Btu/ft^2 \cdot DD$	26	44	40	37
Measured Consumption After	$Btu/ft^2 \cdot DD$	33	38	54	38
Measured Change	MBtu/yr	+30.2	-19.3	+34.0	+1.1
Percentage Change: Regression Analysis	%	+27	-14	+33	+1
Percentage Change: Tracking Method	%	UNA	UNA	UNA	UNA
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	0.0-1.0	0.00	0.00	0.00	UNA

Table 38

Portland Results

(7493 DD_{65})   Weatherized Houses

House Number		7#	9#	10	11#	12#	15#	16#	17#	20#	21#
Measured Consumption Before	MBtu/yr	172.1	173.9	101.7	154.5	246.6	195.0	157.7	102.8	175.1	73.1
Measured Consumption After	MBtu/yr	76.7	83.7	91.2	69.8	78.9	235.9	111.6	59.8	91.2	39.3
Measured Consumption Before	$Btu/ft^2 \cdot DD$	17	14	18	18	38	16	12	13	24	21
Measured Consumption After	$Btu/ft^2 \cdot DD$	7	7	16	8	12	19	5	UNA	12	11
Measured Change	MBtu/yr	-95.4	-90.2	-10.5	-84.7	-167.7	+40.9	-46.1	-43.0	-83.9	-33.8
Percentage Change: Regression Analysis	%	-55	-52	-10	-55	-68	+20	-29	-42	-48	-46
Percentage Change: Tracking Method	%	-43	UNA	-30	-53	-25	UNA	UNA	UNA	-51	-35
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Total Cost	$	2411.00	1565.01	849.23	2362.82	3839.63	2098.97	1926.26	2698.48	1913.92	2718.81
Cost of Infiltration Options	$	50.00	124.01	143.53	169.62	164.95	24.20	154.50	668.00	171.16	173.94
Cost of Conduction Options	$	1366.00	1261.00	705.70	1188.20	2179.68	1874.77	1571.76	1433.48	1165.76	1414.87
Cost of Heating System Options	$	995.00	180.00	-	995.00	1495.00	200.00	200.00	597.00	577.00	1130.00
Simple Payback Period	yr	4	2	19	4	3	-	6	9	3	11

See note, page 79.

Table 38 (Cont.)

Portland Results

($7493\ DD_{65}$) Weatherized Houses (Cont.)

House Number		23#	25#	26#	28#						
Measured Consumption Before	MBtu/yr	203.1	351.9	193.7	321.2						
Measured Consumption After	MBtu/yr	130.5	149.8	86.4	170.7						
Measured Consumption Before	$Btu/ft^2 \cdot DD$	15	27	15	12						
Measured Consumption After	$Btu/ft^2 \cdot DD$	9	12	7	6						
Measured Change	MBtu/yr	-72.6	-202.1	-107.3	-150.5						
Percentage Change: Regression Analysis	%	-36	-57	-55	-47						
Percentage Change: Tracking Method	%	-30	-59	-47	UNA						
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA						
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA						
Total Cost	$	1981.21	1710.03	1533.56	3406.55						
Cost of Infiltration Options	$	296.85	74.32	223.64	40.00						
Cost of Conduction Options	$	1459.36	1128.71	1104.92	2863.14						
Cost of Heating System Options	$	225.00	507.00	205.00	180.00						
Simple Payback Period	yr	4	1	2	3						

See note, page 79.

Table 38 (Cont.)

Portland Results

(7493 DD_{65})

Control Houses

House Number		29	30	31	33						
Measured Consumption Before	MBtu/yr	222.1	203.8	272.8	231.1						
Measured Consumption After	MBtu/yr	216.2	108.1	296.2	194.8						
Measured Consumption Before	Btu/ft•DD		14	14	14						
Measured Consumption After	$Btu/ft^2 \cdot DD$		7	16	12						
Measured Change	Btu/yr	-5.9	-95.7	+23.4	-36.3						
Percentage Change: Regression Analysis	%	-3	-47	+9	-16						
Percentage Change: Tracking Method	%	UNA	UNA	UNA	UNA						
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA						
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	UNA	UNA						

Table 39

St. Louis Results

(4750 DD_{65})

Weatherized Houses

House Number		5	6	7	17	28	29	34	38	40	41
Measured Consumption Before	MBtu/yr	71.1	259.1	166.3	135.4	209.0	296.0	188.9	185.1	83.5	191.6
Measured Consumption After	MBtu/yr	87.1	287.7	86.4	166.5	225.0	360.3	108.7	146.6	163.5	205.4
Measured Consumption Before	$Btu/ft^2 \cdot DD$	14	37	51	15	24	27	33	25	9	39
Measured Consumption After	$Btu/ft^2 \cdot DD$	18	41	26	18	26	33	19	20	18	42
Measured Change	MBtu/yr	+16.0	+28.6	-79.9	+31.1	+16.0	+64.3	-80.2	-38.5	+80.0	+13.8
Percentage Change: Regression Analysis	%	+22	+11	-48	+23	+8	+22	-42	-21	+96	+7
Percentage Change: Tracking Method	%	UNA	+13	-35	0	UNA	UNA	0	-16	UNA	-20
Percentage Change: Load Calculations	%	-64	-14	-46	-28	-25	-8	-50	-42	-29	-18
Composite Comfort Improvement Index	(0.0-1.0)	0.40	1.00	0.80	0.80	0.80	0.60	1.00	UNA	0.60	1.00
Total Cost	$	1851.46	653.61	3550.00	232.00	1334.25	337.84	3269.85	2875.06	1026.55	1179.72
Cost of Infiltration Options	$	19.42	20.89	42.39	-	50.33	49.89	34.39	30.45	33.12	34.52
Cost of Conduction Options	$	1832.04	632.72	3507.61	232.00	1283.92	264.61	3235.46	2844.61	993.43	1145.20
Cost of Heating System Options	$	-	-	-	-	-	-	-	-	-	-
Simple Payback Period	yr	-	-	19	-	-	-	17	32	-	-

Table 39 (Cont.)

St. Louis Results

(4750 DD_{65})

Weatherized Houses (Cont.)

House Number		42	46	49	55	56	77	92	93	
Measured Consumption Before	MBtu/yr	160.3	137.5	254.7	110.7	114.4	221.5	183.6	175.9	
Measured Consumption After	MBtu/yr	102.8	169.1	169.5	67.4	84.2	162.7	152.1	86.9	
Measured Consumption Before	$Btu/ft^2 \cdot DD$	27	14	40	30	27	34	37	29	
Measured Consumption After	$Btu/ft^2 \cdot DD$	17	17	27	18	20	25	30	14	
Measured Change	MBtu/yr	-57.5	31.6	-85.2	-43.3	-30.2	-58.8	-31.5	-89.0	
Percentage Change: Regression Analysis	%	-36	23	-33	-39	-26	-27	-17	-51	
Percentage Change: Tracking Method	%	-38	UNA	-26	-25	-13	-40	-19	-45	
Percentage Change: Load Calculations	%	UNA	-19	-52	-62	-47	-41	-29	-59	
Composite Comfort Improvement Index	(0.0-1.0)	1.00	0.60	0.40	1.00	0.80	0.20	0.40	1.00	
Total Cost	$	1953.49	687.72	2586.46	1853.25	1588.29	3213.85	997.68	2870.26	
Cost of Infiltration Options	$	19.49	23.78	30.77	29.31	27.81	56.24	20.52	20.38	
Cost of Conduction Options	$	1934.00	663.94	2555.69	1823.93	1560.48	3157.61	977.16	2849.88	
Cost of Heating System Options	$	-	-	-	-	-	-	-	-	
Simple Payback Period	YR	14	-	13	18	22	23	13	14	

Table 39 (Cont.)

St. Louis Results

(4750 DD_{65})

Control Houses

House Number		10	23
Measured Consumption Before	MBtu/yr	353.1	91.2
Measured Consumption After	MBtu/yr	398.2	116.8
Measured Consumption Before	$Btu/ft^2 \cdot DD$	52	9
Measured Consumption After	$Btu/ft^2 \cdot DD$	58	12
Measured Change	MBtu/yr	+45.1	+25.6
Percentage Change: Regression Analysis	%	+13	+28
Percentage Change: Tracking Method	%	+12	+32
Percentage Change: Load Calculations	%	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	0.40	0.20

Table 40

Tacoma Result

($5185\ DD_{65}$) Weatherized Houses

House Number		4	21#	39#	45	49	55#	81	83#	87#
Measured Consumption Before	MBtu/yr	85.7	160.8	83.3	120.4	78.8	110.2	96.4	91.1	63.9
Measured Consumption After	MBtu/yr	63.0	74.2	41.6	47.2	50.3	55.5	69.9	41.6	41.7
Measured Consumption Before	$Btu/ft^2 \cdot DD$	15	19	17	26	24	23	18	16	23
Measured Consumption After	$Btu/ft^2 \cdot DD$	11	9	8	10	15	12	13	7	15
Measured Change	MBtu/yr	-22.7	-86.6	-41.7	-73.2	-28.5	-54.7	-26.5	-49.5	-22.2
Percentage Change: Regression Analysis	%	-26	-54	-50	-61	-36	-50	-27	-54	-35
Percentage Change: Tracking Method	%	-18	-23	-40	-40	-34	-49	-22	-41	-27
Percentage Change: Load Calculations	%	-70	-62	-69	-65	-52	-49	UNA	-39	-67
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.40	UNA	UNA	UNA	UNA	UNA	UNA	UNA
Total Cost	$	1210.10	2549.74	1550.90	2476.32	1178.48	2287.36	1379.66	2340.12	1291.48
Cost of Infiltration Options	$	50.06	117.53	57.67	1160.08	106.95	273.45	56.59	41.95	87.19
Cost of Conduction Options	$	1160.04	2355.91	1491.25	1316.26	1071.53	1985.74	1323.07	2087.08	1178.82
Cost of Heating System Options	$	-	76.32	1.98	-	-	28.17	-	211.09	25.47
Simple Payback Period	yr	10	6	7	8	9	9	10	10	13

See note, page 79.

Table 40 (Cont.)

Tacoma Results

(5185 DD_{65})

Control Houses

House Number		37	58	75	76	98
Measured Consumption Before	MBtu/yr	30.4	71.2	29.9	86.4	79.6
Measured Consumption After	MBtu/yr	32.2	43.8	31.5	80.1	62.8
Measured Consumption Before	$Btu/ft^2 \cdot DD$	UNA	UNA	5	12	11
Measured Consumption After	$Btu/ft^2 \cdot DD$	UNA	UNA	6	11	9
Measured Change	MBtu/yr	+1.8	-27.4	+1.6	-6.3	-16.8
Percentage Change: Regression Analysis	%	+6	-38	+5	-7	-21
Percentage Change: Tracking Method	%	+4	-1		-11	-29
Percentage Change: Load Calculations	%	UNA	UNA	UNA	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	0.00	UNA	UNA

Table 41

Washington Results

($4211\ DD_{65}$) Weatherized Houses

House Number		2#	7#	41#	53#
Measured Consumption Before	MBtu/yr	87.9	104.8	80.2	249.2
Measured Consumption After	MBtu/yr	39.5	72.3	48.2	116.5
Measured Consumption Before	$Btu/ft^2 \cdot DD$	31	24	17	77
Measured Consumption After	$Btu/ft^2 \cdot DD$	14	16	10	36
Measured Change	MBtu/yr	-48.4	-32.5	-32.0	-132.7
Percentage Change: Regression Analysis	%	-55	-31	-40	-53
Percentage Change: Tracking Method	%	-41	UNA	UNA	-45
Percentage Change: Load Calculations	%	-69	-66	-59	-56
Composite Comfort Improvement Index	(0.0-1.0)	UNA	UNA	0.75	UNA
Total Cost	$	2692.64	3593.30	2338.88	3070.59
Cost of Infiltration Options	$	185.80	267.49	198.90	178.91
Cost of Conduction Options	$	2371.84	2920.81	1168.98	2336.68
Cost of Heating System Options	$	135.00	405.00	971.00	555.00
Simple Payback Period	yr	7	15	9	13

See note, page 79.

Table 41 (Cont.)

Washington Results

(4211 DD_{65})

Control Houses

House Number		6	57
Measured Consumption Before	MBtu/yr	68.1	83.9
Measured Consumption After	MBtu/yr	78.2	143.8
Measured Consumption Before	Btu/ft^2•DD	16	22
Measured Consumption After	Btu/ft^2•DD	18	37
Measured Change	MBtu/yr	+10.1	+59.9
Percentage Change: Regression Analysis	%	+15	+71
Percentage Change: Tracking Method	%	+6	+67
Percentage Change: Load Calculation	%	UNA	UNA
Composite Comfort Improvement Index	(0.0-1.0)	UNA	0.60

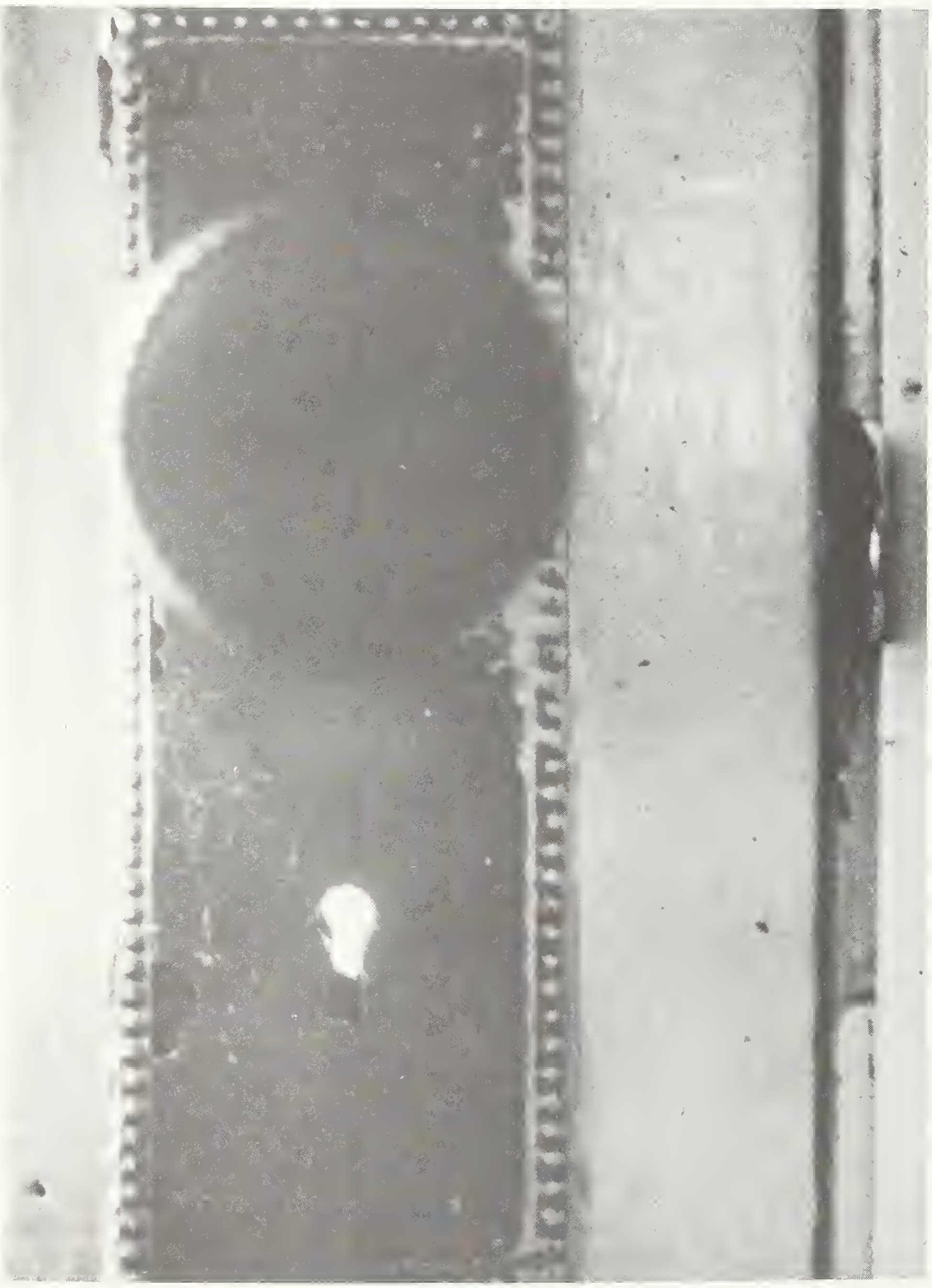
Table 42

Fuel Unit to MBtu Conversion Factors Used

1 gal. of oil	= 138,700 Btu
1 gal. of kerosene	= 135,000 Btu
1 kWh	= 3,413 Btu
100 ft^3 of gas	= 103,000 Btu
1 therm of gas	= 100,000 Btu
1 gal. of propane	= 91,300 Btu
1 SFC* of propane	= 252,100 Btu

*Standard Cubic Foot

● An often overlooked problem
in a Colorado Springs house.



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A P P E N D I C E S

APPENDIX A

BUILDING DATA

The tables presented in this appendix give descriptive data about the houses, and the input and interim results data of the thermal load calculations. Where assumed values had to be employed, they are so indicated with an asterisk (*).

As asterisk beside a house number signifies that pre/post energy consumption comparisons are confounded by a change of occupants of the house during the measurement period.

Symbols and Units Used in the Tables

Construction Type	D1	Detached, One story
	D1.5	Detached, 2nd floor partly occupied
	D2	Detached, Two story
	A	Attached (row or duplex)
	FR	Frame
	MV	Masonry veneer
	M	Masonry (8" of brick or block)
Heating System Type	AF	Forced air
	AG	Gravity air
	WP	Circulated water
	WG	Gravity water
	F	Floor furnace
	V	Vented space (room) heater
	U	Unvented space heater
	S	Space heater (type?)
	BB	Electric baseboard
	/	Indicates the heating system was replaced with a different type during the Demonstration.
Fuel Types	G	Natural gas
	O	Oil
	E	Electricity
	P	Bottled gas (propane or LPG)
	K	Kerosene

All areas are listed in square feet; all volumes in cubic feet.

Foundation Type	B	Basement
	S	Slab
	C	Crawl space
Roof Type	G	Gable
	H	Hip
	F	Flat
	M	Mansard

Age -- of the building at time of admission to the Demonstration (1977, for most).

Number of occupants	A slash (/) indicates change during the demonstration
Infiltration Rate	Air changes per hour
Solar, Interior gains	MBtu per year

On houses with orientation SE, SW, NE, NW, area of window S equals area of window SE and SW and area of window E + W equals area of window NE and NW.

Solar gains were calculated using window areas and solar data from NBS BSS 96* [15].

Internal gains were assumed 19.40 MBtu per year, the default value used in DOE-2.

Note: Since no thermal calculations were ever carried out for the non-weatherized control houses, they do not appear in these tables. However, the floor areas of these houses can be found in the Key Data tables in reference [4].

ATLANTA

HOUSE NUMBER	1	2	17	22	23	29
GENERAL DATA						
Construction Type	Dl FR	Dl FR	Dl MV	Dl FR	Dl M	Dl M
Htg. System Type	U,V	U,V	BB	F	AF	AF
Fuel Space Htg.	G	G	E	G	G	G
Fuel Hot Water	E	E	E	G	G	G
Living Space	869	1392	1014	1170	835	1110
Volume	6948	13923	8110	9363	6680	8877
Foundation Type	C	C	C	C	C	C
Roof Type	G	H	G	G	G	G
Orientation	N	E	NE	W	E	E
Age	65	99	8	27	16	64
Number of Occupants	1	2/1	3	2	2/6	2
Surface Area	2139.40	3378.00	2346.25	2633.00	1983.00	2381.00
Area of Glass	85.26	181.29	112.09	90.09	208.90	91.07
Area Window S	19.37	57.03	62.04	3.59	17.08	0
Area Window E + W	41.01	91.25	19.80	68.18	157.66	69.57
Area Doors	55.00	37.82	37.79	34.30	27.42	37.52
Area Walls	805.02	1289.00	890.12	976.00	697.00	961.30
Area Basement Walls	334.40	452.00	299.00	367.00	218.00	182.00
Area Floor	-	-	-	-	-	-
Area Roof	859.70	1417.00	1007.25	1165.00	831.00	1110.20
BEFORE WEATHERIZATION						
UA+	778.7	1357.0	839.1	844.3	731.6	867.0
R-Value Walls	3.50	3.54	3.98	4.87	3.35	3.17
R-Value Windows	1.01	1.01	1.01	1.01	2.00	1.01
R-Value Floor	-	-	-	-	-	-
R-Value Basement	1.89	1.89	1.89	2.69	1.89	1.89
R-Value Roof	6.66	5.40	3.70	6.33	6.04	5.86
R-Value Door	2.04	2.04	2.04	2.04	2.04	2.04
Infiltration Rate	1.05*	1.17	.38*	1.29*	1.27	1.06
Htg. System Eff.	1.00	1.00	1.00	.70	.57	.55
Solar Gains	14.20*	35.33*	20.59*	16.20*	39.62*	15.52*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	76	68	73	71	72	75
AFTER WEATHERIZATION						
UA+	637.4	875.4	224.8	563.5	665.8	486.8
R-Value Walls	3.50	3.54	14.98	4.87	3.35	14.17
R-Value Windows	2.22	2.00	3.22	2.00	1.43	2.00
R-Value Floor	-	-	-	-	-	-
R-Value Basement	1.89	8.89	8.89	9.69	1.89	8.89
R-Value Roof	25.45	24.40	34.70	25.33	25.04	24.86
R-Value Door	2.04	2.04	2.04	2.04	2.04	2.04
Infiltration Rate	1.05*	1.17	.38	1.29	1.27*	1.06*
Htg. System Eff.	1.00	1.00	1.00	.70	.59	.62
Solar Gains	14.20*	35.23*	20.59*	16.20*	39.62*	15.52*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	76	68	73	71	72	75

* Indicates assumed values.
\+ Conduction + infiltration.

ATLANTA

31	32

D1 M	D1 FR,MV
U(2)	BB
P	E
E	E
900	1147
7200	9176
C	C
H	G
E	S
23	10
3	5
2760.00	2552.00
231.10	224.40
51.23	96
113.40	96
36.12	39.48
692.80	936.40
-	316.90
900.00	-
900.00	1147.00

1498.3	968.7
7.63	3.20
1.01	1.01
-	-
1.63	1.89
6.18	6.01
2.04	2.04
.89*	.46*
1.00	1.00
38.66*	46.45*
19.40*	19.40*
72	75

1183.9	425.3
12.78	15.20
3.22	3.22
-	-
8.63	8.89
36.18	37.01
2.04	2.04
.89	.46
1.00	1.00
38.66*	46.45*
19.40*	19.40*
72	75

CHARLESTON

HOUSE NUMBER	2	3	8	16	18	20	23
GENERAL DATA							
Construction Type	D1 FR	D1 M	D1 M	D1 M	D1 M	D1 M	D1 MV
Htg. System Type	U	V	V	V	U(2)	U(4	U(2)
Fuel Space Htg.	P	P	P	P	P	P	P
Fuel Hot Water	P	E	E	E	N	E	E
Living Space	1344	1088	1088	1276	1120	1288	1368
Volume	10752	8704	8704	9688	8960	10304	10944
Foundation Type	C	S	S	C	C	C	C
Roof Type	G	G	G	G	G	H	G
Orientation	N	SE	SE	S	N	E	W
Age	20	7	7	7	10	12	31
Number of Occupants	2	6/2*	8	6	8/7	7	3
Surface Area	3872.00	2668.00	2668.00	3864.00	2389.00	2694.00	3041.00
Area of Glass	140.50	108.60	107.10	137.00	145.30	190.50	172.50
Area Window S	35.50	68.80	67.30	34.00	50.20	56.60	45.00
Area Window E + W	63.00	39.80	39.80	87.00	40.50	79.40	101.20
Area Doors	35.40	37.70	37.70	80.00	40.00	35.40	55.40
Area Walls	1008.10	1021.70	1023.20	1095.00	766.70	810.10	1068.10
Area Basement Walls	-	292.00	292.00	-	316.90	370.00	377.00
Area Floor	1344.00	-	-	1276.00		-	-
Area Roof	1344.00	1208.00	1208.00	1277.00	1120.00	1288.00	1368.00
BEFORE WEATHERIZATION							
UA	1400.8	911.5	874.6	1203.4	891.7	1004.4	1360.0
R-Value Walls	3.17	3.48	3.46	3.46	3.59	3.46	2.53
R-Value Windows	1.01	1.01	1.01	1.01	1.01	1.01	1.01
R-Value Floor	2.90	-	-	3.84	-	-	-
R-Value Basement	-	1.15	1.15	-	1.89	1.89	1.89
R-Value Roof	5.84	17.15	16.77	6.43	6.42	6.57	5.54
R-Value Door	2.22	2.04	2.04	2.04	2.04	2.04	2.04
Infiltration Rate	1.21*	1.07*	.82*	1.04*	1.07*	.93	1.49
Htg. System Eff.	1.00	.66	.57	1.00	1.00	1.00	1.00
Solar Gains	24.03*	24.78*	24.38*	29.08*	22.94*	33.59*	35.32*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	69	73	68	71	64	72
AFTER WEATHERIZATION							
UA	858.0	622.0	624.1	808.9	627.4	741.4	830.4
R-Value Walls	3.17	3.48	3.46	3.46	3.59	3.46	2.53
R-Value Windows	1.01	1.01	1.01	1.01	1.01	1.01	1.01
R-Value Floor	13.90	-	-	14.84	-	-	-
R-Value Basement	-	9.15	9.15	-	9.39	9.39	9.39
R-Value Roof	24.84	28.15	27.77	25.43	25.42	25.51	24.47
R-Value Door	2.22	2.04	2.04	2.04	2.04	2.04	2.04
Infiltration Rate	1.21	1.07	.82	1.04	1.07	1.14	.58
Htg. System Eff.	1.00	.59	.50	1.00	1.00	1.00	1.00
Solar Gains	24.03*	24.78*	24.38*	29.08*	22.94*	33.59*	35.32*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	69	73	68	71	64	72

CHARLESTON

25	33	39	44	47	49
D1 M	D1 FR	D1 MV	D1 FR	D1 MV	D1 MV
U(2)	U,V	U	U,V	BB	V
P	P,K	P	P,O	E	P
-	P	-	E	E	E
675	1020	1092	1020	1040	1026
5400	8160	8736	7140	8320	8208
C	C	C	C	C	C
G	G	G	G	G	G
NE	E	SE	N	?	N
20	55	46	12	6	6
3	3	2/1	2	5	5
1749.00	3176	2588	2936	2481	2413
100.50	148.00	220.00	95.60	109.80	115.20
35.60	36.00	108.00	17.80	17.20	25.90
64.90	85.00	112.00	42.20	68.60	38.80
35.40	36.00	37.70	37.70	37.70	37.70
696.10	952.00	830.30	762.70	908.50	866.60
242.00	-	408.00	-	-	347.10
-	1020.00	-	1020.00	1040.00	-
675.00	1020.00	1092.00	1020.00	1040.00	1026.00

775.1	1066.9	971.5	953.0	759.63	686.7
3.46	3.48	4.08	3.23	10.31	14.61
1.01	1.01	1.01	1.01	1.01	1.01
-	2.93	-	3.33	2.93	-
1.89	-	2.69	-	-	1.65
6.23	6.47	6.51	6.43	24.41	16.41
2.04	2.04	2.04	2.04	2.04	2.04
2.27	.84*	1.35*	1.08*	.98	1.49*
1.00	.84	1.00	1.00	1.00	.63
26.79*	29.17*	46.72*	14.46*	20.30*	15.91*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
70	68	68	75	70	65

557.2	674.4	733.4	599.4	479.34	480.8
3.46	3.48	4.08	3.23	10.31	14.61
1.01	1.01	1.01	1.01	2.00	1.01
-	13.93	-	14.33	13.93	-
9.39	-	10.59	-	-	9.15
25.23	25.47	25.51	25.43	24.41	35.41
2.04	2.04	2.04	2.04	2.04	2.04
1.92	.84	1.35	1.08	.98	1.49
1.00	.84	1.00	1.00	1.00	.54
26.79*	29.17*	46.72*	14.46*	20.30*	15.91*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
70	68	68	75	70	65

COLORADO SPRINGS

House Number	7	11	13	14	17	20	23	24
GENERAL DATA								
Construction Type	D1 FR	D1 FR	D1 FR	D2 FR,MV	D1 FR	D1 FR	D2 FR	D1 FR
Htg. System Type	AF	AF	F	AF	F	F,V	AF	AF
Fuel Space Htg.	G	G	G	G	G	G	G	G
Fuel Hot Water	G	G	G	G	G	G	G	G
Living Space	688	833	541	1552	682	891	1568	966
Volume	5323	6664	4351	11949	5453	7841	12150	8696
Foundation Type	B,C	C	BC	B	B,C	B,C	B	B,C
Roof Type	G	G	G	G	F	G	G	H
Orientation	S	SE	S	W	S	S	E	W
Age	60	6	30	6	65	78	6	74
Number of Occupants	2	1/2	1	8/7	2	2/1	2/7	2
Surface Area	2117.20	2610	1438	2497	1874	3132	2541	3200
Area of Glass	130.70	95.24	69.58	165.60	139.80	105.21	156.00	278.50
Area Window S	22.50	49.65	24.34	0	30.34	28.08	0	97.80
Area Window E + W	82.60	45.59	36.20	165.60	83.31	66.65	156.00	116.50
Area Doors	18.50	42.54	20.75	26.60	32.82	34.98	38.20	19.50
Area Walls	855.40	806.20	658.30	1290.00	626.80	1039.00	1293.00	892.00
Area Basement Walls	128.40	-	148.80	240.00	143.80	-	270.00	178.50
Area Floor	296.40	833.00	-	-	389.80	976.40	-	704.60
Area Roof	687.50	833.00	540.50	775.90	540.90	976.40	783.90	1127.50
BEFORE WEATHERIZATION								
UA	531.05	445.9	428.3	459.9	775.3	809.4	617.8	888.5
R-Value Walls	4.87	11.58	3.43	12.90	4.01	3.77	18.20	4.54
R-Value Windows	1.95	1.61	1.96	1.32	1.43	1.71	1.20	1.55
R-Value Floor	5.07	4.17	-	-	3.70	3.04	-	4.38
R-Value Basement	1.81	-	2.45	2.27	1.49	-	3.37	2.13
R-Value Roof	10.50	18.09	7.67	16.71	2.32	18.60	15.88	6.99
R-Value Door	3.03	2.30	2.04	2.04	2.04	2.28	2.04	2.53
Infiltration Rate	.91	.44	.76	.62	.71	.59	1.21	.63
Htg. System Eff.	.60	.56	.57	.56	.55	.60	.60	.60
Solar Gains	29.52*	24.01*	17.97*	43.50*	32.43*	27.27*	40.98	64.59*
Interior Gains	19.40	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	70	68	71	71	70	76	74
AFTER WEATHERIZATION								
UA	333.6	288.6	198.0	265.9	339.0	676.3	409.5	718.9
R-Value Walls	11.87	21.01	14.43	18.70	17.00	16.70	23.15	4.54
R-Value Windows	2.02	2.22	2.22	2.02	1.79	2.03	2.22	2.02
R-Value Floor	5.07	11.17	-	-	3.70	3.04	-	4.38
R-Value Basement	8.81	-	9.45	10.13	8.49	-	10.30	2.13
R-Value Roof	31.51	36.09	37.42	34.71	11.91	20.40	33.38	27.23
R-Value Door	3.03	2.30	2.04	2.04	2.04	2.28	2.04	2.53
Infiltration Rate	1.00	.76	1.03	.50	.41	1.26	.97	.58
Htg. System Eff.	.66	.65	.66	.66	.63	.66	.67	.70
Solar Gains	29.52*	24.01*	17.97*	43.50*	32.43*	27.27*	40.98*	64.59*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	70	68	71	71	70	76	74

COLORADO SPRINGS

26	31	37	41	43	44	47	49
D1.5 FR	D2 FRMV	D1 FR	D1 FRMV	D1 FR	D2 FR	D1 FR	D1 FR,MV
AF	AF	AF	AF	AF	AF	AF	AF
G	G	G	G	G	G	G	G
G	G	G	G	G	G	G	G
1136	1581	915	649	923	1572	585	884
9298	12254	7415	5188	7386	12265	4736	7072
BC	B	BC	C	B	B	BC	B
G	G	G	G	G	G	G	G
N	N	S	SE	SW	NE	E	NW
75	7	60	7	15	8	70	6
2	5/3	1	4	1/2	7/5	1	4
2174	2531	2267.70	1667.00	2006.00	2565.00	1940.70	2057.00
158.00	158.00	247.14	89.30	100.80	166.80	225.70	88.10
22.60	81.21	41.70	50.60	58.20	83.00	69.35	37.80
99.70	0	156.10	38.70	42.60	83.80	130.16	50.30
19.30	32.32	43.90	37.30	40.00	32.40	25.80	39.00
1007.50	1279.00	703.60	687.00	832.00	1233.00	719.70	849.00
282.70	271.00	357.60	-	109.40	336.00	275.90	-
-	-	-	648.60	-	-	-	884.00
706.60	790.60	915.00	648.60	923.00	786.20	693.50	884.00

751.8	551.2	636.2	470.3	318.2	488.0	846.7	457.8
4.31	11.53	4.31	12.34	11.02	12.34	3.94	11.83
1.44	1.27	1.70	1.63	1.69	1.28	1.19	1.62
-	-	-	4.15	-	-	-	-
2.13	1.69	1.81	-	1.47	2.57	1.47	4.15
6.06	17.95	28.99	17.93	17.95	16.94	5.42	5.91
2.30	2.04	2.09	2.47	2.50	2.55	2.49	2.04
.90	.84	.58	1.12	.31	.60	1.74	1.28
.61	.55	.62	.61	.58	.56	.61	.62
34.04*	28.22*	55.50*	23.20*	26.36*	41.41*	58.29*	20.86*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
71	73	68	73	66	70	75	71

367.8	265.9	316.7	277.5	246.5	245.1	289.0	276.0
17.20	21.90	18.20	20.90	19.42	19.20	20.99	21.21
2.14	2.22	2.02	2.02	2.02	2.22	2.22	2.22
-	-	-	15.15	-	-	-	15.15
13.13	8.75	8.81	-	9.87	10.87	12.47	-
6.14	35.32	36.99	35.32	35.95	34.94	14.17	35.91
2.30	2.04	2.09	2.53	2.50	2.55	2.49	2.04
.54	.59	.52	1.22	.76	.35	.84	.74
.63	.66	.71	.68	.65	.66	.63	.68
34.04*	28.22*	55.50*	23.20*	26.36*	41.41*	58.29*	20.86*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
71	73	68	73	66	70	75	71

EASTON

HOUSE NUMBER	4	12	20	22	23	25	27
GENERAL DATA							
Construction Type	A2 FM	D2 FR	D2 FR	A2 M	D2 FR	A2 M	A2 FR
Htg. System Type	AF	WP	A	WP	AF	AG	AF
Fuel Space Htg.	O	G	E	O	G	O	G
Fuel Hot Water	G	G		F	G	G	G
Living Space	960	1552	1144	1993	1450	960	1290
Volume	7680	12416	9152	16940	13050	7680	11610
Foundation Type	B	B	B	B	B	B	B
Roof Type	H	G	G	G	G	H	G
Orientation	N	S	W	S	NE	E	W
Age	65	70	7	60	75	99	60
Number of Occupants	4	4	2	1	2/1	5	2
Surface Area	2916	2076	2300	2578	2939	2620	2508
Area of Glass	238.70	189.80	162.00	209.50	180.00	144.40	194.80
Area Window S	102.20	73.00	5.40	75.20	103.70	69.20	100.50
Area Window E + W	135.80	80.20	156.59	101.00	76.30	75.70	84.40
Area Doors	62.46	68.20	37.62	41.00	40.30	34.50	51.60
Area Walls	1612.00	1040.00	1536.00	1241.00	1944.00	1600.00	1314.00
Area Basement Walls	624.00	260.00	192.00	346.70	270.00	300.00	334.30
Area Floor	-	-	-	-	-	-	-
Area Roof	480.00	776.00	572.00	990.00	725.00	480.00	645.00
BEFORE WEATHERIZATION							
UA	1414.8	822.1	604.7	895.3	1042.5	1053.7	786.4
R-Value Walls	2.92	4.12	7.39	3.30	3.45	2.77	3.91
R-Value Windows	1.70	1.81	1.71	1.71	1.50	1.57	1.81
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	2.34	3.42	1.47	2.48	2.70	2.06	2.02
R-Value Roof	3.59	6.44	25.12	7.81	7.20	3.54	6.46
R-Value Door	2.52	2.17	2.46	2.36	2.32	2.28	2.35
Infiltration Rate	2.15*	1.06*	.81*	.37*	.60*	1.86*	.53*
Htg. System Eff.	.52	.63	.52*	.47	.56	.44	.53
Solar Gains	57.93*	37.60*	36.66*	42.87*	44.95*	35.57*	45.92*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	66	68	73	72	76	75	70
AFTER WEATHERIZATION							
UA	1295.7	534.6	480.4	505.3	540.5	933.8	433.1
R-Value Walls	2.92	17.12	18.39	16.30	14.45	2.77	22.91
R-Value Windows	1.70	1.81	1.71	1.71	1.50	1.57	1.81
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	2.34	3.42	1.47	2.48	2.70	2.06	2.02
R-Value Roof	33.59	31.44	25.12	26.81	26.20	30.54	25.45
R-Value Door	2.52	2.17	2.46	2.36	2.32	2.28	2.35
Infiltration Rate	2.15	1.06	.81	.37	.60*	1.86*	.53
Htg. System Eff.	.52*	.58	.52*	.47*	.68	.44*	.53*
Solar Gains	57.93*	37.60*	36.66*	42.87*	44.95*	35.57*	45.92*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	66	68	73	72	76	75	70

EASTON

28	31	33	39	42	44

D2 FR	D1 FR	D1 FR	A2 M	D1 FR	D1 FR
AF	WP	WP	WP	A	AF
0	0	0	0	E	G
G	F	F	F	?	G
1720	1219	1152	1858	768	1274
13760	9750	9216	16479	6144	10195
B	B	S	B	B	B
G	G	G	F	G	H
E	W	SE	S	W	?
70	30	21	99	8	65
1	1	1	3	1	2
3149	2880	14878	2913	2000	3001
178.3	162.40	147.90	180.50	136.10	187.60
132.1	60.70	90.60	84.30	25.60	39.60
46.20	75.20	57.30	38.50	88.40	128.70
43.60	44.60	61.60	44.70	47.60	50.10
1794.1	1208.00	1152.00	1530.00	896.00	1256.00
273.1	453.00	144.00	261.80	336.00	471.00
-	-	-	-	-	-
866.0	1218.70	1152.00	979.00	768.00	1274.00

1151.0	983.7	706.1	723.5	503.8	921.2
4.70	3.36	4.13	5.95	17.35	4.79
1.59	1.73	1.19	1.71	1.65	1.73
-	-	-	-	-	-
2.29	3.52	2.29	3.32	1.65	1.89
6.86	5.97	6.49	29.38	25.44	7.25
2.31	2.42	2.23	2.21	2.29	2.38
1.59	1.02	.21	.77*	1.04*	.57*
0.45	.56	.51	.51	.52*	.54
45.80*	33.18*	37.17*	31.25*	26.74*	39.55*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
	72	74	70	71	67

773.0	463.7	362.1	723.5	503.8	602.4
17.70	16.36	17.13	5.95	17.35	17.79
1.59	1.73	1.19	1.71	1.65	1.73
-	-	-	-	-	-
2.29	3.52	2.29	3.32	1.65	1.89
31.86	24.97	25.49	29.38	25.44	26.25
2.31	2.42	2.23	2.21	2.29	2.38
1.59	.57	.21	.77	1.04	.57
0.45*	.56*	.51*	.51*	.52*	.54*
45.80*	33.18*	37.17*	31.25*	26.74*	39.55*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
	72	74	70	71	67

FARGO

House Number	2	6	10	11	15	17	25
GENERAL DATA							
Construction Type	D1 FR	D1 FR	D1 FR	D1 FR	D1 FR	D1 FR	D1 FR
Htg. System Type	AF	AG/AF	AG/AF	AF	AF	AF	AF
Fuel Space Htg.	G	0	0	0	0	G	0
Fuel Hot Water	G	E	E	G	G	E	G
Living Space	614	634	650	1225	969	763	684
Volume	4546	5709	5202	9800	7753	6018	5472
Foundation Type	B	B	B	B	B	C	B
Roof Type	G	G	H	G	G	G	G
Orientation	S	E	W	N	E	S	S
Age	50	50	50	40	40	25	50
Number of Occupants	1	2	1	1	1	1/3	2
Surface Area	1668.30	1909.30	1721.00	2556.00	2225.00	2018.00	1894.00
Area of Glass	117.50	164.70	96.30	169.10	187.00	102.10	141.20
Area Window S	30.10	73.60	22.40	62.00	51.40	17.00	30.90
Area Window E + W	58.03	40.30	55.90	37.90	85.60	62.50	102.80
Area Doors	37.80	53.40	37.80	35.60	37.80	37.20	34.50
Area Walls	623.20	699.90	681.90	763.30	782.40	864.70	704.30
Area Basement Walls	289.80	357.00	255.00	363.00	251.20	251.00	330.00
Area Floor	-	-	-	-	-	-	-
Area Roof	600.00	634.30	650.20	1225.00	969.10	763.50	684.00
BEFORE WEATHERIZATION							
UA	323.9	518.4	360.8	644.4	358.9	533.6	438.9
R-Value Walls	19.34	7.03	16.51	3.79	15.14	6.63	5.24
R-Value Windows	2.22	2.22	2.22	2.22	2.22	2.22	2.22
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	1.89	1.47	1.47	1.89	3.33	1.47	1.89
R-Value Roof	23.28	20.00	35.94	37.77	37.34	27.31	33.42
R-Value Door	3.03	3.03	3.03	3.03	3.03	3.03	3.03
Infiltration Rate	.57*	.51*	.77*	.74*	.79*	1.33*	.35*
Htg. System Eff.	.56	.54	.48	.61	.50*	.55	.51
Solar Gains	23.05*	33.36*	19.97*	28.99*	36.23*	19.68*	33.33*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	61	66	64	65	69	66	67
AFTER WEATHERIZATION							
UA	180.7	219.1	188.4	324.4	270.5	276.8	187.8
R-Value Walls	24.74	16.93	21.91	15.79	20.54	20.59	20.05
R-Value Windows	3.22	3.22	3.22	3.22	3.22	3.22	3.22
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	7.10	8.47	9.47	7.10	8.54	8.89	7.10
R-Value Roof	32.09	44.00	40.94	40.70	42.34	41.31	41.42
R-Value Door	3.03	3.03	3.03	3.03	3.03	3.03	3.03
Infiltration Rate	.57	.51	.77	.74*	.79	1.33	.35
Htg. System Eff.	54	60	54	59	50*	39	46
Solar Gains	23.05*	33.36*	19.97*	28.99*	36.23*	19.68*	33.33*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	61	66	64	65	69	66	67

FARGO

27	30	32	35	36

D1 FR	D1 FR	D1 FR	D1 FR	D1 FR
AF	AF	AF	WP	AF
O	G	G	G	G
E	G	G	G	G
462	747	945	1225	517
3698	5979	8739	9798	4136
B	B	B	C	C
G	G	G	H	G
W	N	S	S	E
50	60	50	20	15
3	1	1	3	1
1408.00	2041.00	2580.00	2504.00	1472.00
104.20	147.70	132.10	103.60	63.10
25.60	53.90	25.10	54.40	6.90
51.30	93.80	92.00	22.50	42.40
35.60	35.60	37.96	115.70	35.60
548.20	728.70	1036.00	563.90	629.30
258.00	342.00	403.00	142.20	227.50
-	-	35.00	-	-
462.30	787.30	936.00	1224.70	517.00

473.5	398.9	394.2	511.5	312.6
3.35	14.90	14.36	8.06	15.57
2.22	2.22	2.22	2.22	2.22
-	-	5.09	-	-
1.89	1.89	2.69	1.89	1.89
32.70	39.87	34.39	11.00	9.39
3.03	3.03	3.03	2.42	3.03
1.51*	.66*	.42*	.91*	.76*
47	54	55	53	52
19.99*	38.90*	28.99*	23.01*	11.82*
19.40*	19.40*	19.40*	19.40*	19.40*
67	68	70	69	68

228.5	223.8	272.5	387.3	159.0
15.16	25.46	14.36	19.06	20.97
3.22	3.22	3.22	3.22	3.22
-	-	5.09	-	-
7.10	7.10	7.78	1.89	8.14
40.70	42.87	42.39	29.16	39.39
3.03	3.03	3.03	2.42	3.03
1.51	.66	.42	.91	.76
21	60	51	64	60
19.99*	38.90*	28.99*	23.01*	11.82*
19.40*	19.40*	19.40*	19.40*	19.40*
67	68	70	69	68

MINN/ST. PAUL

HOUSE NUMBER	1	2	3	4	8	13	20
GENERAL DATA							
Construction Type	D1.5 FR	F2 FR	D1 FR	D2 FR	D2 FR	D2 FR	D1 FR
Htg. System Type	AF	WP	AF	WG	A/W	V	AF
Fuel Space Htg.	G	G	G	G	O/G	G	G
Fuel Hot Water	G	G	G	G	F/G	G	G
Living Space	1201	1248	960	1944	1560	1680	1260
Volume	11269	10608	7680	15552	14828	13440	9450
Foundation Type	B	B	?	B	B	B	B
Roof Type	G	H	G	G	H	G	H
Orientation	E	S	W	S	N	N	N
Age	70	60	40	80	70	80	15
Number of Occupants	4	4	6	2	2	4	4
Surface Area	2523	3664	2176	4678	3612	3392	2554
Area of Glass	187.40	169.28	112.64	186.20	221.20	166.90	195.50
Area Window S	35.60	28.08	35.60	43.01	84.50	25.50	61.31
Area Window E + W	88.60	90.09	45.20	124.05	136.70	88.46	65.14
Area Doors	40.10	38.79	37.80	78.72	74.50	40.50	38.19
Area Walls	1223.50	2376.00	873.60	2687.10	2064.00	1905.00	898.80
Area Basement Walls	233.40	6046.00	192.00	574.00	472.00	320.00	151.00
Area Floor	-	-	-	-	-	-	-
Area Roof	839.00	624.00	960.00	1152.00	780.00	960.00	1270.00
BEFORE WEATHERIZATION							
UA	905.2	1235.4	623.4	1295.2	1179.4	931.8	753.4
R-Value Walls	3.56	3.63	4.65	4.43	5.37	5.47	3.66
R-Value Windows	1.97	1.97	2.22	2.12	2.13	2.22	2.22
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	2.29	1.81	1.65	1.81	1.65	4.07	1.81
R-Value Roof	4.13	38.24	29.22	17.27	18.77	6.83	16.85
R-Value Door	3.03	3.03	2.04	2.68	2.73	3.03	3.03
Infiltration Rate	.73*	1.12*	1.57*	.67*	1.26*	1.14*	1.46*
Htg. System Eff.	.57	.56	.58	.56	.66	.59	.63
Solar Gains	29.55*	27.58*	20.36*	39.30*	54.55*	26.46*	32.37*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	70	75	70	75	75	75	70
AFTER WEATHERIZATION							
UA	463.9	723.8	489.0	806.9	885.2	583.2	355.5
R-Value Walls	15.56	15.63	14.67	16.43	17.37	16.49	15.66
R-Value Windows	1.97	2.22	2.22	2.22	2.22	2.22	2.22
R-Value Floor	-	-	-	-	-	-	-
R-Value Basement	2.29	1.81	1.65	1.81	1.65	4.07	1.81
R-Value Roof	31.13	38.24	42.22	45.27	45.77	38.78	43.85
R-Value Door	3.03	3.03	2.04	2.68	2.73	3.03	3.03
Infiltration Rate	.73	1.12	1.57	.67	1.26*	1.14	.50
Htg. System Eff.	.57	.56	.58	.56	.66	.59	.63
Solar Gains	29.55*	27.58*	20.36*	39.30*	54.55*	26.46*	32.37*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	70	75	70	75	75	75	70

MINN/ST. PAUL

21	23	26	33	34	40	42	44	45	46

D2 FR	D2 M	D2 FR	D2 FR	D1.5 FR	D1 FR	D1.5 FR	D1 FR	D2 FR	D1 FR
AF	WG	V	AG	WG	AF	WG	AF	AG	AG
G	G	G	G	G	G	G	G	G	G
G	G	E	G	G	G	G	G	G	G
1816	2322	1344	672	2312	1128	1141	1314	1257	1004
17296	22114	11760	5376	18496	9024	8921	10512	10061	8032
-	B	B	B	B	B	B	B	B	B
G	G	G	H	H	-	G	H	H	G
S	W	W	E	S	E	S	S	S	E
45	61	99	50	67	99	50	18	50	65
5	4/7	7	1	3	4	2	6	4	4
3810	4666	2934	2024	2516	2388	2549	2556	2771	2544
147.72	252.20	100.81	133.40	174.30	107.20	201.32	127.73	262.00	181.66
39.63	24.84	26.95	51.87	43.84	27.36	63.42	37.84	85.67	50.82
79.04	164.12	40.64	48.29	121.32	52.48	97.00	69.35	130.20	75.60
38.55	40.43	18.76	36.96	38.90	37.81	39.36	38.19	72.76	37.52
2264.00	2557.00	2026.00	765.60	874.90	975.00	920.32	938.60	1389.00	900.80
408.00	600.00	116.00	416.00	272.00	140.00	387.00	138.00	406.00	420.00
-	-	-	-	-	-	-	-	-	-
952.00	1216.00	672.00	672.00	1156.00	1128.00	1001.00	1314.00	642.00	1004.00

1008.7	1661.1	865.4	540.6	852.5	636.7	791.4	576.8	994.7	699.9
7.70	4.59	4.42	5.00	3.49	4.88	4.39	4.26	4.39	4.28
2.22	2.10	2.22	2.22	2.22	2.22	2.22	2.22	1.30	2.22
-	-	-	-	-	-	-	-	-	-
1.97	2.42	2.77	1.81	1.81	1.81	1.81	1.81	1.81	1.81
8.54	12.45	6.80	17.40	7.86	6.36	6.26	12.83	17.89	14.50
2.40	3.03	2.04	2.40	3.03	2.46	3.03	3.03	2.76	3.03
.55*	1.57	1.00*	.40	.64	.73	.65	.57	1.05	.65
.53	.63	.70	.61	.60	.57	.58	.61	.57	.70*
28.74*	42.28*	16.77*	25.94*	38.97*	19.40*	39.75*	26.15*	53.52*	31.40*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
76	77	73	70	73	70	77	68	72	79

665.9	796.2	456.7	425.5	571.0	354.4	561.0	289.8	458.1	289.7
18.72	15.61	15.44	16.02	15.49	14.90	14.41	14.28	14.41	14.30
2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
-	-	-	-	-	-	-	-	-	-
1.97	9.42	2.77	1.81	1.81	1.81	1.81	8.81	10.13	10.13
11.33	19.11	38.80	37.40	34.86	38.36	12.26	42.83	44.89	40.82
2.40	3.03	2.04	2.40	3.03	2.46	3.03	3.03	2.76	3.03
.55	.95	1.00	.50	.72	.73*	.61	.57*	.90	.46
.53	.63	.70	.61	.60	.57	.58	.61	.57	.70*
28.74*	42.28*	16.77*	25.94*	38.97*	19.40*	39.75*	26.15*	53.52*	31.40*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
76	77	73	70	73	70	77	68	72	79

ST. LOUIS

HOUSE NUMBER	5	6	7	17	28	29	34	38
GENERAL DATA								
Construction Type	D2 FR	D2 M	D1 FR	D1 M	D2 M	D3 M	D2 FR	D2 FR
Htg. System Type	AF	AF	AF	AF	AF	WP	AG/AF	AF
Fuel Space Htg.	G	G	G	G	G	G	G	G
Fuel Hot Water	E	G	G	G	G	G	G	G
Living Space	1039	1477	689	1938	1841	2300	1189	1568
Volume	8104	14922	6690	19347	16319	20935	13260	11961
Foundation Type	S	B	B	C	B	B	B	B
Roof Type	G	F	G	F	F	H	F	H
Orientation	S	S	?	E	E	S	E	W
Age	7	55	50	60	80	80	40	99
Number of Occupants	5	7/6	2/3	4	3	2	7	8/7
Surface Area	2895.12	3789.00	2444.65	2797.00	2526.00	2477.00	2358.25	3014.00
Area of Glass	99.20	283.50	108.10	154.10	353.90	360.80	206.40	185.90
Area Window S	0	71.00	22.60	48.54	69.41	117.20	15.70	44.50
Area Window E + W	99.20	148.20	71.80	83.80	166.14	134.70	126.80	86.50
Area Doors	21.00	147.20	21.00	47.90	88.90	58.60	111.40	52.60
Area Walls	1348.70	2166.00	1058.82	1025.80	630.50	932.70	1186.50	1697.10
Area Basement Walls	93.18	346.20	465.00	394.50	346.20	391.40	124.53	363.80
Area Floor	-	-	-	-	-	-	-	-
Area Roof	528.36	846.20	791.73	1174.40	1106.20	734.00	729.40	714.80
BEFORE WEATHERIZATION								
UA	787.9	1680.7	1195.1	1344.6	1287.1	1265.8	1291.7	1502.7
R-Value Walls	2.74	3.09	3.79	2.57	3.18	4.27	3.03	3.96
R-Value Windows	1.01	1.71	1.01	2.13	1.42	1.38	1.01	1.63
R-Value Floor	-	-	-	-	-	-	-	-
R-Value Basement	1.40	2.36	2.14	2.57	2.61	2.61	2.72	2.37
R-Value Roof	4.38	3.80	2.14	3.48	4.10	3.35	2.92	2.56
R-Value Door	2.04	2.33	2.22	2.04	2.04	2.04	2.50	2.04
Infiltration Rate	1.00*	1.42*	1.76*	1.03*	1.34*	1.03*	1.49*	2.33*
Htg. System Eff.	.53	.56	.55	.61	.57	.54	.57	.61
Solar Gains	21.83*	52.29*	22.06*	31.89*	55.79*	62.12*	32.25*	31.35*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	75	75	76	76	73	72	73
AFTER WEATHERIZATION								
UA	291.2	1445.4	583.2	1042.2	960.0	1166.8	645.7	862.9
R-Value Walls	8.74	3.09	14.79	2.57	3.18	4.27	14.03	15.96
R-Value Windows	2.22	2.22	2.22	2.13	2.22	2.22	2.22	2.22
R-Value Floor	-	-	-	-	-	-	-	2.37
R-Value Basement	1.40	2.36	2.14	2.57	2.61	2.61	2.72	-
R-Value Roof	34.38	33.80	33.80	33.48	34.10	3.35	32.92	32.56
R-Value Door	2.04	2.33	2.04	2.04	2.04	2.04	2.50	2.04
Infiltration Rate	1.00*	1.42*	1.76*	1.03*	1.34*	1.03*	1.49*	2.33
Htg. System Eff.	.55	.56*	.50	.66	.57	.54	.57	.62
Solar Gains	21.83*	52.29*	22.06*	31.89*	55.79*	62.12*	32.25*	31.35*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	75	75	76	76	73	72	73

ST. LOUIS

40	41	42	46	49	55	56	77	92	93

D2 M	D1 M	D2 FR	D2 M	D2 FR	D1 FR	D1 M	D2 M	D1 M	D1.5 FR
AF	WG	AF	AG	AF	AG	AF	AF	AF	AF
G	G	G	G	G	G	G	G	G	G
G	G	G	G	G	G	G	G	G	G
1929	1028	1271	2138	1328	784	885	1356	946	676
18620	9256	10695	20256	13284	6436	7085	11633	8514	5412
B	B	B	B	B	B	B	B	B	B
F	F	G	F	M	G	M	G	F	G
N	W	E	W	N	N	E	W	W	S
57	40	60	90	71	25	50	60	60	65
1	4/3	1	1	2	3	5/6	4	3	2
4302.10	2831.94	2214.93	4476.00	3168.80	1943.00	2317.20	2447.64	2802.70	2001.30
304.30	230.66	171.89	218.00	174.36	142.05	180.00	288.80	140.96	112.90
76.40	78.80	51.13	121.50	39.12	31.25	35.90	43.10	67.96	54.40
133.70	101.00	106.70	96.50	68.60	63.00	98.39	211.10	47.40	35.90
69.80	47.90	51.00	114.20	71.23	54.20	69.48	76.55	33.90	52.80
2402.00	851.97	1409.35	298.50	1995.00	728.00	818.60	1191.39	1139.10	949.30
388.50	469.57	289.79	481.80	166.00	292.00	367.10	293.71	434.80	144.60
-	-	-	-	-	-	-	-	-	-
1137.40	1029.20	617.50	677.20	761.70	726.60	882.10	597.19	1053.80	741.80

1953.8	972.9	1223.7	1006.0	1260.9	868.5	874.7	1186.0	1130.0	884.6
3.50	2.57	3.36	3.57	3.93	3.13	3.49	3.74	3.73	3.57
1.66	1.65	1.01	1.52	1.34	1.01	1.18	1.65	1.17	1.01
-	-	-	-	-	-	-	-	-	-
2.45	3.60	1.89	1.53	2.19	1.89	2.41	2.69	2.45	1.32
4.36	6.10	3.86	3.99	3.51	4.64	4.39	3.57	3.48	3.40
2.23	2.50	2.50	2.28	2.45	2.04	2.44	2.50	2.04	2.31
1.89*	1.10*	1.56*	.67*	1.26*	1.36*	.83*	1.84*	1.12*	.99*
.53	.60	.55	.40	.58	.59	.59	.60	.61	.57
50.59*	44.06*	37.65*	54.90*	25.94*	22.52*	31.60*	58.39*	29.26*	22.97*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
74	79	78	71	70	76	73	75	75	73

1679.8	796.8	639.9	809.9	650.6	353.5	517.2	674.9	801.3	347.6
3.50	2.57	14.36	3.57	13.93	14.13	3.49	14.74	3.73	12.17
2.22	2.22	1.01	2.22	2.22	2.22	2.22	2.22	2.22	2.22
-	-	-	-	-	-	-	-	-	-
2.45	3.60	8.89	1.53	2.19	8.89	9.41	9.69	2.45	8.32
34.36	36.10	33.86	35.99	33.51	34.64	31.29	33.57	33.48	33.40
2.23	2.50	2.50	2.28	2.45	2.04	2.44	2.50	2.04	2.31
1.89*	1.10*	1.56	.67*	1.26*	1.36	.83*	1.84	1.12	.99
.64	.60	.55	.40	.62	.64	.66	.58	.61	.54
50.59*	44.06*	37.65*	54.90*	25.94*	22.52*	31.60*	58.40*	29.26*	22.97*
19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
74	79	78	71	70	76	73	75	75	73

TACOMA

HOUSE NUMBER	4	21	39	45	49	55
GENERAL DATA						
Construction Type	Dl FR	Dl FR	Dl FR	Dl FR	Dl FR	Dl FR
Htg. System Type	BB	AF	BB	V	V	AF
Fuel Space Htg.	E	G	E	G	G	G
Fuel Hot Water	E	G	E	G	E	E
Living Space	1072	1660	960	900	646	928
Volume	8254	12948	6826	7110	5168	7920
Foundation Type	C	C	C	C	B	C
Roof Type	G	H	?	F	G	?
Orientation	?	?	?	?	?	?
Age	8	25	12	29	45	80
Number of Occupants	4	1/2	2	2	1	1
Surface Area	2481	3792	2326	2244	2247	2892
Area of Glass	162.00	272.00	150.20	141.60	112.71	177.60
Area Window S	52.00	131.00	33.00	39.20	20.76	58.00
Area Window E + W	54.00	-	90.80	26.40	57.95	19.25
Area Doors	51.10	20.00	38.70	32.00	38.00	40.00
Area Walls	887.00	1150.00	835.00	897.00	916.00	1523.00
Area Basement Walls	308.00	502.00	342.00	313.00	272.00	266.00
Area Floor	-	-	-	-	-	-
Area Roof	1072.00	1848.00	960.00	900.00	909.00	869.00
BEFORE WEATHERIZATION						
UA	1021.3	1096.5	638.9	866.4	742.0	881.0
R-Value Walls	3.01	5.18	8.81	3.89	4.41	4.31
R-Value Windows	1.01	1.01	1.01	1.01	1.01	1.01
R-Value Floor	-	-	-	-	-	-
R-Value Basement	1.33	1.63	1.63	1.57	1.37	1.63
R-Value Roof	5.71	13.15	5.71	6.50	6.33	13.76
R-Value Door	2.04	2.04	2.46	3.03	2.04	3.03
Infiltration Rate	.82*	.63*	.38*	.73	.52	.76
Htg. System Eff.	1.00*	.59*	1.00*	.58*	.57*	.60*
Solar Gains	21.49*	29.63*	23.82*	13.62*	15.14*	25.91*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	68	73	73	72	68
AFTER WEATHERIZATION						
UA	350.2	470.4	236.6	322.4	399.3	397.3
R-Value Walls	14.01	16.18	19.81	14.89	4.14	15.31
R-Value Windows	2.22	2.22	2.22	2.22	2.22	2.22
R-Value Floor	-	-	-	-	-	-
R-Value Basement	8.83	9.13	9.13	9.07	8.87	9.13
R-Value Roof	35.71	44.15	35.71	35.50	36.33	37.56
R-Value Door	2.04	2.04	2.46	3.03	2.04	3.03
Infiltration Rate	.82	.63*	.38	1.01	.57	.88
Htg. System Eff.	1.00*	.59	1.00*	.58	.57	.60*
Solar Gains	21.49*	29.63*	23.82*	13.62*	15.14*	25.91*
Interior Gains	19.40*	19.40*	19.40*	19.40*	19.40*	19.40*
Interior Temp.	73	68	73	73	72	68

TACOMA

81	83	87

D1 FR	D1 FR	D1.5 FR
BB	AF	U
E	G	G
E	E	G
1008	1080	546
7682	8424	4332
C	C	CB
F	H	?
?	?	?
8	24	50
1	1	1
2350	2921	1766
160.00	221.20	138.70
34.00	31.00	45.79
45.00	189.90	48.25
28.80	39.00	32.76
824.00	1082.00	743.50
330.00	175.00	305.00
-	-	-
1008.00	1404.00	546.00

721.0	843.7	671.6
15.61	4.07	3.84
1.01	1.01	1.01
-	-	-
1.33	1.33	1.63
13.15	17.35	7.27
3.03	3.03	2.04
.35*	.88*	.80
1.00*	.63	.59*
15.80*	41.27*	19.05*
19.40*	19.40*	19.40*
73	70	69

222.8	367.2	252.9
4.61	15.07	14.84
2.22	2.22	1.58
-	-	-
8.83	8.83	7.23
43.15	47.35	37.27
3.03	3.03	2.04
.35	.88	.54
1.00*	.63*	.59
15.80*	41.27*	19.05*
19.40*	19.40*	19.40*
73	70	69

WASHINGTON

HOUSE NUMBER	2	7	41	53
GENERAL DATA				
Construction Type	D1 FR	D1 FR	D1 FR	D1.5 FR
Htg. System Type	S	AF	V	WP
Fuel Space Htg.	P	O	P	O
Fuel Hot Water	E	E	P	F
Living Space	681	1056	1152	772
Volume	5448	8448	9256	6176
Foundation Type	B	C	C	B
Roof Type	G	H	G	G
Orientation	SW	N	?	?
Age	29	45	40	70
Number of Occupants	1	1	1	1
Surface Area	3193	2759	2938	2514
Area of Glass	273.00	309.40	65.00	243.50
Area Window S	67.80	37.00	25.70	79.70
Area Window E + W	134.80	170.90	23.30	69.80
Area Doors	57.40	58.70	35.40	50.00
Area Walls	1135.00	952.00	1051.60	962.50
Area Basement Walls	767.30	495.00	633.60	488.00
Area Floor	-	-	-	-
Area Roof	960.00	1056.00	1152.00	770.00
BEFORE WEATHERIZATION				
UA	1136.1	1193.9	800.6	1018.1
R-Value Walls	4.14	3.84	4.71	4.18
R-Value Windows	1.01	1.01	1.01	1.01
R-Value Floor	-	-	-	-
R-Value Basement	2.57	2.57	2.57	1.89
R-Value Roof	6.38	7.27	17.28	5.34
R-Value Door	3.03	2.50	3.03	3.03
Infiltration Rate	1.29	1.83	1.02	1.15
Htg. System Eff.	.60*	.55*	.60*	.61*
Solar Gains	40.38*	38.65*	10.56*	32.33*
Interior Gains	19.40*	19.40*	19.40*	19.40*
Interior Temp.	69	71	69	74
AFTER WEATHERIZATION				
UA	350.3	410.3	326.8	450.4
R-Value Walls	15.14	16.84	15.71	17.18
R-Value Windows	2.22	2.22	2.22	2.22
R-Value Floor	-	-	-	-
R-Value Basement	18.02	9.57	9.57	7.10
R-Value Roof	45.77	34.27	30.00	32.34
R-Value Door	3.03	3.03	3.03	3.03
Infiltration Rate	.73	.74	.62	1.58
Htg. System Eff.	.60*	.55	.60*	.61
Solar Gains	40.38*	38.65*	10.56*	32.33*
Interior Gains	19.40*	19.40*	19.40*	19.40*
Interior Temp.	69	71	69	74

APPENDIX B

VALUES (FROM REGRESSION ANALYSIS) USED FOR CALCULATING CONSUMPTION

ATLANTA, GA

House #	Fuel Type (Space/Water)	T_ϕ (°F)	B_1 kBtu/DD_{T_ϕ}	B_ϕ kBtu/day	HW Factor (MBtu/yr)
1 Before	G/E	63.0	31.11	20.6	0.0
After	G/E	72.5	14.73	29.9	0.0
2 Before	G/E	67.0	19.98	37.1	0.0
After	G/E	66.5	18.23	48.4	0.0
11 Before	G/G	61.5	24.10	42.2	20.0*
After	G/G	59.0	23.38	59.7	20.0*
17 Before	E/E	59.5	12.90	82.7	16.4
After	E/E	68.0	7.12	77.5	16.4
21 Before	G/G	51.5	18.13	91.7	20.0*
After	G/G	60.5	4.94	74.2	20.0*
22 Before	G/G	57.0	21.63	74.2	15.2
After	G/G	62.5	17.61	86.5	15.2
23 Before	G/G	62.0	21.73	126.7	25.2
After	G/G	64.0	20.60	120.5	25.2
29 Before	G/G	60.5	22.30	181.0	20.0*
After	G/G	61.5	5.10	145.0	20.0*
31 Before	P/E	58.5	26.39	75.8	0.0
After	P/E	46.5	13.60	107.7	0.0
32 Before	E/E	60.0	13.01	112.2	4.1
After	E/E	66.5	8.46	106.9	4.1

CHARLESTON, SC

House #	Fuel Type (Space/Water)	T_ϕ (°F)	B_1 kBtu/DD_{T_ϕ}	B_ϕ kBtu/day	HW Factor (MBtu/yr)
2 Before	P/P	84.5	14.33	-62.1	10.00
After	P/P	61.0	18.35	92.2	12.55
3 Before	P/E	66.5	12.87	78.5	0.0
After	P/E	84.5	5.39	6.4	0.0
5 Before	P/E	63.0	9.50	27.4	0.0
After	P/E	84.5	3.47	1.8	0.0

CHARLESTON, SC (Cont.)

House #		Fuel Type	TØ	B_1	BØ	HW Factor
8	Before	P/E	64.5	15.98	64.8	0.0
	After	P/E	70.5	9.04	21.9	0.0
16	Before	P/E	60.0	27.30	47.5	0.0
	After	P/E	64.0	11.96	42.9	0.0
18	Before	P/-	67.5	13.60	59.3	0.0
	After*	P/-	84.5	5.84	15.5	0.0
19	Before	P/-	81.5	9.04	-52.0	0.0
	After	P/-	73.0	9.86	-16.4	0.0
20	Before	P/E	68.5	12.05	35.6	0.0
	After	P/E	84.5	5.30	-0.9	0.0
21	Before	P/P	73.5	9.50	55.7	20.0*
	After	P/P	76.0	6.66	46.6	20.0*
23	Before	P/E	74.0	12.87	11.9	0.0
	After	P/E	71.0	9.68	27.4	0.0
24	Before	P/P	69.0	13.97	51.1	20.0*
	After	P/P	76.5	7.40	29.2	20.0*
25	Before	P/-	63.5	16.43	42.0	0.0
	After	P/-	65.5	9.40	32.9	0.0
28	Before	P/P	72.5	12.87	24.7	20.0*
	After	P/P	84.5	10.50	-32.9	20.0*
33	Before	K/P	70.5	23.09	-71.6	10.7
	Before	P/P	55.5	5.02	66.6	
	After	P/P	61.0	11.32	48.4	11.9
39	Before	P/-	79.5	10.77	45.7	0.0
	After	P/-	49.0	25.29	33.8	0.0
44	Before	P/E	67.5	11.50	52.0	0.0
	After	P/E	45.0	34.88	72.1	0.0
47	Before	E/E	52.0	12.32	70.0	20.0*
	After	E/E	45.0	10.27	62.1	20.0*
49	Before	P/E	66.5	7.67	38.3	0.0
	After	P/E	84.5	2.01	24.7	0.0

CHICAGO, IL

House #	Fuel Type	TØ	B_1	BØ	HW Factor
5 Before	G/G	59.5	30.18	375.9	6.5
After	G/G	84.5	20.09	-148.3	10.6
9 Before	G/G	67.5	34.20	36.1	7.3
After	G/G	84.5	38.21	-1036.0	7.3
11 Before	G/G	65.0	41.92	216.3	21.1
After	G/G	84.5	28.84	-225.6	21.1
12 Before	G/G	66.0	56.44	200.8	21.0
After	G/G	84.5	18.02	-230.7	21.0
14 Before	G/G	62.5	24.10	80.3	23.8
After	G/G	84.5	22.87	-510.9	31.6
19 Before	G/G	59.0	38.83	162.7	24.0
After	G/G	67.0	26.37	-83.4	24.0
25 Before	G/G	60.5	33.48	192.6	21.9
After	G/G	72.0	26.88	-139.1	21.9
29 Before	G/G	66.0	24.31	60.8	10.2
After	G/G	84.5	24.21	-625.2	9.2
32 Before	G/G	45.0	35.12	264.7	37.2
After	G/G	57.5	40.07	55.6	37.2
38 Before	G/G	60.5	55.31	234.9	9.3
After	G/G	84.5	46.04	-819.9	6.6

COLORADO SPRINGS, CO

House #	Fuel Type	TØ	B_1	BØ	HW Factor
1 Before	G/G	66.5	17.50	88.0	20.0*
After	G/G	65.5	15.35	136.0	20.0*
5 Before	G/G	58.5	39.80	292.0	20.0*
After	G/G	64.5	40.58	223.5	20.0*
7 Before	G/G	70.0	14.50	52.0	21.7
After	G/G	79.0	9.99	-60.8	21.3
8 Before	G/G	50.5	19.90	123.0	20.0*
After	G/G	58.0	13.08	86.5	20.0*

COLORADO SPRINGS, CO (Cont.)

House #	Fuel Type	T∅	B_1	B∅	HW Factor
10 Before	G/G	67.0	21.00	31.0	20.0*
After	G/G	63.5	18.85	52.5	20.0*
11 Before	G/G	61.5	13.60	85.0	20.8
After	G/G	55.5	8.24	52.5	22.3
13 Before	G/G	57.5	10.60	103.0	13.0
After	G/G	79.5	9.27	-73.1	13.7
14 Before	G/G	63.5	18.70	97.0	53.7
After	G/G	45.0	16.07	228.7	53.7
17 Before	G/G	58.0	15.00	136.0	16.4
After	G/G	83.5	9.37	-114.3	16.4
20 Before	G/G	49.0	20.60	97.0	14.8
After	G/G	65.5	10.92	19.6	14.8
23 Before	G/G	61.5	21.90	217.0	20.4
After	G/G	45.0	22.15	254.4	20.8
24 Before	G/G	70.0	32.90	31.0	26.8
After	G/G	45.0	27.50	421.3	33.1
26 Before	G/G	57.5	26.10	116.0	21.2
After	G/G	84.0	18.95	-389.3	21.5
31 Before	G/G	59.0	23.70	110.0	12.6
After	G/G	76.0	8.55	-18.5	12.6
37 Before	G/G	57.0	22.30	159.0	14.8
After	G/G	70.5	14.32	-119.5	14.8
41 Before	G/G	60.5	14.90	109.0	38.8
After	G/G	79.0	8.34	-62.8	36.3
43 Before	G/G	52.5	25.80	113.0	19.0
After	G/G	59.5	14.21	3.1	12.0
44 Before	G/G	65.5	19.50	74.0	24.6
After	G/G	67.5	9.58	29.9	37.6
47 Before	G/G	68.5	26.50	-27.0	14.7
After	G/G	78.5	15.04	-210.1	17.1
49 Before	G/G	69.0	15.30	102.0	27.0
After	G/G	56.0	9.06	88.6	23.7

EASTON, PA

House #	Fuel Type	Tø	B_1	Bø	HW Factor
4 Before	0/G	53.5	38.00	5.5	0.0
After	0/G	53.5	34.26	-2.8	0.0
12 Before	G/G	64.5	27.19	59.7	39.7
After	G/G	53.5	22.76	201.9	39.7
20 Before	E/E	64.0	8.68	23.7	20.0*
After	E/E	79.5	6.67	-48.9	20.0*
22 Before	0/0(F)*	62.5	22.05	76.3	20.0*
After	0/0(F)	84.5	14.98	-210.8	20.0*
23 Before	G/G	60.5	22.35	100.9	19.72
After	G/G	84.0	13.80	-205.0	19.72
25 Before	0/G	52.5	30.65	141.5	0.0
After	0/G	61.0	23.86	-66.6	0.0
27 Before	G/G	63.0	20.09	79.3	24.92
After	G/G	45.0	22.35	99.9	24.92
28 Before	0/G	54.5	24.41	52.7	0.0
After	0/G	53.0	24.13	41.6	0.0
31 Before	0/0(F)	60.5	16.09	86.0	20.0*
After	0/0(F)	61.5	10.54	109.6	20.0*
32 Before	0/0(F)	69.5	25.10	51.3	20.0*
After	0/0(F)	45.0	55.90	208.1	20.0*
33 Before	0/0(F)	69.5	14.42	26.4	20.0*
After	0/0(F)	76.0	8.74	88.8	20.0*
38 Before	G/G	64.0	23.48	49.4	20.0*
After	G/G	60.0	26.16	69.0	20.0*
39 Before	0/0(F)	69.0	24.55	87.4	20.0*
After	0/0(F)	45.5	32.46	359.2	20.0*
42 Before	E/E	59.0	8.28	52.5	20.0*
After	E/E	84.5	5.82	-55.4	20.0*
44 Before	G/G	60.0	20.39	112.3	20.0*
After	G/G	51.0	12.88	141.1	20.0*

* Heated in Furnace

EASTON, PA (Cont.)

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
46 Before	0/0(F)	63.0	38.97	227.5	20.0*
After	0/0(F)	69.5	41.47	-106.8	20.0*

FARGO, ND

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
2 Before	G/G	56.5	13.10	42.0	10.0
After	G/G	64.0	8.24	-39.1	10.0
6 Before	0/E	60.0	14.84	18.0	0.0
After	0/E	65.0	6.80	-38.8	0.0
10 Before	0/E	84.5	12.90	-245.5	0.0
After	0/E	64.5	7.63	-43.0	0.0
11 Before	0/G	48.5	14.84	113.7	0.0
After	0/G	84.5	9.99	-216.4	0.0
13 Before	G/G	60.0	16.80	47.0	20.0*
After	G/G	75.5	12.30	-35.0	20.0*
15 Before	0/G	84.5	10.40	-141.5	0.0
After	0/G	77.5	9.29	-109.6	0.0
17 Before	G/E	69.5	11.20	-17.0	0.0
After	G/E	64.5	8.45	-62.8	0.0
22 Before	G/G	66.0	10.40	11.0	20.0*
After	G/G	68.0	9.27	28.8	20.0*
23 Before	0/-	45.0	36.06	271.9	0.0
After	0/-	59.0	23.72	91.5	0.0
25 Before	0/G	45.0	13.73	122.1	0.0
After	0/G	66.0	9.29	-30.5	0.0
26 Before	G/E	72.5	12.90	-52.0	0.0
After	G/E	65.0	10.51	63.9	0.0
27 Before	0/E	84.5	8.04	-158.1	0.0
After	0/E	66.5	5.13	-13.9	0.0
30 Before	G/G	56.0	14.80	59.0	10.9
After	G/G	68.0	7.21	2.1	12.8

FARGO, ND (Cont.)

House #		Fuel Type	T_0	B_1	B_0	HW Factor
32	Before	G/G	59.0	12.60	58.0	10.6
	After	G/G	84.5	9.06	-151.4	10.6
34	Before	O/E	47.5	12.62	77.7	0.0
	After	O/E	67.5	10.26	-18.0	0.0
35	Before	G/G[1]	59.5	14.50	49.0	9.7
	After	G/G	55.5	11.33	56.6	16.8
36	Before	G/G	65.0	6.20	76.0	7.3
	After	G/G	53.0	4.84	99.1	11.9

MINNEAPOLIS/ST. PAUL, MI

House #		Fuel Type	T_0	B_1	B_0	HW Factor
1	Before	G/G	63.0	17.30	110.2	26.5
	After	G/G	55.0	25.13	132.9	26.5
2	Before	G/G	57.0	24.51	102.0	18.4
	After	G/G	55.0	22.35	102.0	18.4
3	Before	G/G	66.0	10.30	91.7	23.9
	After	G/G	78.0	7.83	31.9	23.9
4	Before	G/G	63.0	23.28	71.1	16.0
	After	G/G	62.0	19.57	77.3	16.0
8	Before	O/O(F)	65.0	33.01	-139.7	2.5
	After	G/G	72.5	13.39	87.6	2.5
13	Before	G/G	63.0	37.49	126.7	19.0
	After	G/G	57.5	24.10	166.9	19.0
20	Before	G/G	59.5	19.47	119.5	19.9
	After	G/G	55.0	15.55	112.3	19.9
21	Before	G/G	65.0	19.98	187.5	19.4
	After	G/G	62.5	15.45	106.1	19.4
23	Before	G/G	83.5	34.09	-199.8	49.7
	After	G/G	50.5	39.04	476.9	49.7
25	Before	G/G	66.0	17.61	92.7	20.0*
	After	G/G	54.0	15.04	280.2	20.0*

MINNEAPOLIS/ST. PAUL, MI (Cont.)

House #	Fuel Type	Tø	B_1	Bø	HW Factor
26 Before	G/E	57.0	29.77	34.0	0.0
After	G/E	51.5	18.44	44.3	0.0
28 Before	G/G	63.5	17.72	51.5	20.0*
After	G/G	61.0	15.55	56.6	20.0*
31 Before	G/G	63.5	52.74	97.9	20.0*
After	G/G	61.5	46.66	109.2	20.0*
33 Before	G/G	64.0	21.01	50.5	11.3
After	G/G	60.0	12.98	87.6	11.3
34 Before	G/G	54.0	18.13	138.0	18.9
After	G/G	46.0	19.57	175.1	18.9
36 Before	G/G	53.0	53.35	287.4	20.0*
After	G/G	59.0	35.02	261.6	20.0*
37 Before	G/G	67.5	34.20	173.0	20.0*
After	G/G	45.0	67.16	388.3	20.0*
40 Before	G/G	49.5	19.16	131.8	30.0
After	G/G	45.5	10.82	156.6	30.0
42 Before	G/G	67.0	18.85	79.3	19.0
After	G/G	84.0	14.52	-61.8	19.0
44 Before	G/G	56.0	20.29	137.0	22.0
After	G/G	57.5	9.27	152.4	22.0
45 Before	G/G	66.5	19.88	96.8	22.3
After	G/G	48.0	18.33	282.2	22.3
46 Before	G/G	65.0	14.49	173.0	33.0
After	G/G	45.0	24.62	223.5	33.0

OAKLAND, CA

House #	Fuel Type	Tø	B_1	Bø	HW Factor
5 Before	G/G	57.5	61.90	183.0	20.0*
After	G/G	53.5	160.80	225.0	20.0*
6 Before	G/G	60.5	46.50	226.0	20.0*
After	G/G	61.5	38.00	186.0	20.0*
9 Before	G/G	54.5	42.20	266.0	20.0*
After	G/G	54.5	38.90	258.0	20.0*

OAKLAND, CA (Cont.)

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
17 Before	G/G	52.0	75.30	123.0	20.0*
After	G/G	56.0	42.20	85.0	20.0
19 Before	G/G	60.5	48.80	58.0	20.0*
After	G/G	54.5	94.40	113.0	20.0*
26 Before	G/G	64.0	35.00	192.0	20.0*
After	G/G	67.0	22.50	298.0	20.0*
31 Before	G/G	63.0	20.00	155.0	20.0*
After	G/G	60.0	28.70	179.0	20.0*
33 Before	G/G	64.0	24.70	60.0	20.0*
After	G/G	69.5	14.40	57.0	20.0*
34 Before	G/G	84.5	17.50	-206.0	20.0*
After	G/G	65.0	18.50	83.0	20.0*
35 Before	G/G	59.5	12.50	88.0	20.0*
After	G/G	58.0	19.10	77.0	20.0*
37 Before	G/G	84.5	31.90	-487.0	20.0*
After	G/G	61.0	63.50	57.0	20.0*
38 Before	G/G	67.5	26.60	-3.0	20.0*
After	G/G	61.0	24.30	80.0	20.0*

PORTLAND, ME

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
7 Before	O/E	58.0	32.73	-40.2	0.0
After	O/E	55.0	16.92	-19.4	0.0
9 Before	O/E	69.5	30.51	-285.7	0.0
After	O/E	84.5	9.85	-158.1	0.0
10 Before	G/G	69.5	14.80	-47.0	16.12
After	G/G	55.0	15.45	90.6	18.43
11 Before	O/E	60.5	23.02	20.8	0.0
After	O/E	56.5	13.87	-11.1	0.0
12 Before	O/O(F)	69.5	28.57	16.6	20.0*
After	O/O(F)	58.5	12.34	73.5	20.0*
15 Before	O/E	52.0	47.85	-20.8	0.0
After	O/E	49.5	65.19	-18.0	0.0

PORTLAND, ME (Cont.)

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
16 Before	0/E	84.5	26.35	-604.7	0.0
After	0/E	66.5	14.42	-16.6	0.0
17 Before	0/?	73.0	14.42	-124.8	0.0
After	0/?	63.0	9.57	-22.2	0.0
20 Before	0/0(F)	69.5	20.67	18.0	20.0*
After	0/0(F)	67.0	9.85	80.4	20.0*
21 Before	0/E	58.0	13.87	-16.6	0.0
After	0/E	57.5	7.77	-11.1	0.0
23 Before	0/E	50.5	49.24	26.4	0.0
After	0/E	48.5	38.70	-15.3	0.0
25 Before	0/0(F)	62.5	38.14	292.2	20.0*
After	0/0(F)	57.0	21.22	148.4	20.0*
26 Before	0/0(F)	55.5	28.16	194.2	20.0*
After	0/0(F)	64.0	12.48	38.8	20.0*
28 Before	0/E	83.5	42.44	-747.6	0.0
After	0/E	56.5	34.26	-31.9	0.0
29 Before	0/E	53.0	50.49	-11.1	0.0
After	0/E	54.5	46.33	-20.8	0.0
30 Before	0/0(F)	56.0	30.79	174.8	20.0*
After	0/0(F)	53.5	19.83	101.3	20.0*
31 Before	0/0(F)	80.0	51.32	-988.9	20.0*
After	0/0(F)	56.0	47.71	187.2	20.0*
33 Before	0/E	53.5	53.26	-37.4	0.0
After	0/E	51.0	50.90	-29.1	0.0

ST. LOUIS, MO

House #	Fuel Type	Tϕ	B_1	Bϕ	HW Factor
5 Before	G/G	58.5	16.30	166.0	53.4
After	G/G	53.0	22.97	197.8	53.4
6 Before	G/G	59.5	62.20	86.0	27.9
After	G/G	64.0	55.93	93.7	27.9
7 Before	G/G	61.5	34.10	160.0	45.7
After	G/G	65.0	19.57	80.3	45.7

ST. LOUIS, MO (Cont.)

House #	Fuel Type	Tø	B_1	Bø	HW Factor
10 Before	G/G	60.5	67.00	233.0	20.0*
After	G/G	63.5	65.40	263.7	20.0*
17 Before	G/G	61.5	27.10	134.0	35.6
After	G/G	51.5	50.26	176.1	35.6
23 Before	G/G	59.5	14.90	82.0	20.0*
After	G/G	65.0	15.86	91.7	20.0*
28 Before	G/G	67.0	38.50	90.0	43.7
After	G/G	53.0	58.90	256.0	43.7
29 Before	G/G	63.5	55.30	120.0	20.0*
After	G/G	49.5	115.10	270.0	20.0*
34 Before	G/G	52.5	50.70	201.0	31.3
After	G/G	63.5	29.66	-16.5	31.3
38 Before	G/G	62.5	41.10	136.0	58.2
After	G/G	63.5	29.77	159.7	58.2
40 Before	G/G	69.5	12.60	76.0	23.9
After	G/G	49.0	55.93	149.3	23.9
41 Before	G/G	63.0	37.70	133.0	38.5
After	G/G	55.5	43.26	266.8	38.5
42 Before	G/G	62.5	32.50	73.0	19.5
After	G/G	57.5	19.26	138.0	19.5
46 Before	G/G	58.5	33.30	84.0	23.7
After	G/G	48.0	52.53	206.0	23.7
49 Before	G/G	66.5	43.90	67.0	15.3
After	G/G	72.5	30.38	-85.5	15.3
55 Before	G/G	64.0	20.30	99.0	27.6
After	G/G	59.5	16.79	71.1	27.6
56 Before	G/G	60.5	25.40	93.0	28.9
After	G/G	71.5	18.02	-27.8	28.9
77 Before	G/G	59.0	45.90	157.0	31.4
After	G/G	70.5	23.38	79.3	31.4
92 Before	G/G	62.5	35.10	98.0	17.4
After	G/G	75.0	20.50	25.8	17.5

ST. LOUIS, MO (Cont.)

House #	Fuel Type	Tϕ	B1	Bϕ	HW Factor
93 Before	G/G	62.0	36.10	81.0	20.0*
After	G/G	82.5	19.98	-263.7	20.0*

TACOMA, WA

House #	Fuel Type	Tϕ	B1	Bϕ	HW Factor
4 Before	E/E	70.0	11.27	106.9	28.1
After	E/E	65.0	10.71	93.4	24.5
21 Before	G/G	69.0	29.70	-17.0	20.0*
After	G/G	78.5	22.35	-330.6	20.0*
37 Before	E/E	61.0	9.54	39.2	20.0*
After	E/E	73.5	7.26	-12.9	20.0*
39 Before	E/E	84.5	15.57	-254.3	7.25
After	E/E	76.0	9.81	-105.1	5.61
45 Before	G/G	83.5	19.00	-213.0	18.84
After	G/G	81.0	17.61	-326.5	18.84
49 Before	G/E	54.5	22.80	82.0	0.0
After	G/E	80.5	11.64	-191.6	0.0
55 Before	G/E	67.5	21.90	-46.0	0.0
After	G/E	82.0	19.20	-420.0	0.0
58 Before	G/E	72.5	11.60	-43.0	0.1
After	G/E	83.5	18.23	-450.1	0.1
75 Before	G/G	56.5	15.40	27.0	20.0*
After	G/G	62.5	12.10	1.0	20.0*
76 Before	E/E	54.5	19.26	178.3	20.0*
After	E/E	55.0	21.58	141.1	20.0*
81 Before	E/E	56.5	18.45	214.7	29.91
After	E/E	80.5	9.84	-38.9	17.63
83 Before	G/E	62.0	22.70	-4.0	0.0
After	G/E	84.5	14.73	-361.5	0.0
87 Before	G/G	72.0	11.00	-11.0	12.57
After	G/G	62.5	9.06	42.2	11.99
98 Before	G/E	53.0	28.90	73.0	0.0
After	G/E	62.0	12.90	28.0	0.0

WASHINGTON, DC

House #	Fuel Type	T∅	B_1	B∅	HW Factor
2 Before	P/E	68.5	16.89	20.1	0.0
After	P/E	84.5	10.59	-166.2	0.0
6 Before	0/0(F)	51.0	28.71	113.7	20.0*
After	0/0(F)	50.5	22.75	172.0	20.0*
7 Before	0/E	71.5	23.44	-66.6	0.0
After	0/E	56.5	23.58	41.6	0.0
41 Before	K/P	50.5	36.18	128.3	0.0
After	P/P	58.0	15.06	84.9	23.0
53 Before	0/0(F)	70.5	36.48	212.2	20.0*
After	0/0(F)	84.0	19.70	-217.6	20.0*
57 Before	K/E	80.5	13.77	-76.9	0.0
After	K/E	84.5	17.96	-71.6	0.0

YEAR TOTAL 'MODIFIED' DEGREE DAYS
(Seven year average)

Heating season: 1973-1980 (Mean) ('CHI': 1973-1979)

WEA.STA:	ABE*	ATL	CHA	CHI*	CSP	FAR	MSP	OAK	POR	STL	TAC	WNA*	WDU*
BAL.PT:													
45	1877	669	353	2604	2331	4875	3771	61	2857	1848	609	947	1647
46	2019	741	401	2758	2490	5066	3946	81	3037	1974	719	1045	1778
47	2167	818	454	2917	2655	5261	4125	106	3224	2104	843	1149	1913
48	2320	901	510	3080	2827	5460	4308	138	3417	2238	978	1258	2055
49	2479	989	571	3248	3004	5662	4494	178	3617	2377	1125	1374	2201
50	2643	1081	637	3420	3188	5869	4685	226	3822	2520	1283	1495	2352
51	2813	1179	708	3596	3378	6081	4880	285	4035	2667	1454	1622	2509
52	2987	1283	785	3777	3575	6296	5078	357	4254	2819	1637	1755	2671
53	3167	1391	866	3963	3778	6516	5281	443	4479	2975	1832	1893	2838
54	3352	1506	952	4153	3987	6741	5489	544	4712	3136	2037	2038	3011
55	3543	1627	1044	4348	4203	6970	5701	661	4951	3301	2254	2187	3189
56	3740	1753	1141	4548	4425	7204	5917	796	5196	3471	2483	2342	3373
57	3943	1886	1245	4753	4655	7444	6140	952	5449	3647	2722	2503	3563
58	4152	2025	1354	4964	4891	7688	6367	1130	5707	3828	2973	2669	3759
59	4367	2171	1469	5179	5136	7938	6600	1330	5972	4014	3234	2840	3960
60	4589	2323	1591	5401	5387	8193	6838	1552	6244	4206	3505	3017	4168
61	4817	2481	1719	5628	5645	8454	7082	1792	6522	4404	3787	3200	4381
62	5052	2647	1853	5861	5910	8720	7331	2050	6806	4607	4077	3389	4601
63	5293	2819	1995	6099	6181	8991	7586	2324	7096	4816	4374	3583	4826
64	5541	2999	2143	6344	6459	9267	7847	2612	7392	5031	4680	3785	5058
65	5794	3186	2299	6595	6742	9547	8115	2913	7694	5252	4992	3992	5296
66	6055	3381	2462	6851	7030	9834	8387	3224	8002	5478	5311	4207	5541
67	6322	3584	2633	7114	7324	10127	8666	3545	8315	5711	5635	4427	5793
68	6596	3796	2812	7382	7624	10426	8951	3874	8633	5950	5964	4655	6052
69	6876	4017	3000	7656	7928	10730	9241	4210	8956	6196	6297	4889	6319
70	7163	4248	3196	7937	8237	11033	9534	4552	9283	6448	6634	5131	6592
71	7458	4489	3401	8225	8551	11347	9835	4898	9613	6708	6975	5380	6874
72	7758	4741	3615	8519	8869	11664	10142	5249	9949	6974	7319	5636	7162
73	8066	5003	3841	8819	9191	11987	10455	5602	10288	7247	7666	5900	7458
74	8379	5275	4077	9126	9516	12313	10772	5958	10631	7528	8016	6172	7761
75	8698	5557	4324	9438	9847	12644	11090	6317	10974	7816	8368	6452	8069
76	9023	5846	4582	9756	10181	12978	11417	6676	11323	8110	8722	6740	8382
77	9352	6144	4851	10079	10518	13311	11748	7036	11675	8412	9077	7037	8701
78	9684	6449	5130	10407	10857	13652	12084	7398	12027	8719	9434	7341	9024
79	10022	6761	5419	10739	11197	13996	12421	7759	12382	9033	9793	7652	9352
80	10363	7080	5718	11074	11545	14344	12763	8122	12739	9352	10152	7969	9683
81	10710	7406	6026	11414	11895	14693	13107	8485	13096	9674	10513	8292	10020
82	11056	7738	6341	11757	12247	15046	13453	8849	13456	10003	10873	8620	10361
83	11409	8076	6664	12104	12601	15400	13804	9212	13818	10337	11235	8953	10706
84	11765	8419	6994	12454	12958	15756	14158	9576	14180	10674	11598	9291	11051
85	12123	8767	7330	12806	13313	16114	14513	9941	14543	11011	11961	9633	11404

* ABE: Allentown, PA (for EASTON site -- which included Allentown and Bethlehem).
CHI: Midway Airport (Chicago).
WNA: Washington National Airport.
WDU: Dulles International Airport (Washington, DC).

APPENDIX D

Abstracts of Reports Documenting the CSA Weatherization Demonstration Project

This appendix presents titles, abstracts, and, for available documents, ordering information for all current technical reports and presentations, published and in preparation, documenting the CSA Weatherization Demonstration Project. A useful supplement, a report on criteria for the installation of energy conservation measures, by Trechsel and Launey, also is included.

Items are listed alphabetically by authors' names.

R. Chapman, R. Crenshaw, K. Barnes, and P. Chen, "Optimizing Weatherization Investments in Low-Income Housing: Economic Guidelines and Forecasts." (NBSIR 79-1948), National Bureau of Standards, Washington, DC, 1980.

This study establishes a framework for systematically analyzing the economic viability of alternative methods of weatherizing low-income housing. These methods include, but are not limited to, insulation, weatherstripping and caulking, and installation of storm windows and doors. The economic framework is illustrated through the development of a series of forecasts (economic guidelines) which show the optimal level of weatherization for low-income residences in 15 cities across the Nation. These economic guidelines are designed to assist the Community Services Administration in carrying out its Weatherization Demonstration Program. In particular, they are designed to achieve a more balanced level of weatherization per dollar spent. The optimal level of weatherization is balanced in the sense that, for a given weatherization budget, no increase in net savings (total savings minus total costs) can be achieved by trading one method for another.

Available from the National Technical Information Service (NTIS) as PB 80-162142, price: $11.00 for hardcopy; $3.50 for microfiche.

R. E. Clark. "The CSA Weatherization Demonstration Data Base: Content and Descriptions." Washington, DC, National Bureau of Standards, Technical Note 1156, February, 1982.

The Community Services Administration (CSA) Optimal Weatherization Demonstration assembled what is probably the most comprehensive collection of measurements of actual energy use in occupied housing. The data comes from 240 houses in 12 sites. The sites cover the range of climatic conditions found in the U.S.

The data prescribed to be collected by the CSA Demonstration project included, in addition to five years of whole-house utility consumption records, many other energy-use and energy use-related measurements: 1) one year or more of weekly readings of: furnace or heater consumption, run times, and cycle counts; water heater energy consumption and hot water usage; utility (gas and electric) meters; (representative) floor temperatures; and indoor humidity; 2) two years of monthly measurements of natural air infiltration rates and of temperature stratification patterns in the house; 3) "before" and "after" measurements of furnace or heater steady-state efficiency; 4) "before" and "after" fan tests (induced depressurization of the house to measure tightness/leakiness); 5) thermography of all insulated walls; 6) measurements of possible leakage of heat into unheated attic spaces; 7) comprehensive "costs of weatherization options" data; and 8) data about occupants' behaviors and attitudes that may affect house energy consumption.

This report lists and describes, house-by-house, the actual information in the data base, since not all prescribed measurements were received from all houses in the Demonstration. It also describes the media and formats in which the data exist. This report should facilitate the effective and efficient use of the data by other researchers.

Available from Center for Building Technology, National Bureau of Standards, Washington, DC 20234.

R. E. Clark. "Effects of Home Weatherization on Occupant Comfort: First Repot of a Field Study." (NBSIR 81-2335) National Bureau of Standards, Washington, DC, 1981.

This study reports preliminary examination of data testing the hypothesis that, when existing residences are treated with weatherization retrofitting measures intended primarily to save fuel, house occpants are likely to report improvement in wintertime comfort. Data were gathered through questionnaire-guided interviews with individuals in 108 experimental houses and 37 control houses. These houses, at nine sites representing a range of U.S. climates were part of a three year National Weatherization Demonstration, sponsored by the Community Services Administration and planned and managed by researchers at the Center for Building Technology of the National Bureau of Standards. The experimental houses had been weatherized to determine how much their fuel usage could be reduced by cost-effective retrofitting. The control houses had not been weatherized in the Demonstration. Interview topics included: thermostat setting patterns, impressions of comparative comfort, amounts of clothing worn, and specific comfort and temperature ratings for the house as a whole and for individual rooms in the house. Preliminary examination of the data has focussed on: 1) a composite "comfort change" index, comprised of: indicators of change in comfort-related attributes of the indoor environment, amounts of clothing worn in winter, and comfort ratings of the house and of individual rooms; 2) the specific comfort ratings; and 3) the specific temperature ratings. The results present strong indications of support for the hypothesis.

Available from the National Technical Information Service (NTIS), Springfield, VA 22161 as PB 81-245-334, price: $9.50 for hardcopy; $3.50 for microfiche.

R. Crenshaw, R. Clark, R. Chapman, R. Grot, and M. Godette, "CSA Weatherization Demonstration Project Plan." (NBSIR 79-1706), National Bureau of Standards, Washington, DC, 1979.

This report comprises the plan of a research and Demonstration effort to determine the fraction of energy that may be saved by installing weatherization retrofits in poor peoples' homes throughout the United States. Two broad groups of weatherization retrofits are considered for application in each dwelling: 1) "architectural", those affecting the building shell; and 2) "mechanical", those affecting space heating and service hot water systems. The optimum combination of weatherization options is defined as that set of retrofits which maximizes net savings (the difference between savings in fuel usage and the cost of the retrofit) over 20 years for a particulr house and climatic environment. The retrofits will be selected through present-value benefit/cost analysis. The savings will be established through analysis of utility billings and fuel delivery records before and after weatherization. The report presents the background of the Demonstration, the research tasks associated with the Demonstration, a description of the diagnostic tests to be used, the rationale for economic decisions, the tests for evaluating mechanical systems, and the calculation methods used in selecting architectural options.

Available for National Technical Information Service (NTIS) as PB 293-498, price: $6.00.

Energy Resources Center. Home Retrofit Manual. Chicago, University of Illinois, 1979.

A manual for the nonprofessional installer of architectural weatherization options that discusses the following retrofits: replacing broken windows, resetting glass, weatherstripping windows, packing and caulking of windows and doors, fixing windows, installing plastic storm windows, installing glass storm windows, installing window insulating shutters and panels, replacing existing windows, installing door thresholds and bottom seals, weatherstripping doors, installing storm doors, and replacing existing doors. For each retrofit option, the text and illustrations cover the selection of materials, and preparation and installation procedures.

Available as: Paul Knight. The Illustrated Guide to Home Retrofitting for Energy Savings. New York, NY, McGraw-Hill, price: $14.95, 365 p.

Energy Resources Center. Home Evaluation Manual. Chicago, University of Illinois, n. d.

Contains three sets of bound evaluation forms for planning and weatherization of homes, one set each for single-family residences, multi-family buildings, and rental units. Each booklet contains 13 evaluation forms covering occupants' retrofit preferences, general building information (covering heating systems), windows, doors, basements, crawl spaces, slabs-on-grade, walls, finished and unfinished attics, holes/cracks, and mechanical systems. Descriptive material about the household, the dwelling unit (e.g., number of rooms), temperature (indoors), etc., is also covered.

R. A. Grot. "An Assessment of the Application of Thermography for the Quality Control of Weatherization Retrofits," In Proceedings of Thermosense II (Second National Conference on Thermal Infrared Sensing Technology for Energy Conservation Programs). Falls Church, VA, American Society for Photogrammetry, 1980.

Approximately 65 single-family low-income homes in eight cities (Portland; Maine; Minneapolis/St. Paul; Minnesota; Fargo, North Dakota;, Tacoma, Washington; St. Louis, Missouri; Washington, DC; Atlanta, Georgia; and Charleston, South Carolina) were retrofitted using a series of weatherization techniques which included air infiltration reducing measures such as caulking and weatherstripping, adding attic insulation, installing storm windows and doors, insulating basements and crawlspaces and insulating exterior walls with either ureaformaldehyde (UF) foam or blown-in cellulosic insulation. Thermographic surveys of these dwellings were performed after the weatherization work was completed in order to assess the effectiveness of installation and to determine the percentage of wall not insulated by the contractors and the defects which still existed in the dwelling. It was not uncommon to find large areas of the wall still uninsulated, ceilings with improperly installed insulation, heat losses around door and window frames, excessive heat losses from eaves and soffits, shrinkage and fissures in the insulation, excessive basement heat losses and air penetration into interior cavities. Examples are presented of typical deficiencies still existing in the dwelling, and data are presented showing the frequency of deficiencies revealed by thermographic inspections. In an effort to assess the inspection techniques being employed by thermographic inspection services, a comparison is made of the results of thermal inspection by private thermographic contractors and those performed by the National Bureau of Standards. The preliminary results of this comparison indicate a need for further development of thermographic inspection methods, training of thermographic inspectors and possibly the certification of thermographic operators for the inspection of buildings.

Proceedings are available from the American Society for Photogrammetry, 105 North Virginia Avenue, Falls Church, VA 22046.

R. A. Grot and R. E. Clark, "Air Leakage Characteristics and Weatherization Techniques for Low-Income Housing," Thermal Performance of Exterior Envelopes of Buildings. In Proceedings of the DoE/ASHRAE Conference, December 1979. New York, NY, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1981.

Data are presented on the air leakage characteristics of approximately 250 dwellings occupied by low-income households in 14 cities, in all major climatic zones of the United States. Two types of measurements were used: a tracer-gas decay technique using air sample bags, which was developed at the National Bureau of Standards to measure natural infiltration rates of buildings; and a fan test, developed to measure induced air exchange rates. The data presented here show that for this group of dwellings natural air infiltration rates are distributed approximately lognormally.

The induced air exchange rates are a measure of the tightness of building envelopes. There is little correlation between the natural air infiltration rates and the induced air exchange rates in these dwellings, unless the buildings are divided into classes of similar buildings. The use of fan depressurization as a diagnostic tool to assist weatherization crews in tightening buildings is discussed. Preliminary estimates are presented of the reduction in induced air exchange rates that may be achieved by applying building weatherization techniques.

For the availability of this proceeding (ASHRAE SP 28), contact the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, NY 10017.

R. A. Grot and R. E. Clark. "Techniques for the Field Evaluation of Residential Building Envelope Weatherization Retrofits." National Bureau of Standards, Washington, DC, in preparation.

Measurement and data analysis techniques for the field evaluation of residential building envelope weatherization retrofits being applied to approximately 200 low-income dwellings in 12 cities in the continental United States [1] are described. Techniques which use fuel bill records and weather data for predicting the past and future energy consumption of dwelling are developed, and their application to the evaluation of the energy savings realized from groups of weatherization retrofits is presented. Submetering requirements, simple methods for monitoring the interior environment of a dwelling and methods for handling the data analysis from these measurements are specified. Several procedures for determining the air leakage characteristics of a building are developed: a simple low-cost procedure for measuring the actual air infiltration rates of each dwelling in this weatherization Demonstration using a tracer gas and air sample bags and the measurement of tightness of a dwelling using a fan depressurization technique. The inspection of dwellings using thermographic techniques for locating the major heat losses is discussed. The application of thermography as a quality control tool for assessing the effectiveness of various weatherization retrofits and methods for analyzing and representing the results of thermographic inspections are developed. The location of not obvious air leakage path still remaining after normal weatherization techniques have been applied using fan pressurization and infrared thermal scanning equipment is described. Measurement techniques for determining, in the field, the thermal conduction values of the major components of the building heating load are described and the location of heat flow sensors using the results of the thermographic inspectors of the dwelling is treated. The determination of the amount of temperature stratification occurring in the dwellings and methods for analyzing temperature stratification data are highlighted. A procedure for identifying the existence of attic bypass heat losses is discussed. Preliminary data gathered from each of these tests is included.

For availability of this document, contact Dr. R. A. Grot, Building Thermal and Service Systems Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, DC 20234.

R. A. Grot and R. W. Beausoliel. "Estimating Savings from Modification or Replacement of Residential Furnaces and Hot Water Heaters." National Bureau of Standards, Washington, DC 20234, in preparation.

This report presents the methodology used in the CSA/NBS Optimal Weatherization Demonstration for the selection of mechanical system retrofits which can be applied in low-income housing. Simple test procedures are given for determining the condition of the heating system, heat distribution system and domestic hot water heater. The tests described consists of: 1) measurement of the steady-state efficiency of the heating system; 2) an energy and flow balance on the heat distribution system; 3) a safety inspection of the heating system; 4) a combination efficiency test of the water heater; 5) a recovery efficiency test for the water heater; and 6) measurement of the flow rate of the showers.

For the availability of this document contact Dr. R. A. Grot, Building Thermal Performance Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, DC 20234.

R. A. Grot, "A Low-Cost Method for Measuring Air Infiltration Rates in a Large Sample of Dwellings," In C. M. Hunt, J. C. King, and H. R. Trechsel (Eds.), Building Air Change Rate and Infiltration Measurements, ASTM STP 719, American Society for Testing and Materials, 1980, pp. 50-59.

A method for collecting air infiltration data in a large sample of dwellings is presented. The method consists of a tracer gas dilution technique employing air sample bags that are analyzed in a central laboratory. The method was later applied in a Community Services Administration Optimal Weatherization Demonstration to approximately 200 dwellings at 12 sites throughout the United States. The method will yield air exchange rates under typical heating season conditions for each dwelling in the Demonstration. Preliminary data on air infiltration rates in low-income housing in Portland, ME are presented.

A limited number of complimentary reprints are available from Dr. R. A. Grot, Building Thermal and Service Systems Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards, Washington, DC 20234.

R. A. Grot. Field Techniques for Measuring the Savings of Energy Improving Retrofits In Single-Family Dwellings. Liege, Belgium: Conference on Comparative Experimentation of Low-Energy Houses. University of Liege, May 1981.

Instrumentation and data handling methods for determining the energy savings from applying retrofits to existing dwellings are described. The application of these techniques to an optimum weatherization program carried out in over 200 dwellings in 12 cities in the United States during the last four years are presented. The techniques used include methods for measuring the air infiltration rates in the dwellings, analysis of fuel records, testing of the mechanical systems, thermographic inspections to determine the quality of workmanship, tests for determining the existence of heat bypasses, and metering requirements. Sample data from these tests are given and several methods using the results of these tests for estimating the savings due to various retrofit measures are presented.

H. R. Trechsel and S. J. Launey. "Criteria for the Installation of Energy Conservation Measures." (NBS Special Publication 606), National Bureau of Standards, Washington, DC 20234, 1981.

Standard installation practices were developed to assist in assuring the effectiveness and safety of energy conservation measures installed under the Residential Conservation Service (RCS). They serve as mandatory standards under RCS but are recommended guides for all installations of the covered materials and products. The criteria are being used by DoE to develop training manuals for installers, inspectors, and energy auditors.

Part I provides information on the intended use of the practices, outlines the RCS program, and discusses major technical and related issues that were considered in the development of the standards: moisture and surface-building retrofit, attic ventilation, electrical wiring, recessed and surface-mounted fixtures, the use of diagnostic tools (infrared thermography, air change rate, and window air leakage measurements), and product certification.

Part II provides the actual practices together with commentary and additional recommendations. The products covered are loose-fill, batts and blankets, rigid foam boards, UF foam and reflective insulations, window devices, caulks and sealants, water heater insulation, oil burner replacements, and vent dampers.

Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, as Stock #003-003-02337-0, price: $6.00.

S. F. Weber, M. J. Boehm, and B. C. Lippiatt, "Weatherization Investment Costs for Low-Income Housing." (NBSIR 80-2167), National Bureau of Standards, Washington, DC 20234, 1980.

This report presents the results of a project involving the collection and tabulation of field data on the costs of retrofitting low-income houses for energy conservation. This project is part of the Community Services Administration Weatherization Demonstration Program being carried out through the National Bureau of Standards. The program involves the installation and evaluation of a broad range of energy conservation techniques for over 200 single-family houses in 14 Demonstration sites throughout the United States. The energy conservation techniques discussed in this report consist of a variety of architectural modifications to building envelopes for the purpose of reducing heat losses due either to air infiltration or conduction. The methods used to collect and synthesize the field data on the major cost components of installing these techniques are described. An analysis of these costs is presented in the form of summary statistics including the weighted mean and standard deviation of the unit cost of installing each architectural option in each demonstration site. The significant inter-city variation found in the mean unit cost of most techniques suggests that unique cost estimating procedures may be needed for each city. Possible sources of variation in the mean unit costs are discussed. Recommendations for further research include investigating the effect on cost that can be attributed to selected sources of variation.

Available from National Technical Information Service (NTIS) as PB-81-133829, price: $9.50 for hardcopy, $3.50 for microfiche.

R. Crenshaw. <u>Thermal and Economic Performance of Low-Income Housing</u>, LBL-14529 Lawrence Berkely Laboratory, Univ. of California, Berkeley, CA, June, 1982.

One hundred forty-two low-income homes in 12 cities across the United States underwent "optimal weatherization," which included insulation, reduced infiltration, and modifications, to windows and heating systems. Average savings of 40 percent were achieved at a cost of $1,800. After the cost-effectiveness of optimal weatherization was measured, some houses were further upgraded with house-doctoring, solar air collectors, circulating fans, and wood stoves; then another set of measurements were taken. Four years of data have been collected and analyzed. From it conclusions can be drawn about the cost-effectiveness of introducing a combination of wood stoves, furnace retrofits, infiltration controls, small solar air collectors, and reductions in thermal conductivity of the building shell.

R. Crenshaw. Instrumented Audits, LBL - 14853, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, August, 1982.

This paper addresses the following questions: How accurate are audits that include measured indoor temperatures, infiltration rates (SF_6), and mechanical efficiencies (Bacharach) and that use a balance point degree-hour method of calculation? This is the type of audit that most researchers say is needed to provide reasonable results, yet the type that most public agencies say they have neither the time nor trained personnel to conduct.

To explore these questions, two types of calculations were performed on 110 houses at 9 sites across the U.S. and then their results compared to measured data. The first is a simple steady-state annual heat loss calculation typical of those found in most current residential energy audits. The second is a balance-point degree hour calculation performed on a monthly basis and including average measured indoor temperatures, estimated internal gains, site-measured infiltration rates, and furnace efficiencies.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes and presents the results of the Community Service Administration's (CSA's) Optimal Weatherization Demonstration Research Project carried out by the National Bureau of Standards (NBS). The CSA/NBS demonstration installed both architectural (building shell) and mechanical systems building weatherization options, and achieved, when both types of options were used, an average reduction in space heating fuel consumption of 41 percent, at an average weatherization cost of $1,862 per house.

The report explains the rationale used for selecting a sample of more than 200 houses at 12 sites across the United States, and for selecting optimal levels of weatherization for each of the houses. It presents measured energy consumption and detailed descriptive data on the houses before and after weatherization, the percentage savings achieved, and shows the costs of infiltration, conduction, furnace and water heater retrofits. Finally, it reports what options actually were installed in each house, and describes how data on the performance of those options were gathered and analyzed.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Community Action Agencies; Community Services Administration; costs of residential weatherization; energy conservation; field measurement of building energy consumption; optimal weatherization; residential energy consumption; weatherization.

13. AVAILABILITY

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National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396).

NOTE: The principal publication outlet for the foregoing data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

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