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…echnical Summary of the Final Report "Optimal Weatherization of Low-Income Housing in the United States: A Research Demonstration Project"

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Environmental Design Research Division
Washington, DC 20234

May 1982

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NONTECHNICAL SUMMARY OF THE FINAL REPORT "OPTIMAL WEATHERIZATION OF LOW-INCOME HOUSING IN THE UNITED STATES: A RESEARCH DEMONSTRATION PROJECT"

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Abstract

This report summarizes in nontechnical language the nature and results of the Community Service Administration's (CSA's) Optimal Weatherization Demonstration Research Project carried out by the National Bureau of Standards (NBS). This summary draws on the final report of the field evaluation of the Demonstration, an NBS publication entitled Optimal Weatherization of Low-Income Housing in the U.S.: A Research Demonstration Project (NBS BSS 144). Unless stated otherwise, this report references the final report.

The CSA/NBS demonstration installed both architectural (building shell) and mechanical systems 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.

This summary report also includes abstracts of all the technical reports documenting the CSA/NBS project. Directions for ordering available reports are included.

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

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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 ($Btu \cdot in/h \cdot ft^2 \cdot °F$)	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.

1. OVERVIEW

The "energy crisis" has made American consumers acutely aware that energy prices are rapidly rising and will continue to rise for the foreseeable future. Rising energy prices have meant that low-income homeowners often spend a disproportionate share of the family budget on energy. Increasing housing expenses have forced some low-income homeowners to spend less on other essentials, such as food, clothing, and health care. Resulting Congressional concern for the health and well-being of low-income Americans coupled with Congressional recognition of the value of weatherization as an energy-conserving strategy led to the passage of the "Headstart, Economic Opportunity, and Community Partnership Act" (Public Law 93-644) in 1975 and the "Energy Conservation and Production Act" (Public Law 94-385) in 1976. As alternatives to subsidizing fuel costs, these two laws established energy conservation programs for low-income families and provided grants for the weatherization of residences. In Public Law 93-644, Congress directed the Community Services Administration (CSA) to conduct a nationwide program to estimate how much money could be saved through optimal weatherization [1].*

In partial fulfillment of this mandate, CSA asked the National Bureau of Standards (NBS) in 1977 to devise a research plan for measuring the technical effectiveness of weatherization activities of Community Action Agencies (CAA's). The purpose of the demonstration was to provide a technical basis for estimating how much money and energy could be saved by "optimal" weatherization of houses occupied by low-income families [6]. The Demonstration also sought to learn about the effectiveness of three broad categories of building retrofit: (1) increasing the thermal resistance of the building shell by adding insulation or storm windows ("conduction"); (2) reducing infiltration (of cold air) and exfiltration (of heated air) by such means as caulking and weatherstripping ("infiltration"); and (3) improving the efficiency of heat producing and distributing systems in houses ("mechanical systems") [6].

The CSA/NBS Demonstration ultimately obtained results from 183 houses at 12 sites (see figure 1) representing a range of U.S. climatic zones. This climatic variety was needed in order to identify the range of savings that weatherization could achieve. "Before weatherization" rates of fuel consumption of the houses were established by analyzing two years of recorded fuel delivery or consumption records. Based on the local climatic conditions, the local costs of fuel saved, and the local prices of installing various energy-conserving retrofit options, a cost-effective set of weatherization options was selected for installation at each house, using economic (life cycle benefit-cost) analysis. The criterion used for selecting retrofit options was that the package would generate the greatest possible net savings, in dollars, for the dollars spent over the life of the options. These options would provide

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* Numbers in brackets "[ ]" are keyed to the references listed in section 4 of this report.

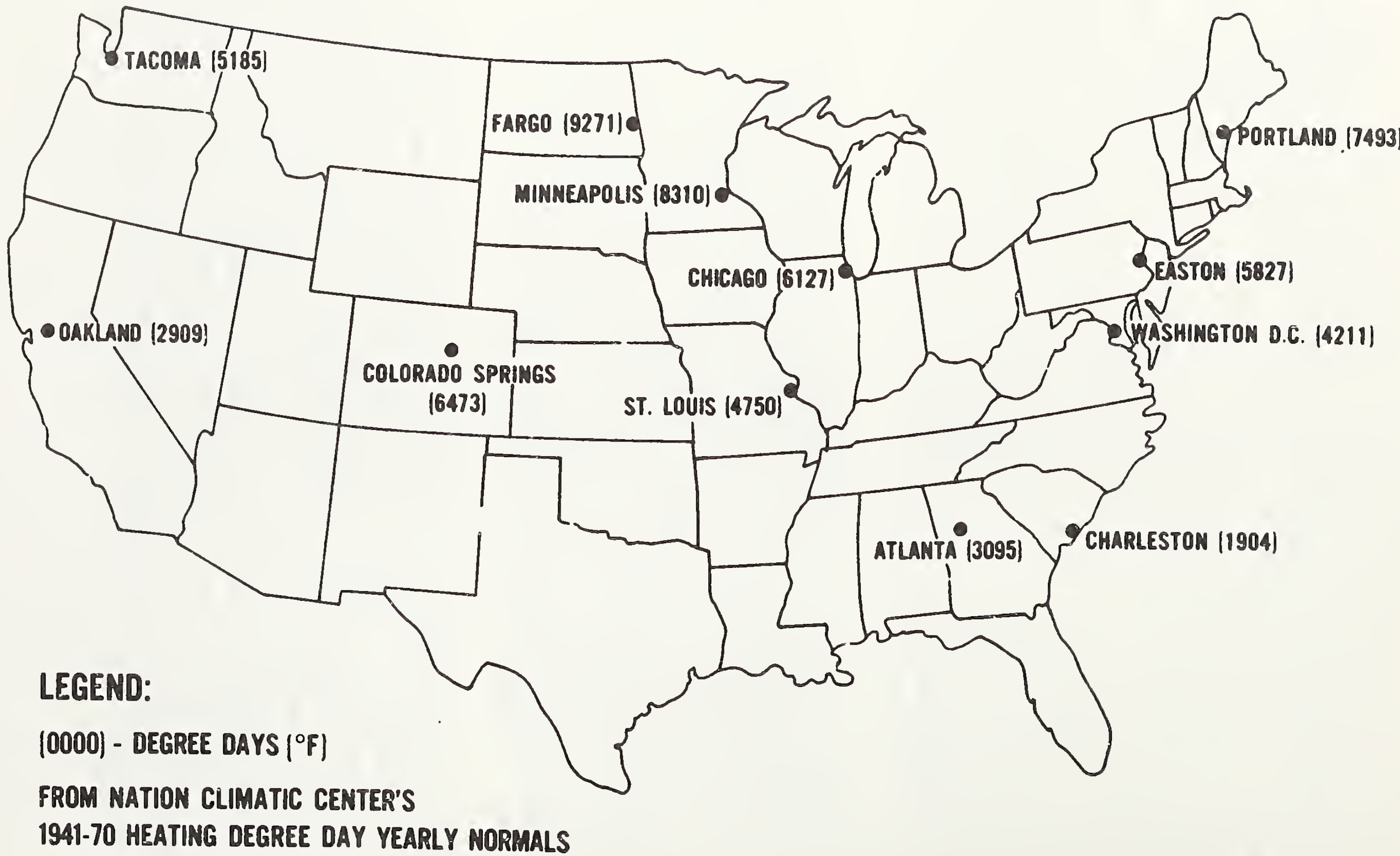

Figure 1. Selected sites for the demonstration

economically "optimal" weatherization.* Architectural (i.e., conduction and infiltration-related) and, in many cases, mechanical system options were installed by local Community Action Agency (CAA) crews in the site area, and/or by local contractors.

Energy use in the houses was monitored for at least one heating season following weatherization. A number of physical measurements of each house (e.g., temperature, infiltration rate) were made. Physical measurements, cost data, and fuel consumption readings were supplemented by interviews with occupants at nine sites about the wintertime comfort of their homes [2].

To clarify the effectiveness of the retrofit installations, several dwellings in which no weatherization options were installed were measured at each site for comparison purposes. Thus, the energy use, thermal performance, and occupant evaluations of comfort of the weathered buildings were compared to otherwise similar houses "without" weatherization. This comparison was made to isolate and measure the effectiveness of weatherization strategies for residential energy conservation.

In summary, at 12 sites across U.S. climatic zones, 142 low-income household's homes were weatherized; the choices of which options to use were based on economic analyses. In addition, 41 residences were not weatherized and were used for comparison purposes. Energy use, occupant comfort, costs, and estimated savings were measured. The overall results are summarized in table 1.

The measures in table 1: costs vs. savings (estimated payback period), fuel consumption, and comfort improvement, all favor weatherization over no weatherization. Furthermore, installing mechanical systems as well as architectural options, although it will cost somewhat more than installing architectural options alone, will pay back faster, result in greater reductions in fuel consumption, and in somewhat greater improvements in wintertime comfort inside the house.

To better understand the results, each of the row headings in table 1 will be briefly explained.

Cost of an option reflects actual costs reported by CAA's. Costs include labor, material, overhead, and profit.

Payback period is a simple savings measure. It is obtained by dividing the total cost of weatherizing a house by the product of the amount of fuel saved and the 1980 cost of that fuel. This measure was chosen over more mathematically sophisticated ones, because it is an understandable measure, meaningful to more people.

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* In general, the economically optimal package included mechanical system retrofits as well as architectural modifications. However, in some cases, no mechanical options were found to be cost-effective, or feasible, for the heating system present in a house.

Table 1. Comparison of the Impact of Extent of Weatherization on Costs Savings, Energy Consumption and Comfort Improvement (All Values are Averages)

	Houses in CSA Demonstration			
	Weatherized			Nonweatherized
	(1) Arch. & Mech. Options	(2) Arch. Options Only	(3) Total Weatherized (1) & (2)	(4) Control Group
Cost of Options	$1,862	$1,336	$1,610	--
Payback Period (in years)	6	15	8	--
Percent Savings in Fuel Consumption	41	17	31	4
Comfort Improvement	0.66	0.56	0.61	0.09
Number of Houses in the Sample	74	68	142	41

Percent savings in fuel consumption was generated from a statistical analysis of the relationship between fuel consumption and "degree days", a term that expresses the amount of coldness during a winter heating season. The results of this analysis were used to estimate what the pre- and post-weatherization fuel consumption of the houses would be for a "typical" year.

Comfort improvement is based on the occupants' evaluations of their thermal comfort at home during the pre- vs. post-weatherization heating seasons. This composite measure takes into account changes in thermostat settings, expressed wintertime comfort, amount of clothing worn indoors during the winter, and comfort ratings of individual rooms and of the house as a whole. A 0.0 means the occupants reported no change in comfort. A 1.0 means the occupants reported change in the direction of improved wintertime comfort on all of the aforementioned indicators [2, pp. 29-30].

The implications of these results are clear. Weatherization is a cost-effective alternative to subsidizing fuel costs during the heating season, and a means of helping to ensure the health and well-being of low-income families pressed by rising fuel costs. Unlike subsidization of fuel bills, weatherization pays for itself. After the retrofit package has paid for itself, the householder can put the continuing savings to uses the family considers important. In fact, as fuel prices continue to rise, weatherization becomes increasingly attractive as a homeowner investment, since the savings are greater and the payback period shorter.

Public money will be saved through weatherization of housing. Also, the Nation's dependence on foreign fuel supplies will decrease. Put this statement into perspective: there are now over 84 million dwelling units in the United States. It is estimated that these units will comprise 85 percent of all dwelling units available in the year 2000. Today's existing units, then, are the largest share of the Nation's housing stock tomorrow. Most of these residences could be made more energy efficient. Heating the current housing stock requires 11 percent of all energy used in the U.S. "Optimal weatherization" could significantly reduce this consumption. If an average 40 percent reduction in energy use could be achieved in all housing, it would result in an estimated saving of energy equivalent to more than 100 million barrels of oil a year. This could have a positive effect on the Nation's economy as a whole and on the household budgets of all families paying fuel bills in order to keep warm.

Going further, although this Demonstration achieved an average 40 percent fuel savings in optimally weatherized homes, savings as high as 70 percent were achieved in individual houses. Average savings of 50 to 70 percent could probably be achieved by adding other energy-saving strategies, such as "house doctoring" and solar heating, to optimal weatherization. House doctoring involves the use of furnace tests to assess mechanical system efficiencies, thermography (heat-sensing photography) of walls to determine thermal leakages, and fan tests to measure air leakages, as bases for selecting needed, house-specific retrofit options. The CSA/NBS Demonstration Project staff have suggested that house doctoring alone could achieve fuel savings of an additional 10 percent.

2. DETAILS OF THE CSA/NBS OPTIMAL WEATHERIZATION DEMONSTRATION

This section is for the reader who wants to lean a bit more about the CSA/NBS Optimal Weatherization Demonstration than was presented in the Overview section.

2.1 INTRODUCTION

There are 55.5 million single-family residential units in the United States. This includes 10 million dwellings of low-income homeowners. Among these houses are many typical of middle-income Americans, particularly those houses occupied by retired citizens who, because of their change in job status, find themselves in a low-income category. Thus, the findings of a study of homes of low-income homeowners are applicable to not only the 10 million homes of low-income families but also to houses of middle-income Americans that are similar to the dwellings of low-income retired Americans analyzed in this Demonstration.

There is good reason to focus on low-income households. They often spend a disproportionate share of their family budget on energy. During the winter, fuel costs can confront the low-income homeowner with a painful choice between home heating and the purchase of food, clothing, or health care. Congress recognized this problem and responded with the passage of Public Laws 93-644 and 94-385. These two laws established energy conservation programs for low-income families and provide funds for weatherization (i.e., energy conservation retrofitting) grants. Public Law 93-644 also assigned the leadership role in administering a nationwide evaluation of weatherization to the Community Services Administration (CSA).

CSA selected the National Bureau of Standards (NBS) to conduct a nationwide demonstration of how much money and energy could be efficiently saved through weatherization of low-income families' homes.

2.2 WEATHERIZATION AND OPTIMAL WEATHERIZATION

Although several alternatives to reducing the impact of rising fuel costs on low-income homeowners were considered by NBS, including the use of renewable energy sources such as the sun or wind, energy conservation offered the most savings for the cost. Moreover, the technologies were readily available in every region of the Nation.

Weatherization refers to the installation or retrofitting of energy conserving designs or devices on an existing structure. There are two advantages to investing in weatherization. A particular advantage is that most weatherization options can pay for themselves in saved fuel cost over the term of the typical home improvement loan. Another is that, as energy prices continue to rise, weatherization investments act as a hedge against the destructive effects of inflation on low-income families, particularly those on fixed incomes. In all, weatherization offers low-income homeowners an opportunity to permanently increase future consumption of essentials, such as food and clothing, without drastically reducing their wintertime health and well-being [1].

Levels of weatherization can differ. Therefore, a major objective of the CSA demonstration was to identify and test "optimal" weatherization levels, levels that took into account local climatic conditions and local supply and demand factors in the energy and construction sectors. The technical approach to identifying "optimal" weatherization levels for the low-income families' homes was explicitly economic. The economic analysis was based on the premise that improving the efficiency of space heating systems and increasing the thermal resistance of the building envelope (i.e., adding insulation to, and reducing air leakage through, the exterior walls, roof, and ground floor that enclose the house) are nearly perfect substitutes for energy consumption [9]. Therefore, to find the "optimal" level of weatherization investment for a house, it is necessary to weigh the costs of weatherization against future reductions in energy consumption. Economic analysis demonstrates that each additional unit or level of weatherization should result in smaller reductions in energy consumption. In this approach, the economically optimal level of weatherization -- the one that results in the maximum net savings over the life of the weatherization option -- typically will not be the level that minimizes energy consumption [1]! In other words, low-income homeowners must be careful not to over-invest their scarce dollars in too much weatherization.

The economic analysis developed by NBS for calculating weatherization costs and savings designates a group of weatherization options for a particular house by determining for each increment in weatherization whether the additional dollars saved in energy costs over the life of an option (increment) are greater than the cost of purchasing and installing that option. The economically-optimal level, in this life-cycle benefit-cost approach, is that set of options whose incremental cost equals its incremental savings [1].

An optimal level at any one time or in any one house is unlikely to be optimal at another time or house. Over time, new technologies and materials are introduced, costs of materials and labor change, fuel costs change, and the like. Different places offer their particular climatic conditions, fuel costs, and initial levels of weatherization of the houses. Thus, the 12 sites participating in the CSA Demonstration, each with its unique conditions, require individual calculation of optimal weatherization options.

2.3 THE SITES

The selection of cities in which the homes of low-income homeowners would be weatherized was based on the need to accurately measure the effects of as many important determinants of weatherization savings as possible. Climate, as the major variable affecting energy consumption, hence, energy savings, was the principal determinant in site selection. By conducting a weatherization demonstration in a range of climatic conditions, better estimates of nationwide savings attributable to weatherization options was possible [1].

Based on a careful analysis of climatic conditions and building climate zones, 16 cities representing a variety of climatic conditions were selected initially as candidate sites for the weatherization Demonstration.

Each site had to meet two selection criteria. First, the local Community Action Agency (CAA) had to be able to provide field crews who could not only effectively install weatherization options, but who were also able to collect and organize energy use data from the houses in the Demonstration. Second, hourly climatic data had to be available for that location on National Weather Service computer tapes.

The 12 cities that finally participated are shown in figure 1. The number of degree days (DD) for each city appears in parentheses near the city's name.

2.4 DWELLING SELECTION

To be considered for the demonstration, houses had to meet five criteria [6]:

1. Accurate data on prior energy consumption had to be available.

2. The houses must have been occupied continuously by the same family for the two years before the Demonstration began (i.e., since April 1975).

3. There had to have been no major changes to the building's envelope or heating system during the two years before the Demonstration began (i.e., since April 1975).

4. The house should be in an acceptable state of repair.

5. The shape of the house should be simple, preferably a rectangle.

Additional factors were considered in the selection candidate houses [5, 6]. These were:

6. Housing (building) type, such as single-family detached.

7. Construction material, such as wood frame or masonry veneer.

8. Type of heating system, such as floor furnaces, vented and unvented space heaters, baseboard heaters, in addition to hot water or hot air circulated central heat.

9. Age of the house -- whether it was pre-World War I or post-World War II vintage, or was constructed between World Wars.

10. Building size.

11. Percent of wall area consisting of glass.

12. Building orientation.

13. Occupant characteristics.

Factors 6-13 were treated as follows. The variables mentioned in items 6-9 were controlled by NBS. Each site was asked to submit at least three houses from each of the time periods noted in item 9. Building type and construction materials (items 6 and 7) were controlled by asking local CAA workers to submit at least five of each locally available combination of one- and two-story detached and attached houses of frame, masonry, masonry veneer, and adobe construction. Local CAA officials also were asked to submit a variety of heating system types, such as those noted in item 8. The aim was to have at least five of each type in the Demonstration. Item 10, building size, was statistically controlled by expressing energy use as Btu's (a unit for measuring energy), per square foot. Items 11-13, glass area of wall, building orientation, and occupant characteristics, were allowed to vary within and across sites. This was based on the assumption that they would introduce no systematic bias into the results. These attempts at controlling important variables were generally successful.

In the end, 222 houses were chosen for weatherization and 68 houses for the nonweathered comparison group. The nonweatherized comparison group (its purpose is explained in the next section) came from the same pool of houses as did the houses to be weatherized, showed similar pre-weatherized fuel consumption as did the to-be-weatherized houses in the site city, but differed principally from the to-be-weatherized houses in three ways: 1) the building type and construction material combination were unusual in the pool (i.e., five cases could not be found in the city); 2) the house did not have a simple shape (e.g., it might have been "L" shaped), which made certain thermal analysis calculations more difficult; or 3) the owners did not want their house to be weatherized as part of the Demonstration [2, p. 21].

Sufficient data were taken for the required time period from only 142 weatherized houses and 41 comparison group houses of the original 290 houses identified Houses were lost from the weatherization group because owners no longer wanted to participate or the houses were physically abandoned. Comparison group houses were lost for the same reasons and, in some cases, because the owners partially weatherized their own homes. Of the 142 weatherized houses, 74 received mechanical systems as well as architectural options; see the section on the selection of weatherized options.

2.5 RESEARCH DESIGN

A research design is the basis for establishing whether there is a relationship between the events under study (in this case, between weatherization and energy consumption), what the relationship is (in this case, the prediction that weatherization should result in a decrease in energy consumption), and how the relationship can reasonably be explained (in the present case, that changes in energy consumption are due to weatherization) [8].

The Demonstration's research design employed two research techniques to help assess the effects of weatherization on energy consumption. First, energy usage and related factors were measured before and after weatherization. Second, housing from the same housing pool as the weatherized housing, but which did not receive weatherization (the comparison housing) also had its energy usage and related factors monitored during the pre- and post-weatherization periods.

What relationships among events did the NBS researchers expect? They expected the weatherized and nonweatherized (comparison) housing within site cities to have comparable pre-weatherization energy consumption. They expected the weatherized housing, but not the nonweatherized comparison housing, to save energy, specifically, to decrease energy consumption during the post-weatherization period of measurement. (Both expectations were supported by the results.)

The numbers of weatherized houses (from which adequate data were received) are shown in the city-by-city summary data (table 5). The number of nonweatherized (control) houses at each site from which adequate data were collected ranged from two to five.

2.6 THE SELECTION OF WEATHERIZATION OPTIONS

For the CSA Optimal Weatherization Demonstration, optimal weatherization was that group of "architectural" (building shell) and "mechanical" (space heating systems) retrofit options generating the greatest possible dollar value of net savings over the life of the options. Using techniques of economic analysis, the group of options for a specific house was selected by analyzing, over the life of each option, the cost and the future energy savings associated with each increment in weatherization. The economist's optimal level of weatherization is the level where incremental cost equals incremental savings. These options might not result in maximum energy savings, but will be the most cost-effective energy-saving option package [1].

An "increment of weatherization" is a single, specific energy saving modification that can be made to a house. In the case of architectural options, these increments may include an added inch of insulation, or storm windows over single glazing, or caulking a door. For mechanical options, increments may include installing a clock thermostat, installing a flue damper, or replacing a furnace [4].

As noted earlier, the introduction of new materials and technologies; differences and changes in the cost of materials, labor and fuel; variations in the initial physical condition of a house; difference in climate; and the like, mean that what constitutes "optimal" weatherization options for installation will vary with the location of the house and over time.

Again, the CSA Demonstration focused on the savings related to combinations of energy conserving retrofits. Future studies could address savings associated with individual options and other strategies such as alternative energy sources (e.g., passive and active solar energy options).

To select architectural options, areas of the house considered were walls, the roof, floors, basement walls, doors, windows, and cracks or holes in these areas. For each of these areas, each possible incremental installation (option) was examined for its costs and benefits (estimated savings). Optimal combinations were established taking into account climate, option prices, and fuel costs.

The cost-benefit ratio was calculated using the following formula:

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Predicted Fuel Savings X Present Value Factor X Cost of Fuel}}{\text{Replacement Factor X Cost of Option}}$$

where

Predicted Fuel Savings were calculated, in Btu's, using a modified version of the ASHRAE steady-state heat balance equation (discussed in ref. [1]).

Present Value Factor makes future energy savings in dollars comparable to the present cost of an option.

Cost of Fuel was obtained at each city in the Demonstration, and reflected local taxes, surcharges, and block rates (which are used for electricity and natural gas, and affect the price of fuel depending on the amount used).

Replacement Factor relates to options that are not expected to have a 20 year physical life. Twenty years was selected as a criterion because it was the maximum life of most of the weatherization options being considered by NBS. In some cases, the first cost of an option was adjusted to reflect the present value of future costs of any replacements needed to achieve a 20 year life.

Cost of an Option includes first costs based on estimates obtained for CSA officials and contractors in Demonstration site cities, and it includes any future costs resulting from maintenance, repair, or replacement, discounted to present value, over a 20 year period of use.

The selected architectural options are summarized in table 2 [4]. Unit-by-unit summaries are in [5].

The mechanical options were selected independently of the architectural ones. For this analysis, it was assumed that architectural options had reduced the building load by 50 percent and the mechanical systems were "optimized" to that reduced load. Assumed seasonal efficiencies for oil systems were 60 percent; for gas systems, 70 percent; and for unvented space heaters, 100 percent [4].

Whereas architectural options were based on climate, mechanical options were based on the type of space heating system. Using results of earlier NBS research on space heating system tests (discussed in [6], pp. 42-54), efficiency improvement values were assigned to each retrofit that could be physically added to an existing space heating system.

This value was then multiplied by the energy load of the building (reduced by 50 percent to allow for the predicted effects of the architectural options) to calculate expected energy savings. The calculated equivalent dollar savings and estimated option cost data (obtained from CSA officials or contractors in demonstration site cities) were entered into benefit-cost calculations. Next,

Table 2. Selected Architectural Options, By City

ARCHITECTURAL OPTIONS

	Atlanta	Charleston	Chicago	Colorado Spr.	Easton	Fargo	Minn./St. Paul	Oakland	Portland	St. Louis	Tacoma	Washington
Seal holes and cracks	Gas	Gas + Oil	Gas + Oil	Gas	Gas + Oil	Gas + Oil	Gas + Oil	Gas	Oil	Gas	Gas + Oil	Oil
Weatherstrip and caulk	e p	Oil	Gas + Oil	Gas	Gas + Oil	Gas + Oil	Gas + Oil		Oil	Gas + Oil	Gas + Oil	Oil
Storm windows		e	Gas	Gas			Gas			Gas	Gas	Oil
Storm windows and insulating shutters			Oil	p								
Triple glazing	e p				Gas + Oil				Oil		Oil	
Triple glazing and insulating shutters						Gas + Oil						
Storm door on doors with glass	e p		Oil	p	Oil	Gas + Oil	Oil		Oil		Oil	Oil
R 11 attic insulation		Gas + Oil										
R 19 attic insulation	Gas	e p						Gas				
R 30 attic insulation	e p		Gas + Oil	Gas	Gas + Oil				Oil	Gas	Gas + Oil	Oil
R 38 attic insulation				p	e	Gas + Oil	Gas + Oil					p
Wall insulation R 11	e p	e	Gas + Oil	Gas	Gas + Oil	Gas + Oil	Gas + Oil		Oil	Gas	Gas + Oil	Oil
Basement crawl space insulation R 7	Gas	Gas + Oil	Gas + Oil	Gas	Gas + Oil	Gas + Oil	Gas + Oil		Oil	Gas	Gas + Oil	Oil

Fuel used: Gas (/// hatching); Oil (\\\ hatching)

Electricity: /// + \\\ + e

Propane: /// + \\\ + p

the options were ranked on estimated Btu's saved. Savings then were recalculated option-by-option, to allow for the reduced load resulting from the installation of previously selected options. When discounted savings over 11 years no longer justified the first cost of an additional option, the cost-effective set of options had been identified.*

The selected heating system options are summarized in table 3.

2.7 INSTALLATION OF WEATHERIZATION OPTIONS

A successful weatherization program requires that options be properly selected, installed, and used. NBS commissioned and CSA sponsored the preparation of a Home Retrofit Manual [7] to aid local CAA workers with installation of options. (Also see ref. [10].)

Options were installed either by local CAA agencies using Comprehensive Employment and Training Act (CETA) labor or by local contractors. In general, mechanical options were installed by contractors while infiltration-related options (e.g., replacing broken glass, resetting glazing, replacing thresholds, sealing cracks and holes, weatherstripping and caulking windows and doors) was done by CAA's. Insulation (in attics, walls, or in basements or crawl spaces, for example) was installed by both contractors and local CAA's. Budget and staffing limits precluded a systematic examination of the quality of the installations, but informal inspections suggested that the quality of the installation work varied. Assessing the impact of these variations in adequacy and quality of installation on energy consumption was beyond the scope of the present Demonstration.

Starting with the list of selected options for a house, what was actually installed was affected by the already existing level of weatherization of the house and the initiative of local CAA personnel in installing the options. The lack of installation of mechanical options in all houses at certain sites was a result of local CAA decisions. In some cases, particularly the presence of a space heater in a home, installation of mechanical options was not feasible. (See ref. [5], chapter 7 for a house-by-house summary of installed options).

2.8 DATA COLLECTION PROCEDURES

The Demonstration focused on collecting a range of general measurements for many houses in daily use rather than on highly detailed measurements of a few laboratory houses. The resulting database, documented in reference [3], allowed an evaluation of the effects of weatherization retrofits on energy consumption and, as important, will provide an invaluable archive to other researchers.

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* The formula used for the cost-benefit calculations is on page 16 of ref. [6]. An NBS report in preparation will present a detailed discussion of the

Table 3. Selected Mechanical System Options, By City

MECHANICAL OPTIONS	Atlanta	Charleston	Chicago	Colorado Spr.	Easton	Fargo	Minn./St. Paul	Oakland	Portland	St. Louis	Tacoma	Washington
Flue or vent damper			●	●	●	●	●		all	●	●	●
Flue or vent restrictor	●					●				●		
Electron ignition	●		●	●	●	●				●	●	
Two stage gas valve			●	●		●				●	●	
Derate furnace(gas)			●	●	●	●	●			●		
Replace burner					●	●			●			●
Optimal nozzle (all)					●	●			●			●
Replace furnace or space heater	●		●	●		●			●	●		
Insulate ducts and pipes			●	●						●	●	
Night setback thermostat	●		●	●	●	●	all	all	all	●	●	●
Insulate water heater	all	all	all	all	all	all	all	all	all	all	all	all
Replace water heater		●							●			
Reduce hot water temp.	all	all	all	all	all	all	all	all	all	all	all	all
Shower flow restrictor	all	●		●			●	all	●		all	●
Timer on elect.water heaters	all	all			all	all	all	all			all	all
Aquabooster												●
Insulate hot water pipes from water heater										●		●
Flue damper water heater			●	●	all		all	all		●		

● - Installed on a few of the sample homes

all - Installed on all of the sample homes

Basically, the pre-weatherization data was based on a two year period and the post-weatherization data on one year. Including an entire heating season in the post-weatherization year was the desired (but not always achieved) goal.

Although the houses were carefully instrumented with energy consumption and running-time meters on heating systems in order to develop a fall-back database,* the data used for the evaluation of the weatherization retrofits was based, in most cases, on whole house meter readings. This was done to obtain comparable pre- and post-weatherization data. Specifically, for houses that were heated using electricity or natural gas, utility meters on the house were used as the data source during the pre- and post-weatherization periods. For houses using oil for space heating, delivery records were used during the pre-weatherization period, and consumption was measured during the post-weatherization period by using the heater run time multiplied by the nozzle rate, with the nozzle rate calibrated against fuel delivery data, whenever possible. (All meters in the houses were read weekly, thus, providing much richer data for evaluation than could be obtained from typical utility or fuel delivery records.) For houses using propane (bottled gas) for space heating, delivery records were used throughout the Demonstration.

Because fuel consumption is strongly related to outdoor temperature, and because not all heating seasons are equally cold, it was necessary to normalize the fuel consumption data for the pre- and post-weatherization periods in order validly to compare the pre- and post-weatherization period data. Normalization was based on a "standard" seven year (1973-1980) average of degree days for the locale, calculated by NBS from the daily data recorded by the National Weather Service.

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* This store of data is likely to be of interest to specialists in energy management control systems. See reference [3].

3. RESULTS AND CONCLUSIONS

The key findings are summarized in table 1.

Results are presented for four measures: the actual cost of installed options, the estimated payback period, in years; the percent savings in fuel consumption; and occupant-indicated comfort improvement. The number of houses in each sample is given. These measures were explained in the Overview section.

The Demonstration results suggest the following conclusions:

1. When houses receiving both mechanical system retrofits and architectural modifications were compared with houses receiving only architectural options, the houses with both mechanical systems and architectural options reported:

   a. the average price for purchase and installation of options was higher ($1,862 vs. $1,336), as expected. However, in houses with both types of option,

   b. the percent savings in fuel consumption was larger (41 percent vs. 17 percent),

   c. the payback period was shorter (6 years vs. 15 years), and

   d. occupants reported somewhat greater improvments in comfort (average 0.66 vs. 0.56, where 0.0 = no comfort improvement reported and 1.0 = all indicators of improvement reported; see discussion of comfort indicators on page 4).

2. Comparing all weatherized units with nonweatherized comparison units, the results indicate that the weatherized units:

   a. had a much larger percent reduction in fuel consumption (31 percent vs. 5 percent), and

   b. showed much greater improvements in comfort as indicated by occupants (0.61 vs. 0.09).

The small changes in fuel consumption and comfort registered in the non-weatherized comparison group suggests that fuel consumption and comfort over the Demonstration period were relatively stable.

The conclusion is clear: weatherization conserves fuel and more weatherization (particularly economically-optimal levels) conserves even more fuel.

Table 1 does not indicate the variation in fuel savings for individual houses. Some dwellings saved up to 70 percent and a few increased their fuel usage [4]. There are no unequivocal explanations of this variability, but several possible reasons may be suggested. One suggestion has been that variations in the quality of the installion might account for these differences. Another possible explanation is that occupants operate and maintain their heating systems differently. Another is that even properly installed and operated retrofits do, in time, suffer a decline in performance.

A final explanation bears particular attention: the nature of the statistical analysis itself. Project staff assumed a 10 percent standard error in measuring fuel use. It is therefore possible that some residences reporting extremely high fuel savings reflect the situation where pre-weatherization fuel use readings on a residence were on the "high" side of the standard error of the measurement, while the post-weatherization fuel use readings for that residence were on the "low" side of the standard error. This logic applies also, except in reverse, to residences reporting either low or no fuel savings. Therefore, extreme values reported for fuel savings should be used cautiously.

One objective of the Demonstration was to assess how much money could be saved by weatherization. Focusing on the homeowner who has weatherized his or her home, the best available indicator is the estimated payback period.

Table 1 indicated an average payback period of 11 years; this was an encouraging result since the Demonstration had aimed to achieve a payback period of this term. Table 4 lists the distribution of payback periods.

Table 4. Payback Periods for Weatherized Houses

Payback Period in Years	Cumulative Percent of All Weatherized Homes Achieving Payback by the End of this Period
1-3	8
3-5	24
5-7	43
7-9	53
9-11	65
11-13 (11.4 overall mean)	71
13-15	81

If the assumed life of the options is 20 years, then in about half that time, (i.e., the end of the 9th year), 53 percent of homeowners will have been paid back the cost of these options in saved fuel costs, leaving the remaining years to reap the permanent savings the options will afford. If fuel prices were to rise faster than the cost of purchasing and installing weatherization options, then the cost of retrofits will be paid back to homeowners even sooner.

Table 5 presents the averages for the five variable rows of table 1, plus average cost of weatherization on a site-by-site basis for weatherized units.* Sites are listed alphabetically within degree day climate zones. This table is included for readers seeking site-specific information.

In summary, there is no doubt that weatherization can result in considerable fuel savings for households, particularly if both architectural and mechanical system options are installed. Nevertheless, the results do show a range of fuel savings and of costs. Energy savings ranged from net increases in fuel use (i.e., non-savings, in 10 percent of the experimental houses) to savings of 70 percent. Costs to retrofit a house varied from $24 to $4000. As expected, the greater savings were achieved when both architectural and mechanical options were installed in colder climates, with a higher number of degree days per year.

Although savings of 40 percent were achieved in "optimally" weatherized homes, the project staff had expected savings of 50 to 70 percent. The discrepancy resulted, in part, from the high level of existing weatherization found in colder areas of the Nation. For example, most houses in Fargo already had wall insulation, R-30 attic insulation and storm windows. Despite this, savings of nearly 40 percent (see table 6) were achieved there. Quality of installation, while difficult to measure, also appeared to vary considerably. This, too, can affect fuel consumption. It has been suggested that variations in quality of installation of retrofits that occurred in the Demonstration might be representative of what happens in typical retrofitting [4].

Although weatherization costs and percent savings in fuel consumption are two measures used in the Demonstration, there is not a perfect relationship between them. This is a consequence of using economic criteria for determining optimum levels of weatherization. That is, more money might have been spent intentionally on a house with a lower percent savings and high fuel prices in order to obtain greater dollar savings.

Perhaps the best indicator of the success of the CSA Weatherization Demonstration is the payback period [4]. NBS originally anticipated an 11 year payback period. The measured overall average was 11.4 years. This average, however, was raised by a small number of houses with unusually long payback periods (see table 6, data for Atlanta, for a site-wide indication of this). Statisticians are aware that a small number of aberrant cases in a sample might lead to misrepresentation. To illustrate this point and to provide a more accurate interpretation, the reader should examine table 4. This shows that over half (53 percent) of the weatherized houses had a payback period of nine years or less.

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* There are two to five nonweatherized houses per site. Because the number of houses per site was so small, only the aggregated values are being presented in table 5. Readers wishing detailed results should see table 28 of [5].

Table 5. Mean Values of Six Measures from CSA Weatherization Demonstration

Site City: / Degree Days:	CHA 1904	OAK 2909	ATL 3095	WASH 4211	ST L 4750	TAC 5185	ABE 5827	CHI 6127	CSP 6473	POR 7493	MSP 8310	FAR 9271	Ctr[d] ----
Fuel Consumption Before Weatherization ($Btu/ft^2 \cdot DD$)	27.2 (13)[a]	23.9 (8)	24.0 (8)	37.2 (4)	28.4 (18)	20.0 (9)	14.2 (13)	26.4 (10)	24.0 (16)	18.6 (14)	16.0 (17)	15.7 (12)	19.7 (38)
Fuel Consumpion After Weatherization ($Btu/ft^2 \cdot DD$)	17.4	23.5	20.0	19.0	23.8	11.1	10.7	14.6	12.8	9.9	12.4	9.2	19.4 (38)
Percent Savings (Based on Regression Analysis)	32.9	5.6	12.5	44.8	7.1	43.7	23.7	39.3	45.3	41.4	20.8	39.4	4.4 (41)
Comfort Improvement Index	0.6	0.3	0.9 (5)[b]	**	0.7 (17)	**	0.3 (7)	N/A	0.7 (11)	N/A	N/A	0.7 (6)	0.09 (19)
Cost, in Dollar, of Retrofits	977	274	1211	2924	1781	1807	1035	2347	1765	2215	1761	1626	----
Payback Period, in Years	6.8	22.7 (6)[c]	30.8 (6)	11.0	19.2 (10)	9.1	7.6 (12)	5.9 (9)	15.6	5.5 (13)	N/A	5.9	----

Legend

a Number of houses in the sample.

b For average based on a subsample of houses, subsample size appears in parentheses.

c Number excludes houses in sample for which there were no net energy savings. (For these houses, the payback period would be "infinite" in duration.)

d See footnote, previous page.

NA Data not available
** Too few cases

Abbreviations

CHA = Charleston, SC
OAK = Oakland, CA
ATL = Atlanta, GA
WAS = Washington Hughesville, MD
ST L = St. Louis,
TAC = Tacoma
ABE = Allentown/Bethlehem
CHI = Chicago
CSP = Colorado Springs
POR = Portland, ME
MSP = Minneapolis/St. Paul
FAR = Fargo
Ctr = Controls (unweatherized)

The main objective of the Demonstration -- to evaluate the savings in fuel and in dollars, given the costs of weatherization, of retrofitting low-income families' houses -- was accomplished. Fuel consumption savings averaging nearly 20 percent overall and 40 percent for "optimally" weatherized homes, with associated average payback periods 11 years overall and 8 years for "optimally" weatherized homes were achieved. Additional fuel savings can be achieved, as noted in the Overview section, by employing other energy-conservation strategies.

4. REFERENCES

[1] Chapman, Robert E., Crenshaw, Richard, W., Barnes, Kimberly A., and Chen, Phillip T., "Optimizing Weatherization in Low-Income Housing: Economic Guidelines and Forecasts," National Bureau of Standards (U.S.), NBSIR 79-1948, February 1980, 141 p.

[2] Clark, Roy E., "Effects of Home Weatherization on Occupant Comfort: First Report of a Field Study," National Bureau of Standards (U.S.), NBSIR 81-2335, September 1981, 83 p.

[3] Clark, Roy E., "The CSA Weatherization Demonstration Data Base: Concepts and Descriptions," National Bureau of Standards (U.S.) Technical Note 1156, February 1982.

[4] Crenshaw, Richard, CSA Optimal Weatherization Demonstration/Research Project. In Optimal Weatherization - Proceedings of the National Conference on Optimal Weatherization - December 1980. Silver Spring, MD, Information Dynamics, 1981.

[5] Crenshaw, Richard and Clark, Roy E., "Optimal Weatherization of Low-Income Housing in the U.S.: A Research Demonstration Project," National Bureau of Standards (U.S.) Building Science Series 144.

[6] Crenshaw, Richard, Clark, Roy, Chapman, Robert, Grot, Richard, and Godette, McClure, "Community Services Administration Weatherization Demonstration Project Plan," National Bureau of Standards (U.S.) NBSIR 79-1706, March 1979, 73 p.

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

[8] Margulis, Stephen T., "A Methodology for Evaluating Housing in Use: A Case Study Approach," National Bureau of Standards (U.S.), NBSIR 81-2258, June 1981, 221 p.

[9] Petersen, Stephen R., "Retrofitting Existing Housing for Energy Conservation: An Economic Analysis," National Bureau of Standards (U.S.), Building Science Series 64, December 1974.

[10] Trechsel, Heinz R. and Launey, Sheila J., "Criteria for the Installation of Energy Conservation Measures," National Bureau of Standards (U.S.), Special Publication 606, July 1981, 196 p.

APPENDIX

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 are 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 Report 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. <u>Home Evaluation Manual</u>. 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 Technial Information Service (NTIS) as PB-81-133829, price: $9.50 for hardcopy, $3.50 for microfiche.

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U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR 82-2539	2. Performing Organ. Report No.	3. Publication Date August 1982

4. TITLE AND SUBTITLE

NONTECHNICAL SUMMARY OF THE FINAL REPORT "OPTIMAL WEATHERIZATION OF LOW-INCOME HOUSING IN THE UNITED STATES: A RESEARCH DEMONSTRATION PROJECT"

5. AUTHOR(S)

Stephen T. Margulis and Roy E. Clark

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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Community Services Administration
1200 19th Street, NW
Washington, D.C. 20506

10. SUPPLEMENTARY NOTES

☐ 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 summarizes in nontechnical language the nature and results of the Community Service Administration's (CSA's) Optimal Weatherization Demonstration Research Project carried out by the National Bureau of Standards (NBS). This summary draws on the final report of the field evaluation of the Demonstration, an NBS publication entitled Optimal Weatherization of Low-Income Housing in the U.S.: A Research Demonstration Project (NBS BSS 144). Unless stated otherwise, this report references the final report.

The CSA/NBS demonstration installed both architectural (Building shell) and mechanical systems 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.

This summary report also includes abstracts of all the technical reports documenting the CSA/NBS project. Directions for ordering available reports are included.

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.

13. AVAILABILITY

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