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USING SHORT-TERM MONITORING TO IMPROVE VIRGINIA'S WEATHERIZATION PROGRAM

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ABSTRACT

An evaluation of Virginia's low-income weatherization program was conducted in order to develop a set of recommendations for improving the program's effectiveness. This paper provides a short overview of the first two steps of the evaluation: an assessment of measured savings being achieved by the existing weatherization program and engineering/economic analyses of alternative energy conservation measures and techniques to identify those most applicable to Virginia's housing stock and climate. The paper then focuses on the heart of the project: the use of short-term monitoring to examine the energy savings and cost-effectiveness of new retrofit measures installed in a 60-house pilot study. Measures examined in the pilot study included high-density wall insulation, advanced air-sealing techniques, heating system safety inspections, and furnace cleaning and tuning. While the small sample size in the pilot study did not allow for evaluation of savings due to individual measures, the overall package of new measures substantially improved the cost-effectiveness of Virginia weatherization. New standards based on this work are presently being incorporated into the statewide weatherization program. This work is of particular significance in that it is one of the first comprehensive evaluations of weatherization done in a mild-climate state.

INTRODUCTION

Since the early 1970s, the U.S. Department of Energy (DOE) has funded energy conservation work in low-income housing throughout the country in an effort to reduce energy costs and increase the affordability of housing for this segment of the population. Referred to as "low-income weatherization," this program has installed energy conservation measures in more than 60,000 low-income housing units in Virginia. The Virginia Association of Community Action Agencies, Inc. (VACAA) operated the program for the state of Virginia by issuing subcontracts to local community action agencies and other subcontractors, establishing installation standards, and inspecting and monitoring completed jobs.[1] For many years, VACAA based its installation standards on "Project Retro-Tech," a somewhat antiquated set of retrofit procedures developed by DOE in the 1970s (Commonwealth of Virginia 1980). Recent advances in building science convinced VACAA staff that these standards were probably not as effective at saving energy as they could be and, in 1988, VACAA began making changes to the standards to reflect some of these advances. However, the agency soon realized that a full assessment of the program would be necessary in order to see which measures would be best suited to Virginia's mix of climate, housing stock, and local agency capabilities and which would prove to be most cost-effective to the commonwealth. Although similar studies have been done in northern states, this is one of the first comprehensive evaluations of weatherization in a state with a mild climate (3,400-5,000 heating degree-days base 65°F [1,900-2,800 HDD base 18°C]; 600-1,500 cooling degree-days base 65°F [300-800 HDD base 18°C]).

The main objective of the evaluation was to develop a set of recommendations to improve the program's effectiveness. More specifically, VACAA was interested in finding out how new weatherization techniques, such as high-density wall insulation, which have been used successfully in northern states, would work in a milder climate like Virginia's. To answer these questions, we designed a three-step evaluation: first, analysis of the savings and cost-effectiveness of weatherization implemented under the existing program using the Princeton Scorekeeping Method (PRISM) (Fels 1986); second, a literature review combined with engineering-economic calculations to identify promising new energy conservation techniques applicable to Virginia's housing stock and climate; and third, short-term monitoring to test the suitability of the new techniques for Virginia weatherization through a pilot study. The results were used to develop improved weatherization standards incorporating

[1]VACAA no longer operates the Virginia weatherization program. In 1991, administration of the program was transferred to the Virginia Department of Housing and Community Development.

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the best of the old and new measures. In addition, we were to examine administrative procedures and recommend improvements and to develop a training manual specifying installation procedures for the new measures. More details on methodology and results may be found in the project's final report (Randolph et al. 1991). The evaluation focused on site-built single-family and mobile homes. While some multifamily units were included in the evaluation of the existing program, they were not included in the pilot study and so will not be discussed here.

This paper provides a brief discussion of the first two steps of the evaluation, then focuses on the heart of the project: the use of short-term monitoring in the pilot study to examine the energy savings and cost-effectiveness of new retrofit measures. First, however, we present an overview of the current state of low-income weatherization.

THE STATE OF LOW-INCOME WEATHERIZATION

Since low-income weatherization first began, many changes have been made in the definition of "effective weatherization." In its early days, weatherization typically focused on caulking of the exterior of the building shell, storm windows, and attic insulation. However, evaluations in the late 1970s and early 1980s revealed that savings from these measures were on the order of 10%, rather than the 20% to 40% that had been expected based on engineering estimates (see, for example, Hewitt et al. 1984; Peabody 1984; Little 1987). Attic insulation still survives as a mainstay of weatherization programs across the country, but in the more advanced states, extensive caulking and window replacements have given way to diagnosis of air leakage sites using tools such as blower doors and infrared cameras. Experience from leading states has revealed other important lessons about factors contributing to effective weatherization (Cummings et al. 1990; Fitzgerald et al. 1990; Kushler and Witte 1988; Schlegel et al. 1990; Shen et al. 1990):

- Heating system work has become an essential part of advanced weatherization programs. Many programs have included efficiency improvements, such as cleaning and tuning, burner replacement, furnace replacement, installation of setback thermostats, and attention to the distribution system (duct sealing, insulation, and balancing). Moreover, it has become clear that, at a bare minimum, weatherization programs must address heating system safety concerns since tightening of the building shell can easily exacerbate any existing problems, such as backdrafting, improperly vented furnace and water heaters, cracked heat exchangers, or fuel leaks.
- Better understanding of air movement in buildings and improved "house doctoring" diagnostics have improved weatherization air sealing methods. Attention has focused on leaks in basements/crawlspaces and attics—air leakage sites that generally contribute the most to air infiltration losses because of the pressure differential resulting from the stack effect. Leaks in these areas have been shown to be far more important than those in the living space (such as around windows and doors), which are the subject of most caulking work in "traditional" weatherization. Diagnostic methods have also effectively identified "bypasses," where air movement can bypass insulation or sealing as a result of quirks in design or construction and dramatically increase heat loss. Blower doors have been shown to be very useful in diagnosing air leakage problems. Even more important to the task, however, are trained and experienced diagnosticians.
- Several northern states have employed blown-in wall insulation as a weatherization measure. Research has shown that high-pressure blown cellulose can ensure a high-density pack that resists settling and, more importantly, seals small avenues of air leakage. High-density blown cellulose can thus both improve wall insulation and control air leakage. It is also an effective method for sealing bypasses.
- Traditionally, weatherization has tried to apply single-family house retrofit measures to mobile homes. Recent research has shown this to be largely ineffective. The most cost-effective mobile-home measures for cold climates have been shown to be blower-door-directed air sealing and duct repair, furnace tune-ups, blown bellyboard insulation, interior storm window panels, and blown roof insulation (see, for example, Kinney et al. 1988; McBride and Thomas 1989; Judkoff 1991).

These lessons guided us in deciding which measures to examine for possible inclusion in an improved weatherization program for Virginia.

VIRGINIA'S EXISTING WEATHERIZATION PROGRAM

Virginia's existing weatherization program concentrated on attic insulation, primary window replacement, storm window installation, and caulking and weatherstripping. Other measures, such as water heater blankets, attic vents, and replacement doors, were also frequently installed. Mobile home weatherization focused on caulking and window replacements.

The primary purpose of analyzing the savings and cost-effectiveness of the existing program was to develop a baseline with which to compare the effectiveness of the new measures to be tested in the pilot study. The analysis was conducted using PRISM, a regression model that derives weather-normalized annual energy consumption from utility billing data. PRISM's requirement of one year each of pre- and post-retrofit utility bills led us to look at houses weatherized between July 1988 and June 1989 (the most recent program year for which the necessary amount of post-retrofit data would be available). Therefore, the "existing program" referred to here is the weatherization program for fiscal year 1989, which differed in some respects from the program as it existed at the start of this evaluation project (for example, storm windows were eliminated from the installation standards as of July 1989).

Utility billing data were combined with information on heating fuel type, installed measures, and weatherization costs to determine the savings and cost-effectiveness of weatherization. Although we tried to calculate savings for all gas-heated and electrically heated homes weatherized during fiscal year 1989 (close to 1,500 homes), reliable energy savings estimates were obtained for only 188 homes, due primarily to difficulties in obtaining billing data. Results for just 148 of these 188 homes are discussed here, as the remaining 44 homes were multifamily apartment units and, therefore, not relevant for comparison with the pilot study (which looked at single-family and mobile homes).

As shown in Table 1, the energy savings being achieved by the existing program were rather low. Median savings in gas-heated homes were 6.9 MBtu/dwelling (7,300 MJ), or 8% of normalized annual consumption (NAC), which included energy used for space heat only, space heat and hot water, or space heat, hot water, and cooking. For electrically heated homes, median annual savings were only 2.3 MBtu/dwelling (2,400 MJ or 670 kWh; Btu value based on site conversion of 3,412 Btu = 1 kWh), or 4% of NAC (which typically included space heating, hot water, cooking, lights, and appliances). Mobile homes in the sample, all of which were electrically heated, had median savings of only 1.7 MBtu/dwelling (1,800 MJ), or 3% of NAC.

TABLE 1
Results of Pilot Study Compared to Existing Virginia Weatherization Program[1]

	Existing Program		Pilot Study
	Gas/Oil	Electric	Gas/Oil
Number of Dwellings			
• Site-Built	91	21	43
• Mobile Home	0	36	12
Pre-Retrofit NAC (site MBtu/dwelling)			
• Site-Built	104	65	--
• Mobile Home	--	55	--
Pre-Retrofit Space Heat (site MBtu/dwelling)			
• Site-Built	84[2]	28[2]	107
• Mobile Home	--	30[2]	66
Energy Savings (site MBtu/dwelling)			
• Site-Built	6.9	2.3	24.2
• Mobile Home	--	1.7	10.9
Energy Savings (% NAC)			
• Site-Built	8.3	4.1	--
• Mobile Home	--	3.0	--
Energy Savings (% Space Heat)			
• Site-Built	10.3[2]	5.1[2]	24.4
• Mobile Home	--	9.5[2]	17.0
Total Cost[3] ($/dwelling)			
• Site-Built	1489	857	1119
• Mobile Home	--	1289	1145
Simple Payback Time[4] (Years)			
• Site-Built	30	21	10
• Mobile Home	--	53	17
Benefit-Cost Ratio[4,5]			
• Site-Built	0.33	0.50	1.1
• Mobile Home	--	0.17	0.54
Cost of Conserved Energy[5] ($/site MBtu)			
• Site-Built	$17	$32	$5.20
• Mobile Home	--	$100	$11

[1]Value given are medians (1 MBtu = 1055 MJ).
[2]Space heat consumption as derived by PRISM.
[3]Total costs for existing program are calculated as material costs multiplied by a reimbursement rate of 229% (in 1988/89 dollars), which is the formula used by the state agency to reimburse local agencies (i.e., local agencies are not reimbursed according to their actual material and labor costs). Total costs for the pilot study are actual material, labor, and administrative costs (in 1989/90 dollars).
[4]Based on 1988 average Virginia residential energy prices of $5.65/MBtu ($5.35/GJ) for gas and oil, and $16.61/site MBtu ($15.74/site GJ) for electricity.
[5]Based on a real discount rate of 7% and measure-specific lifetimes.

Table 1 also presents these savings as a percentage of space-heating use in order to facilitate comparison with the results of the pilot study. Since space heating was not measured directly for the homes weatherized under the existing program, we relied on PRISM's estimates of the space-heating fraction. Since this statistic is not as well determined as the NAC and usually tends to overestimate space heat use, we place more confidence in the NAC results.

We looked at three indicators of the cost-effectiveness of weatherization: the simple payback time, the benefit-cost ratio, and the cost of conserved energy (for definitions of these indicators, see "Cost-Effectiveness Calculations"). Weatherization in this sample of homes was clearly not cost-effective: median simple payback times were in excess of 20 years, benefit-cost ratios were substantially less than 1, and costs of conserved energy were two to three times higher than Virginia residential energy prices. Figure 1 compares these results with other evaluations of standard low-income weatherization programs documented in the BECA-B data base (Cohen et al, 1991); the existing Virginia program had savings at the lower end of this range of weatherization evaluations and was the least cost-effective of any. From these results, we concluded that changes were indeed necessary to improve the effectiveness of Virginia's weatherization program.

SELECTION OF NEW MEASURES TO BE TESTED

A review of the literature and examination of other state weatherization programs were combined with engineering-economic analysis to select measures for testing in the pilot study. Analyses were performed for five measures that are amenable to engineering calculations: attic insulation, advanced air sealing, wall insulation, primary window replacements, and storm windows. The approach used to estimate energy savings is the ASHRAE modified degree-day method (MDD) in which annual savings are a function of the annual heating degree-days (HDD) (ASHRAE 1989). There are more sophisticated models, but this model's level of accuracy was deemed suitable to the task at hand. The wide range of possible values for some of the key parameters, coupled with uncertainty in the energy price data, does not warrant more detailed models.

In the MDD method, savings (in Btu/ft^2·yr) are given by the equation

$$\text{Energy Savings} = C_D \cdot 24 \cdot (U_{Before} - U_{After}) \cdot \text{HDD} \quad (1)$$

where

U_{Before}, U_{After} = equivalent U-values of building components (attic, walls, windows) before and after weatherization,

HDD = total annual heating degree-days (base 65°F),

C_D = "empirical correction factor," which adjusts for the errors inherent in the MDD method. All the analyses below assume a C_D of 0.65.

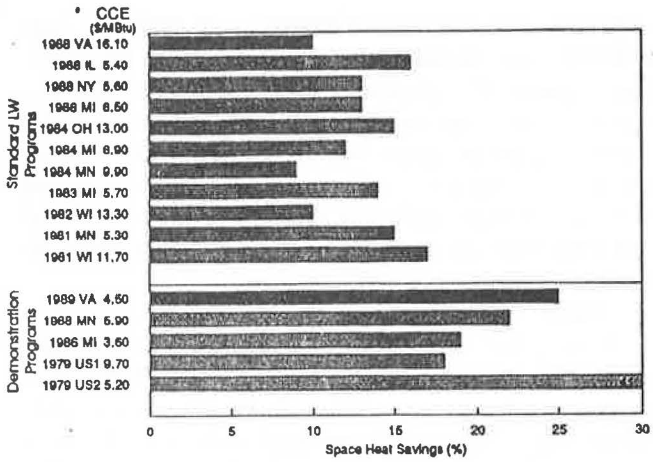

Figure 1 *Space heat savings and cost of conserved energy for Virginia evaluations compared to other standard and demonstration weatherization programs. "US1" and "US2" refer to the Community Services Administration study of shell and shell/system measures, respectively. Source: Cohen et al. (1991).*

For each measure, economic analyses were conducted for Virginia's three climatic zones (3,400, 4,200, and 5,000 heating degree-days base 65°F [1,900, 2,300, and 2,800 HDD base 18°C]), three fuel prices (gas/oil [which were similarly priced at the time of this study], electricity, and a weighted average price), three assumed installed costs, and various engineering assumptions. Because of the large number of variables, the engineering and cost-effectiveness calculations were performed on a spreadsheet and formatted to produce the range of results for each measure in a simple table. A sample is given as Table 2, which shows the results for sidewall insulation. Engineering and economic assumptions are given at the bottom of the table, and three cost-effectiveness measures (CCE = cost of conserved energy, SPT = simple payback time, B/C = benefit-cost ratio) are given for the three climatic zones, three installed costs, and three energy values. Table 3 summarizes the results of the analyses for all the measures. Annual savings, cost, simple payback time (SPT), and benefit-cost ratio (B/C) are given for each of the measures. The savings given are those for the weighted average of fuel costs, $13/MBtu ($12/GJ), and for the "median climate" of 4,200 HDD base 65°F (2,300 HDD base 18°C). The measures are listed in order of cost-effectiveness by SPT. The analyses showed that

- R-30 attic insulation is extremely cost-effective, except when existing levels exceed R-19;

TABLE 2
Economics of Sidewall Insulation

Region	Installed Costs		CCE	Value of Energy Saved					
				$11/MBtu		$13/MBtu		$23/MBtu	
	Range	($/ft²)[1]	($/MBtu)[2]	SPT	B/C	SPT	B/C	SPT	B/C
Coast	Low	$0.60	$5.23	5.5	2.1	4.7	2.5	2.6	4.4
3400	Ave	$0.80	$6.97	7.4	1.6	6.2	1.9	3.5	3.3
HDD[3]	High	$1.00	$8.72	9.2	1.3	7.8	1.5	4.4	2.6
Piedmont	Low	$0.60	$4.23	4.5	2.6	3.8	3.1	2.1	5.4
4200	Ave	$0.80	$5.64	6.0	1.9	5.1	2.3	2.9	4.1
HDD	High	$1.00	$7.06	7.5	1.6	6.3	1.8	3.6	3.3
Mountains	Low	$0.60	$3.56	3.8	3.1	3.2	3.7	1.8	6.5
5000	Ave	$0.80	$4.74	5.0	2.3	4.2	2.7	2.4	4.9
HDD	High	$1.00	$5.93	6.3	1.9	5.3	2.2	3.0	3.9

ASSUMPTIONS:

Interest rate	10%
Inflation rate	4%
Discount rate	7%
Economic lifetime	25 yrs
Initial R-value	3.8
Finished R-value	12.9

C_D = 0.65

No savings due to air sealing.

Older construction -- full dimension 2 x 4's, lath and plaster interior, 3/4-inch wood siding.

[1] $1/ft² = $11/m²

[2] $1/MBtu = $0.95/GJ

[3] 1 $HDD_{base\ 65°F}$ = 0.556 $HDD_{base\ 18°C}$

TABLE 3
Relative Cost Effectiveness of Measures

Weatherization Measure	Measure-Specific Assumptions[1]	Savings ($/yr)	Cost ($)	SPT (yrs)	B/C
Attic Insulation	R-4 to R-30 No infiltration savings Cost = $0.40/ft² Area = 1250 ft² Lifetime = 25 years	$230	$500	2.2	5.4
Advanced Air Sealing	30% reduction in initial ACH of 1.5 Volume = 10,000 ft³ Lifetime = 10 yrs	$69	$300	4.3	1.6
Sidewall Insulation	No infiltration savings Cost = $0.80/ft² Area = 1100 ft² Lifetime = 25 yrs	$173	$880	5.1	2.3
Storm Windows	No infiltration savings Cost = $6/ft² Area = 100 ft² Lifetime = 15 yrs	$33	$600	18	0.6
Replacement Windows	No infiltration savings Cost = $14/ft² Area = 100 ft² Lifetime = 20 yrs	$45	$1,400	31	0.3

Assumptions for all measures:
- Value of energy saved = $13/MBtu ($12/GJ)
- Heating degree days = $4200_{base\ 65°F}$ ($2300_{base\ 18°C}$)
- "Average" installed costs
- C_D = 0.65

[1] $1/ft² = $11/m²; 1 ft² = 0.093 m²; 1 ft³ = 0.028 ft³

- while air sealing is very difficult to quantify, since costs and the infiltration reduction achieved can vary widely, under the "average" scenario air sealing is very cost-effective;
- sidewall insulation is extremely cost-effective, even when no infiltration savings are assumed;
- storm windows are cost-effective only under the most favorable assumptions of high energy prices (i.e., electricity) and low installed costs; and
- replacement primary windows are not cost-effective even under the most favorable assumptions.

In addition, the literature review suggested that heating system work needed to be incorporated into Virginia's program, possibly from an energy-savings standpoint and definitely for safety reasons, as any existing problems such as backdrafting, improperly vented furnace and water heaters, cracked heat exchangers, or fuel leaks would be exacerbated by tightening the building shell.

TESTING NEW MEASURES: THE PILOT STUDY

The pilot study was designed to test how well selected new weatherization measures performed in Virginia's housing stock and climate, as well as how capable Virginia weatherization crews were of learning to install these measures. During the winter of 1989-90, 43 site-built single-family homes and 16 mobile homes were weatherized by crews from four local agencies.[2] The new measures tested in the pilot study included the following:

- high-density, blown cellulose wall insulation;
- advanced air-sealing techniques focusing on attics, basement/crawl spaces, bypasses, and ducts and registers;
- heating system safety inspections; and
- furnace cleaning and tuning.

Some measures from the existing VACAA standards, such as water heater wraps, attic insulation, and belly-board insulation (for mobile homes), were retained. Conventional caulking and window replacements were specifically de-emphasized in the pilot study. Special installation standards were developed for use by the crews. Crews underwent abbreviated training (less than two weeks) on the pilot measures.

Methodology

Elapsed-Time Meters Because the VACAA wanted to make improvements to Virginia's weatherization program as quickly as possible, a short-term monitoring technique was selected to measure energy savings in homes in the pilot study. Elapsed-time meters, attached to the furnace by weatherization crews and read weekly by the occupant, were chosen as a relatively inexpensive approach that would yield pre- and post-retrofit consumption data over the course of one heating season. These meters have previously been used in other energy-savings evaluations (Kinney et al. 1989; SSC 1987). These meters record the run-time of the furnace; energy consumption for each measurement period is then obtained by multiplying the run-time by the furnace's firing rate.

For a gas furnace, this approach involved wiring the elapsed-time meter in parallel with the solenoid valve that controls gas flow to the burner (Figure 2). The firing rate was determined by firing the furnace, shutting off all other gas appliances, and measuring the consumption rate at the gas meter. For an oil furnace, the procedure was slightly more complicated. The elapsed-time meter along with a transformer were installed in parallel with the motor that drives both the oil pump and fan. The firing rate of the oil burner was found by removing the burner assembly and reading the consumption rate (in gallons per hour) off the nozzle. This consumption rate was then multiplied by the energy content of the oil to determine the firing rate in Btu per hour. The elapsed-time meter usually was not installed on the furnace itself but in the living space, where it could be conveniently read by the occupant.

Weekly timer readings were obtained by telephoning the occupants. The space-heating energy intensity was then calculated in Btu per square foot per heating degree-day (base 65°F) (Btu/ft^2·HDD) (Equation 2). The heated floor area was measured at the time the meter was installed; HDD data were collected for the weather station closest to each of the four weatherization agencies.

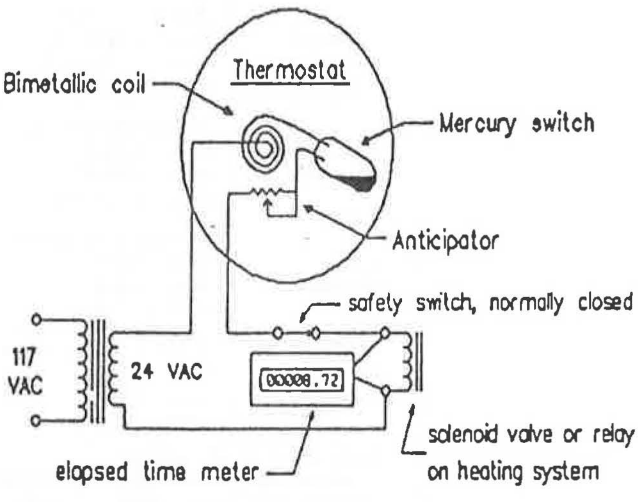

Figure 2 Installation of elapsed-time meter on gas furnace.

[2]Results for only 12 of the 16 mobile homes are discussed here, as two of the mobile homes were electrically heated (and therefore not easily comparable with savings for the remaining homes in the pilot study, which were all heated with gas or oil) and major changes were made to the heating systems of two others during the course of the pilot.

VIRGINIA WEATHERIZATION PROGRAM SPECIAL DEMONSTRATION PROJECT

Page 1

Client Number PA-04 Agency People Inc Tel. (H) ____
Client's Name ____ Firing Rate (Btu/hr) 80,000 FR (W) ____
Address ____ House Area (sqft) 887 SF Best Time to Call client will call Wed 9:00

1 Time	2 Day	3 Month	4 Year	5 Meter Reading	6 Burner On Time This Period (C.5 - C.5)	7 Btu's This Period (C.6 x FR)	8 Degree Days This Period	9 Btu's Per Degree Day (C.7/C.8)	10 Btu's Per Degree Day Per Square Foot (C.9/SF)
2:50	18	Oct	89	.01	Initial	Installation		26	
8:38	25	Oct	89	35.9	35.9	2,872,000	109	26,348.6	29.7
8:40	1	Nov	89	43.4	7.5	600,000	53	11,320.7	12.8
8:20	8	Nov	89	83.9	40.5	3,240,000	110	29,454.5	33.2
8:48	15	Nov	89	169.9	26	2,080,000	85	24,470.5	27.6
8:45	22	Nov	89	170.7	60.8	4,864,000	150	32,426.7	36.6
8:30	29	Nov	89	239.0	68.3	5,464,000	163	33,521.5	37.8
6:30am	6	Dec	89	340.9	101.9	8,152,000	216	37,740.7	42.5
9:45	13	Dec	89	407.8	66.9	5,352,000	193	27,730.6	31.3
9:00	20	Dec	89	534.9	127.1	10,168,000	299	34,006.7	38.3
10:00	27	Dec	89	665.9	131	10,480,000	349	30,028.7	33.9
9:10	3	Jan	90	717.9	52	4,160,000	213	19,530.5	22.0
9:30	10	Jan	90	753.2	35.3	2,824,000	163	17,325.2	19.5
Work begin 1/9/90 about 10:00 a.m and ended 1/12/90									
9:50	17	Jan	90	800.2	47	3,760,000	182	20,659.3	23.3
6:45am	24	Jan	90	830.2	20	1,600,000	127	12,598.4	14.2
9:25	31	Jan	90	846.4	16.2	1,296,000	155	8,361.3	9.4
9:20	7	Feb	90	844.9	8.5	680,000	126	5,396.8	6.1
6:45	14	Feb	90	855.9	11	880,000	133	6,616.5	7.5
7:45	21	Feb	90	863.8	7.9	632,000	111	5,693.7	6.4
10:40	28	Feb	90	881.8	18	1,440,000	173	8,323.7	9.4

Figure 3 Logging sheet for collection of weekly elapsed-time meter data. Firing rate and house area are recorded during the initial visit to install the meter.

House weekly energy consumption (Btu/ft²·HDD) =

$$\frac{\text{Weekly furnace runtime (h)} \times \text{furnace firing rate (Btu/h)}}{\text{floor area (ft}^2) \times \text{weekly HDD}} . \qquad (2)$$

The logging sheet used for this procedure is shown in Figure 3. Energy consumption was monitored for several weeks (at least 3 and, on average, 11 weeks before weatherization and 8 weeks after), and the mean Btu/ft²·HDD was calculated for the pre- and post-weatherization period for each house (Equation 3).

Mean energy consumption (Btu/ft²·HDD) =

$$\frac{\Sigma \text{ weekly energy consumption (Btu/ft}^2 \cdot \text{HDD)}}{\text{number of weeks}} . \qquad (3)$$

Periods with anomalous data, as revealed in client interviews (e.g., house unoccupied for a week), were excluded from the average, as were periods with Btu/ft²·HDD differing from the mean by more than 50%.[3] Savings were then calculated as the difference between the mean pre- and post-retrofit Btu/ft²·HDD (Equations 4 and 5).

Energy savings = Mean pre-wx energy consumption − Mean post-wx energy consumption. (4)

$$\text{\% Energy savings} = \frac{\text{Energy savings}}{\text{Mean pre-wx energy consumption}} . \qquad (5)$$

[3]Obvious outliers were first noted by visual inspection; the "50% different from average" rule evolved out of this visual inspection. Outliers usually corresponded with weeks that had extremely mild weather. This rule typically resulted in the exclusion of one or two data points for each house.

Other Data Collection Logging sheets were developed to record the materials cost and labor time required for each installed measure. This information, combined with agency data on wage rates and overhead costs, allowed us to calculate actual on-site and total (including program support) costs. Blower door readings were also taken periodically to ascertain the infiltration reduction attributable to specific sets of measures. Post-weatherization visits were made to most of the homes in the pilot study to inspect the installation quality and interview the occupants. Weatherization personnel were also interviewed to assess their perceptions about the effectiveness of the training sessions and the ease of implementation of the new measures.

Cost-Effectiveness Calculations In order to determine cost-effectiveness, we first had to compute annual energy savings. The savings for each house, in Btu/ft^2·HDD, were multiplied by the heated area of the house (ft^2) and the long-term average annual heating degree-days base 65°F (HDD) for the weather station nearest the particular weatherization agency involved. These annual MBtu savings were then multiplied by $5.65/MBtu ($5.35/GJ) for gas and oil and $16.61/MBtu ($15.74/GJ) for electricity to yield annual dollar savings. Costs used in these calculations are the total costs, including materials, labor, and administration, developed from the data collected as described above. (Note that the costs used in the cost-effectiveness calculations for the existing program used estimated labor and administration costs, based on the average reimbursement rate [total cost equals 229% of materials cost] negotiated between the VACAA and the individual weatherization agencies. That is, the VACAA did not pay the local agencies for their actual labor and administration costs but rather reimbursed them according to this formula.)

Three cost-effectiveness indicators were employed and are reported in Table 1: simple payback time (SPT), benefit-cost ratio (B/C), and cost of conserved energy (CCE). The SPT, a crude measure that neglects both the time value of money and the lifetime of the measure, is simply the length of time necessary for a measure to pay for itself and is calculated by dividing the initial cost by the annual dollar savings. The B/C is calculated by dividing the present value of the annual stream of energy savings by the cost of the measure. Present values were calculated using a 7% real discount rate and measure-specific lifetimes. The CCE is a relatively new measure of cost-effectiveness created for "least-cost planning," where one is interested in comparing the cost of energy "supplied" by conservation with the cost of more traditional supply-side energy sources. It is calculated by dividing the annualized cost of the conservation measure by the annual energy saved (in MBtu). One advantage of this measure is that it requires no assumptions about the value of the energy being saved.

Selection of Houses The four local agencies were selected to provide a mix of large and small, urban and rural agencies. No special effort was made to select a representative sample within these agencies, however. The use of elapsed-time meters meant that all pilot study houses had to have thermostatically controlled space-heating systems; all but three of the houses were heated with natural gas or oil. The restrictions on the heating system type imposed by the monitoring technique, combined with the need for a client willing to report weekly consumption, narrowed the number of eligible houses. Therefore, we included all houses within the four selected agencies that met the restrictions and were eligible for weatherization during the course of the study.

Retrofit Measures and Costs

Since the weatherization agencies involved in this pilot study were not relieved of their usual responsibilities, there were competing demands between our research objectives and the agencies' other obligations. While, overall, the cooperation provided by all participants was very good, there were instances when, for various reasons, agencies did not follow the pilot installation standards as closely as we would have liked. For the 43 site-built single-family houses in the study, the weatherization work conformed fairly well with the standards (see Figure 4). All 43 homes received some degree of advanced air-sealing; walls were insulated in 40%, attics were insulated in 65%, and less than 20% received more than one replacement window. The mobile home retrofits followed the new installation standards with regard to duct and register boot sealing, which was done in 81% of the homes, but failed to follow the new standards' directives regarding other measures. Floor insulation, which was to be done wherever feasible, was installed in only 25% of the mobile homes, and window and door replacements (specifically de-emphasized in the standards) were installed in 81% and 75% of mobile homes, respectively.

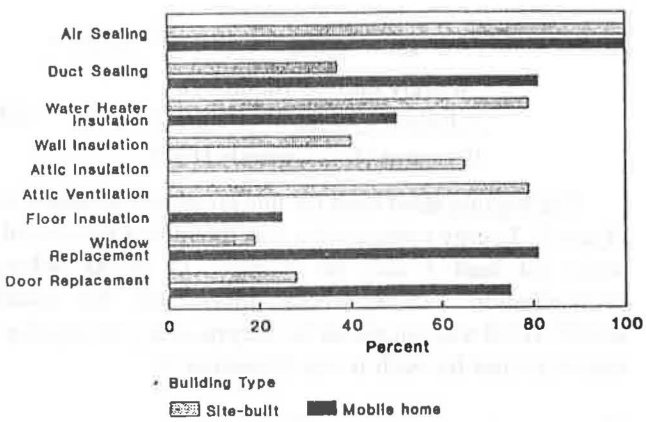

Figure 4 *Percentage of site-built single-family and mobile homes weatherized in pilot study that received specified measures.*

Heating system inspections were done on 44 of the 59 pilot units. Inspections included flue gas and steady-state efficiency measurements, identification of fuel leaks, and inspection of the heat exchanger and venting systems. Safety problems, primarily unsafe flues and fuel leaks, were found in one-third of the inspected units. One agency cleaned and tuned 10 furnaces; this typically included cleaning the heat exchanger, adjusting the draft, adjusting the combustion air, and adjusting oil pump pressure. Steady-state efficiencies in these units increased from an average of 75% to 79% as a result of this work (difference in efficiency significant at 5% level). We decided not to retain cleaning and tuning in our recommended installation standards, as the magnitude of energy savings resulting from the steady-state efficiency increase is not clear, and there is some question as to the persistence of the efficiency increase.

Median on-site labor and materials costs were $653 for single-family homes and $679 for mobile homes. Median total costs, including program support, were $1,119 for single-family homes and $1,145 for mobile homes.

Energy Savings and Cost-Effectiveness

Median space heat savings for the pilot study were 24% in single-family houses and 17% in mobile homes. Savings ranged from 26% to 71% for one agency's single-family homes, all six of which received wall insulation.

It is difficult to precisely compare savings from the existing program with savings from the pilot study because the savings were measured in different ways. The evaluation of the existing program focused on gas-heated and electrically heated homes and used one year each of pre- and post-retrofit utility bills to derive savings. The pilot study looked primarily at gas- and oil-heated homes and derived savings from weekly submetered space-heating data. Ideally, the same measurement method would have been used for both parts of the evaluation; however, time constraints ruled out this course of action. (We plan to do a PRISM analysis on homes in the pilot study as sufficient utility billing data become available.)

Despite these differences in measurement techniques, however, it is clear that the pilot study savings were substantially greater than savings from the existing program. Table 1 contains absolute and percentage savings for both groups of houses by building and heating fuel type. Percentage savings from the pilot study were measured as a fraction of space-heating consumption, while, as noted above, space heat use for homes weatherized under the existing program was approximated using the PRISM-derived space heat fraction. However, the percent savings for single-family homes in the pilot study was more than two times greater than the percent space heat savings for gas-heated single-family homes in the existing program. Therefore, despite the difficulties in comparing savings for the two groups, we are confident that savings from the pilot study measures were substantially greater than those from the existing program.

Weatherization cost-effectiveness was also much improved. For fuel-heated single-family homes, simple payback times improved from 30 years for the existing program to 10 years for the pilot study. These indicators are based on total costs (including program costs), which are typically about 50% greater than on-site (materials and labor) costs. The cost of conserved energy for the single-family homes in the pilot study was less than prevailing residential gas and oil prices, and the benefit-cost ratio was greater than one. Mobile home weatherization in the pilot, while much more cost-effective than the work done as part of the existing weatherization program, was still not quite cost-effective (payback time of 17 years, cost of conserved energy greater than fuel prices, and a benefit-cost ratio of 0.54).

Not only did the pilot study represent a substantial improvement over the existing Virginia weatherization program, it also compares favorably with other weatherization demonstration programs throughout the country (Figure 1). Savings were greater than in all but one of the other demonstration programs documented in the data base (Cohen et al. 1991).

While the simple payback times based on actual costs are somewhat long, we expect the cost-effectiveness of the pilot measures to improve for several reasons. First, the new standards were not correctly implemented in all the homes in the pilot study (e.g., less than half of the single-family homes received wall insulation; windows were replaced in four-fifths of the mobile homes). Second, the crews had only a short training period to learn installation techniques for the new measures and were basically "learning by doing." With more experience, labor time and costs would most likely drop. Third, the pilot study required additional crew time to record measure-specific installation time data and to perform frequent blower door tests (in order to document changes in infiltration caused by specific measures). These tasks would not be required under nonresearch conditions.

Lessons from the Pilot Study

The most important lesson from the pilot study was that the new weatherization measures were substantially more cost-effective than the work being done under the existing weatherization program. Although the sample size for the pilot was small and differences in techniques used to measure consumption made the precise comparison of savings difficult, the large magnitude of the difference in savings allows us to recommend with confidence that the new measures be widely implemented. The heating system work carried out in the pilot uncovered many serious safety problems; therefore, safety inspections are also recommended as a component of all future weatherization work.

Crews demonstrated that they were capable of learning and applying the new measures and techniques; however, post-weatherization inspections revealed that the quality of the work was mixed. For example, agencies did a good job of achieving a high-density pack with wall insulation but missed some key bypasses. Similarly, heating system inspectors had no trouble carrying out inspections but were unsure of how to deal with the problems they found. Since the training sessions held for the pilot study were rather short (one day of classroom study and three days of field work for the wall insulation/advanced air-sealing training; two days in the classroom and two days in the field for the heating system training), the need for further training was not unexpected. Agency personnel reported that additional follow-up field training would be the most useful method for improving their skills.

We were pleased with the short-term monitoring technique chosen for the pilot study. It provided results relatively quickly and inexpensively. However, we would offer some cautionary notes regarding future applications of this method. Because of the shortness of the heating season during the particularly mild winter of the pilot study, combined with delays in weatherization caused by equipment problems, a series of snowstorms, and a fire that destroyed the offices of one of the participating agencies, we were able to collect only three or four weeks of post-retrofit data for some homes. The small number of data points increases the uncertainty of the savings for these homes. Fortunately, savings in the pilot program were so much greater than savings from the existing program that we had no reservations about recommending further implementation of the pilot measures. However, we would be cautious about future use of this split heating-season design in a mild climate such as Virginia's.

We also ran into some problems with the reporting of meter readings by occupants. A few occupants tired of the weekly phone calls and refused to report further meter readings. Several elderly occupants had difficulty reading the small numbers on the elapsed-time meter. New products for measuring furnace run-time developed since the pilot study was conducted address some of these problems and also provide additional benefits.[4]

A final lesson we learned concerns the importance of follow-up interviews with occupants to ensure correct interpretation of the metered data. Erratic readings could often be traced to vacations, house guests, etc. A few clients had major furnace repairs performed during the course of the study that invalidated their energy consumption data. Without the follow-up on-site interviews, we would never have learned of these problems and could only have guessed at the reasons for unusual readings.

IMPLEMENTATION OF EVALUATION RESULTS

Based on the evaluation of the existing program, the engineering analysis, and the pilot study, new installation standards were recommended for site-built single-family and mobile homes in Virginia's weatherization program. The new standards are basically the same as those used for homes in the pilot study (except furnace cleaning and tuning are not part of the statewide standards). These standards have been approved for inclusion in the program for the 1991-92 contract year. To prepare for the statewide implementation of the new standards, the VACAA held local agency training on high-density wall insulation, advanced air sealing, and heating system safety inspections during the spring of 1991.

CONCLUSION

The new measures tested in the pilot study substantially improved the cost-effectiveness of Virginia weatherization. In site-built single-family homes, median space heat savings of 24% were found; the median simple payback time of 10 years represents a vast improvement over the cost-effectiveness of the existing program, and it is expected to decrease as crews become better and faster at implementing the new measures. The short-term monitoring technique allowed us to quickly and inexpensively assess the savings resulting from the pilot study, and the multi-step evaluation allowed us to be sure that the new measures were indeed an improvement over the existing program. The pilot study also allowed us to assess the training and equipment requirements of the new measures in order to better prepare for statewide implementation.

This research suggests that measures such as high-density wall insulation and advanced air sealing, previously limited to northern states, have just as great a potential for savings in milder climates. We believe that there are a number of explanations for this: there are more houses with no wall insulation in the South, and the housing stock is leakier, with more opportunities for savings from infiltration-reduction work. In addition, these measures would also be expected to reduce cooling loads, which are much more significant throughout the South than in the northern states. For these reasons, we believe that southern weatherization programs have just as great a need for these and other new weatherization advances as do their northern counterparts.

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[4]For example, a new thermostat now being marketed has a number of advantages, chief of which is that it stores in memory the cumulative firing time of the heating system for "today," "yesterday," "this week," and "last week." This technology represents an improvement over elapsed timer technology in that it is easier to install, the readout is more accurate, and the "last week" time period is identical for all users. Further, since it is also a multiple setback thermostat that has a large, easy-to-read digital display plus a reminder about changing furnace filters, the thermostat also doubles as a conservation and an energy education device (Residential Energy Services et al. 1991).

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