IMPROVING VIRGINIA'S LOW-INCOME WEATHERIZATION PROGRAM: EVALUATING THE PERFORMANCE OF NEW TECHNIQUES

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Introduction

Since its inception in 1975, the Virginia Weatherization Program has installed energy conservation measures in more than 60,000 low-income housing units. The Virginia Association of Community Action Agencies, Inc. (VACAA) operates the program for the State of Virginia by issuing subcontracts to local community action and other agencies, establishing installation standards, and inspecting and monitoring completed jobs. For many years, VACAA based its installation standards on "Project Retro-Tech" (Ref. 2); however, recent advances in buildings science convinced VACAA staff that these standards probably were not as effective at saving energy as they could be. In 1988, VACAA began making changes to their 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 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 mild climate state (3400-5000 heating degree-days, base 65°F; 600-1500 cooling degree-days, base 65°F).

The main objective of the evaluation was to develop a set of recommendations to improve the effectiveness of the program. 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) (Ref. 4); second, literature review combined with engineering calculations to identify promising new energy conservation techniques applicable to Virginia's housing stock and climate; third, short-term monitoring to test the new techniques' suitability for Virginia weatherization through a pilot study. The results were used to develop improved weatherization standards incorporating 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 (Ref. 7). The evaluation focused on site-built single-family and mobile homes. While some multifamily units were examined as part of the evaluation of the existing program, they were not included in the pilot study and so will not be discussed here.

Effectiveness of the Existing Program

The 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. We also hoped to gain some information about the relative effectiveness of the measures being installed under the existing program. A utility-bill analysis was conducted using PRISM. PRISM's requirement for 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 herein 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).

Methodology

Utility billing data were combined with information on building and heating fuel type, installed measures, and weatherization cost to determine the savings and cost effectiveness of weatherization. Although we tried to calculate savings for all gas- and electrically-heated homes weatherized during fiscal year 1989 (close to 1,500 dwellings), reliable energy savings estimates were obtained for only 188 homes, due primarily to difficulties in obtaining billing data. Concern about this extreme sample attrition led us to compare our final sample of 188 homes with all houses weatherized during fiscal year 1989. From the comparison, we concluded that overall program results would probably be a bit better than the results for the gas-heat houses we examined, primarily because our analysis was unable to look at houses heated with oil or wood (accounting for about half of Virginia's weatherized units), in which we would expect to see somewhat higher savings because of higher weatherization investments and poorer pre-retrofit structural conditions.

We originally intended to construct a control group by collecting consumption data for individuals on waiting lists for weatherization services. We were unable to follow this course of action, however, because of the unanticipated length of time it took to collect utility bills for the weatherized sample. As an alternative, we looked at weather-corrected residential consumption trends for four electric and gas utilities using aggregate residential sales data (Refs. 5 and 8). Based on this comparison, we decided to make no adjustments to the gross savings attributed to the weatherization program. The changes in consumption for our pseudo-control group were small (less than 3%), and in all but one case, not statistically significant at the 90% level. This brief investigation of residential consumption trends reassured us that no major changes in household energy use took place over the course of our study period.

Retrofit Costs

We calculated total costs (including materials, labor, and program support) as the materials cost multiplied by the median reimbursement rate (229%) of the local agencies included in the study (since VACAA reimburses local agencies based on a fixed percentage of materials costs). Table 1 summarizes the total costs for homes in this sample, by building and heating fuel type. The median cost for gas-heated single-family homes was $1,489—very close to the federally mandated limit of an average expenditure of $1,600 per house. Weatherization of electrically-heated single-family homes was substantially cheaper at $857 per unit (due to less infiltration work, attic insulation, and door replacements in these homes). Weatherization of mobile homes cost $1,289 per unit; this high cost can be attributed to a large number of window replacements.

Energy Savings and Cost Effectiveness

As shown in Table 1, the energy savings from the existing program were rather low: 6.9 MBtu/dwelling for gas-heated single-family homes, or 8% of gas normalized annual consumption (NAC) (used for either space heating only, space heat and hot water, or space heat, hot water, and cooking); 2.3 site MBtu/dwelling (670 kWh) for electrically heated single-family homes, or 4% of electricity NAC (typically space heating, hot water, cooking, lights, and appliances); 1.7 site MBtu/unit for mobile homes (all of which were electrically heated), or 3% of electricity NAC. Table 1 also shows the existing program savings as a percentage of space heat usage (necessary to compare existing program results with the pilot study). Space heat consumption was not measured directly, but rather approximated using the PRISM-derived space heat fraction. Since PRISM's space heat fraction is not as well-determined as the NAC and usually overestimates space heat usage, we place more confidence in the NAC results.

We looked at three indicators of the cost effectiveness of weatherization: the payback time, the cost of conserved energy, and the benefit-cost ratio. Weatherization in this sample of buildings clearly was not cost-effective: average payback times were in excess of 20 years, costs of conserved energy were two to three times higher than Virginia residential energy prices, and benefit-cost ratios were substantially less than one. Figure 1 compares these results with other evaluations of standard low-income weatherization programs documented in Lawrence Berkeley Laboratory's BECA-B database (Ref. 1); the existing Virginia program had savings at the lower end of this range of weatherization evaluations, and was the least cost-effective of any.

In addition to looking at program-wide savings, we were also interested in determining savings attributable

Table 1. Summary of Results for Existing Virginia Weatherization vs. Pilot Study[a]

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

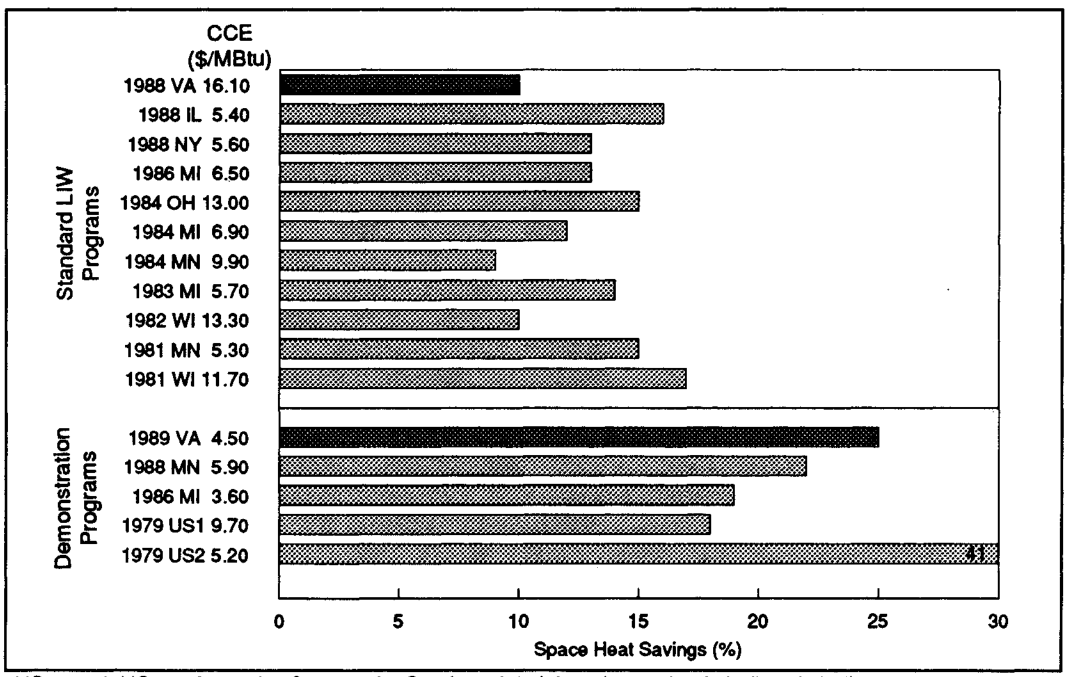
[a]Values given are medians.

[b] Space heat consumption as derived by PRISM.

[c] Total costs for existing program are calculated as material costs multiplied by a reimbursement rate of 229% (in 1988/89 dollars). Total costs for the pilot study are actual material, labor, and administrative costs (in 1989/1990 dollars).

[d] Based on 1988 average Virginia residential energy prices of $5.65/MBtu for gas and oil, and $16.61/site MBtu for electricity.

[e] Based on a real discount rate of 7% and measure-specific lifetimes.



"US1" and US2" refer to the Community Services Administrationstudy of shell and shell/system measures, respectively. Source: Ref 1.

Figure 1. Space Heat Savings and Cost of Conserved Energy for Virginia Evaluations Compared to Other Standard and Demonstration Weatherization Programs

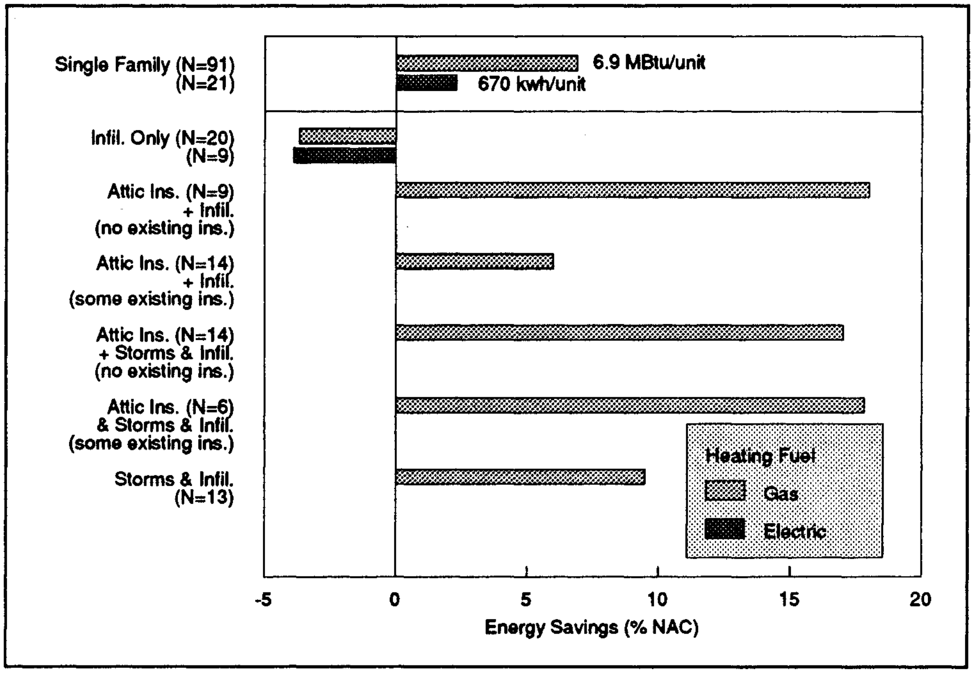


Figure 2. Savings by Primary Retrofit Strategy for Single-family Homes Weatherized under the Existing Program

to specific conservation measures. Since more than one conservation measure was installed in almost every home, it is impossible to attribute energy savings to specific retrofits; however, we were able to categorize the houses by the combination of weatherization measures installed. Figure 2 summarizes energy savings for six commonly installed "packages" of measures in single-family homes. Each house was assigned to the narrowest category, which encompasses all the conservation measures installed in that building. For example, a house weatherized with attic insulation and caulking would be placed in the "Attic Insulation and Infiltration" category, while one with only caulking and weatherstripping would be placed in the "Infiltration Only" category. As used here, "infiltration" includes caulking, weatherstripping, window and door repair, replacement of one or two windows, and/or door replacement. Houses were assigned to a "window" category if more than two primary or storm windows were installed. (In defining these categories, we ignored the effects of water heater wraps and attic venting, as these measures were installed in nearly all homes.)

None of the groups of retrofits illustrated in Figure 1 appears to be a clear-cut success:

- Median energy use in site-built single-family homes that received only infiltration work *increased* slightly after weatherization.
- The packages containing attic insulation, particularly those cases in which there was no existing attic insulation, came closer to being cost effective than any of the remaining groups of measures; however, payback times were still in excess of ten years.
- Homes in the "storms and infiltration" group typically saved 10%, but the costs were so high that this weatherization was not cost effective. There was no correlation between the number of storms installed and energy savings.

We attribute the lack of cost effectiveness of these retrofit packages to the large amount of money being spent on infiltration-reduction measures with questionable energy savings. Thirty to fifty percent of materials costs in the "attic insulation and infiltration," "attic insulation and storms and infiltration," and "storm and infiltration" categories are for infiltration-reduction measures (excluding window and/or door replacements). This infiltration work consists of considerable sealing of leaks in the neutral-pressure plane (caulking and weatherstripping around windows, doors, and baseboards); hundreds of dollars were spent on caulk alone in many homes (three-quarters of the single-family homes had over 20 tubes of caulk installed). As the results for the "infiltration only" site-built single-family homes show, little energy savings were realized from this type of work.

Lessons from the Evaluation of the Existing Program

The evaluation of the existing program showed that there was considerable room for improvement in Virginia's weatherization program, with 8% savings in gas-heated homes, 4% savings in electrically heated homes, and payback times in excess of 20 years. Too much money was being spent on ineffective weatherization strategies like caulking in the neutral-pressure plane, window replacements, and storm windows, leading to low overall savings. Although anecdotal evidence suggested that the gas- and electrically-heated units in this sample are in better structural condition than typical Virginia low-income housing, the pre-weatherization energy consumption for the various building and heating fuel types (shown in Table 1) was as high or higher than the relevant national averages, despite the smaller size of the Virginia dwellings (Ref. 3). This high energy intensity indicates that there may be substantial opportunities for savings in Virginia's housing stock. In this sample, however, there was no correlation between pre-retrofit energy use and resulting savings, indicating that the weatherization did not take full advantage of the opportunities for savings which were present.

Selection of New Measures to Be Tested

Review of the literature and other state weatherization programs was combined with engineering-economic analysis to select measures for testing in the pilot study. Analyses were performed for four measures that are amenable to engineering calculations: attic insulation, wall insulation, primary window replacements, and storm windows. For each measure, economic analyses were conducted for Virginia's three climate zones (3400, 4200, and 5000 heating degree-days, base 65°F), three fuel prices (gas, electricity, and a weighted average price), three assumed installed costs, and various engineering assumptions. The analysis showed that:

- R-30 attic insulation is extremely cost-effective, except when existing levels exceed R-19.
- Sidewall insulation is extremely cost-effective, even when no infiltration savings are assumed.
- Replacement primary windows are not cost-effective even under the most favorable assumptions.
- Storm windows are cost-effective only under the most favorable assumptions of high energy prices (*i.e.*, electricity) and low installed costs.

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 the hazardous effects of inadequately vented combustion gases, cracked heat exchangers, and fuel leaks would all 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 and 16 mobile homes were weatherized by weatherization crews from four local agencies. The new measures tested in the pilot study included:

- High-density, blown cellulose wall insulation.
- Advanced air sealing techniques focusing on attics, basement/crawlspaces, bypasses, and ducts and registers.
- Heating system safety inspections.
- Furnace cleaning and tuning.

Some measures from the existing VACAA standards, such as water heater wraps, attic insulation, and bellyboard insulation (for mobile homes) were retained. Conventional caulking and window replacements were specifically de-emphasized in the pilot study.

Methodology

Because 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 pilot houses. 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 (Refs. 6 and 9).

These meters recorded the run-time of the furnace; energy consumption for each measurement period was obtained by multiplying the run time by the furnace's firing rate. The space heating energy intensity was then calculated, in Btu per square foot per heating degree-day (base 65°F). Energy consumption was monitored for several weeks (at least three, and on average, 11 weeks before weatherization and 8 weeks after), and the average Btu/ft^2-DD was calculated for the pre- and post-weatherization period for each house. 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/ft^2-DD differing from the average by more than 50%. 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 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 restrictions imposed by the monitoring technique on the heating system type, 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.

Log 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 pilot homes 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.

Retrofit Measures and Costs

For the site-built single-family houses, the weatherization work conformed fairly well with the pilot installation standards discussed above. Of the 43 single-family houses, all 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.

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 performed cleaning and tuning on 10 furnaces, which 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.

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 \$1119 for single-family homes and \$1145 for mobile homes. Costs calculated based on reimbursement rates (as was done for the existing program) are lower than the actual costs for the single-family pilot homes, due to the low materials-cost, high labor-input measures installed as part of the pilot study. This finding led us to recommend that the reimbursement system be changed to reflect the differing labor requirements of various conservation measures, so that local agencies will financially be able to install cost-effective, low materials-cost items like wall insulation and duct sealing.

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 averaged 46% in one agency's single-family homes, all of which received wall insulation.

It is difficult to compare precisely 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- 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 should 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 the pilot homes 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. Space heat usage for homes weatherized under the existing program was approximated using the PRISM-derived space heat fraction, which is not as well-determined as the NAC. However, the percentage savings for single-family homes in the pilot study was over two times greater than the percent space heat savings for gas-heated single-family homes in the existing program. Therefore, despite the difficulties of precision 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 better. For fuel-heated single-family homes, paybacks improved from 30 years for the existing program to 10 years for the pilot study. The cost of conserved energy for the single-family pilot homes was less than prevailing residential gas and oil prices, and the benefit-cost ratio was greater than one. Mobile home weatherization in the pilot was not cost-effective (payback time of 17 years, cost of conserved energy greater than fuel prices, and a benefit-cost ratio of 0.54). However, even the mobile home pilot weatherization was much more cost-effective than work done as part of the existing weatherization program.

Not only was the pilot study a substantial improvement over the existing Virginia weatherization program, it also compares favorably with other weatherization demonstration programs throughout the country (see Figure 1 again). Savings were greater than all but one of the other demonstration programs documented in the BECA-B database (Ref. 1).

While the paybacks based on actual costs are somewhat lengthy, 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 pilot houses (*e.g.*, less than half of single-family homes received wall insulation, windows were replaced in four-fifths of mobile homes). Second, the crews had only short training periods to learn installation techniques for the new measures, and were basically "learning" by doing. With more experience, labor time and costs would likely drop. Third, the pilot study required additional crew time to record measure-specific labor-time data and perform frequent blower door tests (to document changes in infiltration caused by specific measures). These tasks would not be required under non-pilot 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 recommended as another component of future weatherization work.

Crews demonstrated that they were capable of learning and applying the new measures; 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 with 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 a wall insulation/advanced air sealing training; two days in the classroom and two days in the field for the heating system training), this need for further training is not unexpected. In interviews with agency personnel, they reported that follow-up training in the field would be the most useful method for improving their skills.

Implementation of Evaluation Results

Based on the evaluation of the existing program, the engineering analysis, and the pilot study, a framework for new installation standards was formulated for site-built single-family and mobile homes (Table 2). VACAA has integrated these recommendations into a new set of standards, which have been approved for inclusion in the program for the 1991-92 contract year. To prepare for the state-wide implementation of the new standards, VACAA has held local agency trainings on high-density wall

Table 2. Recommended Installation Standards

Site-built, Single-family Homes	Mobile Homes
1. Heating System Inspection • Inspect heating system for safety problems • Perform simple repairs, improvements 2. Heating System Ducts and Registers • Seal leaks in forced air plenum, ducts and register boots • Insulate ducts/pipes if in unheated area 3. Large Leak and Bypass Sealing • Blower door test (record pre-weatherization reading; use as diagnostic tool to find major leaks in attic, basement/crawlspace 4. Sidewall Insulation (using high-density blown cellulose) 5. Attic Insulation • If existing insulation is < R-19 6. Water Heater Insulation (electric and gas water heaters) • Lower thermostat setting 7. Caulking and Weatherstripping • Install ONLY IF needed for client comfort AND still above MVR 8. Weatherization Repairs • Replace windows or doors if inoperable or deteriorated beyond repair • Perform any other repairs necessary to protect weatherization work	1. Heating System Inspection • Inspect heating system for safety problems • Perform simple repairs for safety problems 2. Heating System Ducts and Registers • Seal leaks in forced air plenum 3. Large Leak Sealing • Blower door test (as above under site-built homes) • Major air sealing (if above MVR) 4. Floor Insulation (blown between floor and bellyboard or batts if no bellyboard) 5. Water Heater Insulation (electric and gas water heaters) • Lower thermostat setting • Insulate first 3 feet of hot and cold water lines • Install insulation jacket 6. Caulking and Weatherstripping • Install ONLY IF needed for client comfort AND still above MVR 7. Weatherization Repairs • Replace windows or doors if inoperable or deteriorated beyond repair • Perform any other repairs necessary to protect weatherization work

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 payback time of 10 years was a vast improvement over the cost-effectiveness of the existing program, and is expected to decrease as crews become better and faster at implementing the new measures. The multi-step evaluation allowed us to be sure that the new measures were indeed an improvement over the existing program, as well as pointing out which measures in the existing program were more or less effective. The pilot study also allowed us to assess the training and equipment requirements of the new measures to better prepare for state-wide implementation.

This research suggests that measures like 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 several 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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